International Workshop on Heliothis Management

International Crops Research Institute for the Semi-Arid Tropics

Proceedings of the

International Workshop on *Heliothis* Management

ICRISAT Center
Patancheru, India
15-20 November 1981

International Crops Research Institute for the Semi-Arid Tropics
ICRISAT Patancheru P.O.
Andhra Pradesh, India 502 324

Objectives of the Workshop:

- To assemble the world's most experienced and active scientists who are working on aspects of *Heliothis* spp management
- To review the known information
- To determine the priorities tor future action and cooperation

Organizing Committee

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Acknowledgments

We wish to acknowledge the support of the many organizations who have financed the travel of participants. We are particularly grateful for generous financial support provided by the Australian Development Assistance Bureau which has enabled participants from developing countries and Australia to participate.

Foreword

An important function of an international research institute is to hold workshops, conferences, and symposia where delegates from many parts of the world can meet to discuss research problems and progress. ICRISAT has hosted many such workshops in the past, but this is the first in the entomological field. *Heliothis* spp are pests of all our mandate crops—pigeonpea, chickpea, groundnut, sorghum, and millet—in almost all areas of the world where they are grown. Thus ICRISAT has a particularly keen interest in the management of these pests.

Much research on the management of *Heliothis* has been conducted on cotton, especially in the USA, Africa, and Australia, and we are pleased to welcome several cotton entomologists from these areas to this workshop. To control *Heliothis* spp on cash crops, including cotton, insecticides have been used extensively and intensively, with good short-term economic returns but with consequent longer term problems in some areas. Most of ICRISAT's target farmers use no pesticides, partly because the economics of our mandate crops—with the possible exception of groundnut—do not permit the use of such costly inputs, but also because the farmers have no access to suitable pesticides or to the means and knowledge required for their efficient application.

We therefore concentrate our research upon those elements of *Heliothis* management that are likely to be of practical value in the fields of these farmers who have limited resources. In particular, we hope to use our extensive germplasm resources to select and breed crops that are resistant to attacks by *Heliothis* and other pests. However, we cannot rely entirely on a single means of pest management, so we are also studying several other elements that may be of value in the farmers' fields.

This volume contains the papers that were presented by specialists on several important aspects of *Heliothis* management research and summaries of the discussions that followed. I was very pleased to learn that new cooperative research initiatives were agreed upon during the workshop. I hope that these Proceedings will be of value to the many people who are concerned with *Heliothis* management.

L.D. Swindale
Director General

Opening Session

Chairman: J.C. Davies

Welcome to ICRISAT and the Workshop

J.S. Kanwar and J.C. Davies*

While welcoming the 55 participants from 11 countries to ICRISAT, Dr. Kanwar outlined the objectives of ICRISAT, these being:

- To serve as a world center to improve the yield and nutritional quality of sorghum, pearl millet, pigeonpea, chickpea and groundnut.
- To develop farming systems which will help to increase and stabilize agricultural production through better use of natural and human resources in the seasonally dry semi-arid tropics.
- To identify socioeconomic and other constraints to agricultural development in the semi-arid tropics and to evaluate alternative means of alleviating them through technological and institutional changes.
- To assist national and regional research programs through cooperation and support and to contribute further by sponsoring conferences, operating international training programs, and assisting extension activities.

Dr. Kanwar also explained the organization and structure of ICRISAT's research programs both in India and in other countries. He told the participants that the ICRISAT Center farm is 1394 ha, of which 140 ha have been preserved free from pesticide use. These pesticide-free areas are particularly useful for entomological and other research, for they provide conditions that are closer to the farmers' conditions than are normally available on research stations. He also described the closed season that has been adopted at ICRISAT: for 2 months each year no crops are grown on the farm. This measure has helped to reduce the pest problems and, consequently, the pesticide use, at ICRISAT. These and other measures were cited to illustrate the practical approach that the institute is taking towards pest management and towards ensuring that the research conducted on the farm will be of use in our target farmers' fields.

Dr. Davies then welcomed the participants to the workshop. He outlined the objectives of the workshop, which were:

- To assemble the world's most experienced and active scientists working on various aspects of *Heliothis* spp management.
- To review the known information.
- To determine the priorities for future action and cooperation.

He commented upon the excellent response that we have had from the scientists interested in *Heliothis.* Of those invited, all but a few had come, despite major problems of busy schedules and restricted funds. Dr. Davies also paid tribute to the many people who had been involved in all stages of the preparation and operation of the workshop.

This workshop provides a unique opportunity for us to compare and discuss the research work that has been carried out on the different species of *Heliothis* that are pests in the Old and New Worlds. It also gives an opportunity for entomologists who have concentrated their research upon single crops, such as cotton and maize, to come together and to examine the potential for integrating the findings. *Heliothis* is being increasingly recognized as a broad-spectrum pest, and especially where agriculture is improving.

Noting that the pest was one that attacks all five crops in ICRISAT's mandate and that these are often grown in intercrop or relay-crop situations by small farmers, Dr. Davies stressed the importance of the exchange of existing information to enable research priorities and strategies to be determined. He also emphasized that the major benefits from such a workshop could be expected to originate in the discussions and exchanges of views that will take place both within the sessions and outside. He hoped that initiatives would be taken that would help the ICRISAT scientists to advance their *Heliothis* management research in cooperation with the other participants, who have an enormous range of experience and expertise, and to determine gaps in knowledge of the species to be defined.

***Director of Research and Director for International Cooperation, respectively, ICRISAT, Patancheru, A.P., India.**

International Crops Research Institute for the Semi-Arid Tropics. 1982. Proceedings of the International Workshop on *Heliothis* Management, 15-20 November 1981, Patancheru, AP, India.

Dr. Davies hoped that areas of cooperative research and collaboration between ICRISAT scientists and the scientists of developed and developing country institutions would be identified in the field of *Heliothis* pest management and outlined the complex nature of some of the problems posed by the pest to small farmers of direct concern to ICRISAT.

The Nomenclature of *Heliothis* and Associated Taxa (Lepidoptera: Noctuidae): Past and Present

I.W.B. Nye*

Abstract

The *history of the nomenclature of* Heliothis, *particularly of the species* armigera *and* zea, *is reviewed. From 1806, when the name* Heliothis *was first used, there has been continuing contusion, with several changes in both generic and specific names. The confusion is not yet fully resolved, but the author has requested the International Commission on Zoological Nomenclature to rule that the gender of the generic name* Heliothis *is feminine. It this request is granted, the long-accepted spellings of specific names, including* armigera, *will be retained.*

Résumé

*La nomenclature d'*Heliothis *et des taxons associés* (Lepidoptera: Noctuidae)*—passée et présente: L'histoire de la nomenclature d'*Heliothis, *surtout des espèces* armigera *et* zea, *est revue. Depuis 1806, année où l'on a utilisé pour la première fois le nom* Heliothis, *il y a toujours eu une confusion due à plusieurs modifications des noms génériques et spécifiques. Ce problème n'est pas encore tout à fait résolu; mais l'auteur a demandé à la Commission internationale de la nomenclature zoologique d'établir que le genre du nom générique* Heliothis *est féminin. Si cette demande est acceptée, l'orthographe des noms spécifiques, dont* armigera, *consacrée par un long usage, sera retenue.*

This paper should perhaps be subtitled "A Tale of Great Confusion" and, as the generic name *Heliothis* and the specific names *armigera* and *zea* are used to denote taxa of such immense economic importance, a summary of the nomenclatural history of these names is provided.

In or about 1806, J. HUbner of Augsburg, Germany, distributed a single quarto sheet printed on both sides, entitled *Tentamen determinations digestionis atque denominationis singularum stirpium Lepidopterorum, peritis ad inspiciendum et dijudicandum* communicatum, a JacoboHubner. A facsimile of this rare work is provided by Hemming (1937). This *Tentamen* presented the plan of a classification of the Lepidoptera in which each of 107 *stirpes* (equivalent to present-day genera) were used in combination with a single specific name. The importance of the *Tentamen* lay in the fact that out of the 107 generic names, 94 were used for the first time, including *Heliothis.* The question of whether the names in the *Tentamen* were to be regarded as available for nomenclatural purposes resulted in controversy for many years, culminating in the application for a ruling by the International Commission on Zoological Nomenclature (ICZN 1926). The results of this application were published in Opinion 97, the summary of which is as follows:

> SUMMARY. Hubner's *Tentamen,* 1806, was obviously prepared essentially as a manifolded manuscript, or as a proof sheet (cf. Opinion 87), for examination and opinion by a restricted group of experts, i.e., in Lepidoptera, and not for general distribution as a record in Zoology. Accordingly, the conclusion that it was published in 1806 is subject to debate. Even if the premise be admitted that it was published in 1806, the point is debatable whether the contained binomials should be construed as generic plus specific names. Even if it be admitted that the binomials represent combinations of generic plus specific names, they are essentially *nomina nuda* (as of the date in question) since authors who do not possess esoteric infor-

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> mation in regard to them are unable definitely to interpret them without reference to later literature. If published with more definite data at later dates, these names have their status in regard to availability as of their date of such republication.

By present-day standards, the combinations of generic plus specific name referred to in this summary would not be regarded as *nomina nuda,* provided that the specific name was available within the meaning of the International Code of Zoological Nomenclature (ICZN 1964) (Articles 10-15). The unsatisfactory wording of the summary of Opinion 97 resulted in some authors continuing to argue that the names were not properly rejected. Such was the vehemence expressed in publications that the case was reopened, and in a ruling by the Commission (ICZN 1954) in Opinion 278, the *Tentamen* was placed on the Official Index of Rejected and Invalid Works in Zoological Nomenclature as Work No.14. The only nominal species included by Hubner in his *Tentamen* concept of *Heliothis* was *Phalaena dipsacea* Linnaeus, 1767, from Europe.

The *Tentamen* is now nomenclaturally dead, but its continuing relevance lies in the fact that from the time of its distribution in 1806, authors have used many of the generic names proposed in it, all of which were monotypic and based on Palaearctic species. When Opinion 97 was being discussed in 1926, it was accepted that the next published use of the *Tentamen* generic names would make them nomenclaturally available. In the case of *Heliothis,* this next usage was believed to be by Ochsenheimer (1808), who included *dipsacea* Linnaeus and *armigera* Hiibner among the 14 nominal species he placed in his concept of this genus. *Heliothis* then became firmly entrenched in the European literature based on *dipsacea* Linnaeus, 1767 (a junior subjective synonym of *Phalaena viriplaca* Hufnagel, 1766) as a type-species by subsequent designation by Samouelle (1819).

After the Commission's rejection of the *Tentamen,* Hemming (1935) stated that he had "recently received a photostat copy of a very important and hitherto unnoticed pamphlet published by Jacob Hubner in 1808." This work by Hiibner consisted of a title page and four sheets printed on both sides and entitled *Erste Zutrage zur Sammlung exotischer Schmetterlinge.* A facsimile of this rare work, known only from three copies, is provided by Hemming (1937). In a short introduction, Hubner stated that lepidopterists in foreign countries (America and Columbia [sic] are named on the title page) had sent him specimens of a large number of a new species, which he proposed to figure and describe in a work entitled *Zutrage zur Sammlung exotischer Schmetterlinge.* He then listed 75 combinations of generic plus specific names, and above each placed two numbers that ran consecutively from 1 to 150. Figure numbers 81 and 82 were named *Heliothis jucunda,* a North American species in a different subfamily from the European *dipsacea.*

During the period 1808-1818, Hubner published the plates of the first volume of his *Zutrage zur Sammlung exotischer Schmettlinge* (sic). The work was issued as a series of plates containing consecutively numbered illustrations. Each species was figured twice, but no name or word of text occurred on any of the plates. The plate containing Figures 81-82 was published by 1813, and these illustrations, together with the name *Heliothis jucunda* proposed in the 1808 *Erste Zutrage,* would have made *Heliothis* Hubner, 1813, nomenclaturally available for a generic concept entirely different from that in the *Tentamen.* What Hubner did in his *Erste Zutrage,* was to place New World species in Old World genera. However, within a few years, Hubner had realized that the New World species mostly represented different generic concepts and therefore required different generic names. Accordingly, when in 1818 he published the text and descriptions to the illustrations, he usually retained the same specific name that he had used in his *Erste Zutrage,* but he proposed many new generic names. Figures 81-82 were then named *Melipotis jucunda.*

In order to resolve the nomenclatural chaos caused by the rediscovery of the *Erste Zutrage,* an application to the Commission was submitted by Nye (1964), requesting that the *Erste Zutrage* be rejected for the purposes of zoological nomenclature on the grounds that it was a printer's proof and not published within the meaning of the Code. The Commission (ICZN 1966) agreed and ruled "that the incomplete pamphlet of Jacob Hubner, dated 1808, entitled *Erste Zutrage zur Sammlung exotischer Schmetterlinge,* has not been published within the meaning of Article 8 of the Code, and therefore that neither the generic nor the specific names used in that pamphlet are available for nomenclatorial purposes." The *Erste Zutrage* was placed on the Official Index of Rejected and Invalid Works in Zoological Nomenclature as Work No.72. Under the same ruling, the name *Heliothis* Hubner, 1808, was placed on the Official Index of Rejected and Invalid Generic Names in Zoology as Name No. 1857. Thus the known nomenclatural obstacles to the use of *Heliothis* Ochsenheimer, 1816, have been removed. However, two more nomenclatural problems have arisen that affect, not the name *Heliothis* itself, but first, the spelling of the subfamily name based upon it, and second, the spelling of the specific names with which it is combined.

There are other genus-group names in the *Heliothis* complex, but *Chlorides* in particular was common in the literature in the first third of this century. *Chloridea* Duncan [& Westwood], 1841, was established for a single species *Phalaena rhexiae* Smith, 1797, which is a junior subjective synonym of *Noctua virescens* Fabricius, 1777, and distributed in North America. Hampson (1903), in his major work on Lepidoptera, ignored the previous designations of *dipsacea* as the type-species of *Heliothis* and based his usage of the name on a different species *Phalaena cardui* Hubner, 1790, which is correctly the type-species of *Melipotis* Hubner [1823]. Hampson then used *Chloridea* for *dipsacea* and *armigera, and* this interpretation was followed by Warren (1914) in the standard reference work, *Die Gross-Schmetterlinge der Erde.* The result was confusion for the next quarter of a century, until *Heliothis* once again regained a dominant place in the literature.

More recently, *Helicoverpa* Hardwick (Hardwick 1965b) was established, having *Noctua armigera* Hubner (1808) as its type-species, but authors have been reluctant to adopt its use. Boursin (1965) placed *Helicoverpa* as a synonym of *Chloridea,* as at that time Boursin used *Heliothis* in the *Erste Zutrage* sense. Hardwick (1970) reiterated with reasons his opinion that *Helicoverpa* and *Heliothis* were generically distinct. Todd (1978), in his "Checklist of Species of *Heliothis* Ochsenheimer," stated that "Hardwick (1970:18) feels that if the corn earworm group *(Helicoverpa* Hardwick, 1965) is included in *Heliothis,* the species of *Schinia* Hubner, 1818, should also be transferred to *Heliothis.* That premise does not hold if the characters on which his classification was based are given a different weight of significance. Accordingly, *Helicoverpa* Hardwick is treated as a synonym of *Heliothis,* and the species of *Schinia* have not been included in this list."

My own view as a museum taxonomist, but formerly an agricultural entomologist, is that as generic boundaries are generally a matter of opinion, depending on the user's tendency to lump or to split, it is better to have a broad-based genus *Heliothis* for the sake of field workers and to divide it into subgenera such as *Helicoverpa* for the convenience of taxonomists. Why not have the best of both worlds?

The spelling of the subfamily name based on *Heliothis* as type-genus depends on what is considered to be its correct stem. Boisduval (1928) first used the name Heliothidi for a tribe containing *Heliothis.* Since then and up to the present day the subfamily name ending -inae has been added to Helioth- by some authors and to Heliothid- by others. Steyskal (1971) pointed out that the name *Heliothis* is an aorist passive participle of the Greek verb helioo, and strict application of the International Code, Article 29(a), would require the use of the stem Heliothent- in forming the subfamily name. This has never been followed. Steyskal continued:

> However, if Article 11 (b) of the Rules, which states that zoological names 'must be either Latin or Latinized', be interpreted strictly, we may consider that the complex Greek participial system was not part of Latin, except in the case of a few words used as nouns and not to be found in Latin dictionaries. We may then consider *Heliothis* as declinable in the way the great majority of Latin nouns ending in *is are* declined. If this is done, the stem used in forming family-group names will be Helioth- and the subfamily name consequently Heliothinae.

The name Heliothinae is certainly in general, though not in universal, use. In any case it is customary in the Lepidoptera to avoid the clumsy -ididae or -idinae termination; for example, *Pyralis,* family Pyralidae (Opinion 450) and *Pieris,* family Pieridae (Opinion 500). An application to the Commission by Steyskal (1972) to have the name Pyralidae changed to Pyralididae was refused in Opinion 1094. In order to resolve the confusion, Nye (1980) referred the case to the Commission and requested a ruling that the stem of the generic name *Heliothis* Ochsenheimer, is *Heliothis.* The Commission has not yet voted on this application.

Up to the beginning of the present century, the corn earworm and the cotton bollworm were usually treated in both the Old and the New World as one somewhat variable species, generally known as *Heliothis armigera* (Hubner). But Aurivillius

(1897) showed that *Bombyx obsoleta* Fabricius (Fabricius 1793) was the senior name for this pest, so *Heliothis obsoleta* (Fabricius) gradually came into general use, particularly in North America. Heinrich (1939) then indicated that *Bombyx obsoleta* should not be used, as it was a duplicate of an order name *Bombyx obsoleta* Fabricius, 1775, used for a totally different species of moth in another family. So, once again *armigera* came into more general, but not exclusive, use. It was Common (1953) who showed that *armigera* was restricted to the Old World and that the species in the New World was distinct and had already been described as *Heliothis umbrosus* Grote (Grote 1862). Before there was time for *umbrosus* to be adopted in the literature, Todd (1955) showed that the oldest name for the New World pest species was *Phalaena zea* Boddie (Boddie 1850) and so, as *Heliothis zea* (Boddie) the name gained almost immediate acceptance and has been used thousands of times ever since.

The use of *armigera* for the Old World species has been extremely stable, but Hardwick (1965) in his masterly monograph on the corn earworm complex, cited *Noctua barbara* Fabricius as the oldest name for the species, but he treated it as a *nomen oblitum* and at the same time (Hardwick 1965a) requested the Commission to rule that *barbara* should be suppressed. This the Commission agreed *to* do in Opinion 1120 (ICZN 1979) and *Noctua barbara* Fabricius was accordingly placed on the Official Index of Rejected and Invalid Specific Names in Zoology as Name No. 1045. Thus all threats to the stable use of *armigera* were overcome until Steyskal (1971) pointed out that the gender of *Heliothis* was masculine and would require a ruling by the Commission to fix it as feminine. In an Editor's Note at the end of Steyskal's paper it was suggested that the case should be referred to the Commission for a ruling. This was not done, presumably because no one anticipated that anyone would wish to upset the traditional feminine treatment of the generic name.

Recently, Todd (1978) in his "Checklist of species of *Heliothis* Ochsenheimer" stated without any further comment that "The generic name, *Heliothis,* is masculine in gender, but has usually been treated as feminine. In addition, names proposed in feminine genera have been transferred to *Heliothis* unchanged. All necessary changes to masculine endings have been made in this paper. As under the International Code, Article 30, an adjectival specific name must agree in gender with the generic name; if *Heliothis* is treated as masculine, then *armigera* (the feminine form of a Latin adjective meaning 'bearing arms') would become *armiger.* It is fortunate for our colleagues in the New World that the name of their species *zea* is a noun and therefore does not have to be changed to the masculine form *zeus.* Their literature remains unaffected and they will not incur the wrath of the king of the Olympian gods by linking his name with that of a major pest!

Once again confusion has returned to the name *armigera;* so, in order to resolve the issue not only for *armigera* but also for the names of about 30 other species placed in *Heliothis* that would also have to be changed to the masculine form, Nye (1980) has reviewed the case and requested the Commission to rule that the gender of the generic name *Heliothis* is feminine. The Commission has not yet voted on this application.

Such is the simplified saga of the scientific names for two of the major pest species of the world. Whether to use *Helicoverpa* to denote a genus or a subgenus will always remain a decision for taxonomists and not for the International Commission on Zoological Nomenclature, but the correct stem of *Heliothis,* as discussed above, and its gender for the purposes of nomenclature are decisions that must be made by the Commission. My application to the Commission has been strongly supported by colleagues. If you also agree with its proposals, please pass a resolution of support at this workshop and send it to the Secretary of the Commission for publication.

Note on Referendum

At the International Workshop on *Heliothis* Management, which brought together many of the world's most experienced and active *Heliothis* scientists, the nomenclature of *Heliothis* was discussed. Following the presentation of I.W.B. Nye's paper on the past and present confusion of nomenclature in this genus, the participants were asked to choose one of the following alternatives:

1. I support the retention of the established nomenclature for *H. armigera, H. peltigera, H. punctigera,* etc.
2. I support the suggested change in nomenclature to *H. armiger, H. peltiger, H. punctiger,* etc.

Of the 41 replies to this referendum, 39 chose the former and 2 the latter. Thus, this workshop, by a large majority, recommends to the International Commission on Zoological Nomenclature that the well-established *Heliothis* spp names, including *armigera, peltigera,* and *punctigera,* should continue to be used.

References

AURIVILLIUS, C. 1897. Bemerkungen zu den von J. Chr. Fabricius aus Danischen Sammlungen beschriebenen Lepidopteren. Entomologisk Tidskrift 18:139-174.

BODDIE, J.W. 1850. Insect physiology. II. Southern Cultivator 8:132.

BOISDUVAL, J.A. 1928. Europaeorum Lepidopterorum Index Methodicus. Paris. 103 pp.

BOURSIN, C. 1965. Errata et addenda a mon travail "Les Noctuidae Trifinae de France et de Belgique" paru dans ce meme Bulletin, 1964, No. 6, p.204. Bulletin Mensuel de la Societe Linneenne de Lyon 34:182-187.

COMMON, I.F.B. 1953. The Australian species of *Heliothis* (Lepidoptera:Noctuidae) and their pest status. Australian Journal of Zoology 1:319-344.

FABRICIUS, J.C. 1793. Entomologia Systematica 3(1). 487pp. Hafniae.

FABRICIUS, J.C. 1794. Entomologia Systematica 3(2). 349pp. Hafniae.

GROTE, A.R. 1862. Additions to the catalogue of U.S. Lepidoptera. Proceedings of the Entomological Society of Philadelphia 1:218-219.

HAMPSON, G.F. 1903. Catalogue of the Lepidoptera Phalaenae in the British Museum 4. London: British Museum. 689 pp. 125 figs.

HARDWICK, D.F. 1965a. *Noctua barbara* Fabricius, 1794 (Insecta, Lepidoptera): proposed rejection as a *nomen oblitum.* Bulletin of Zoological Nomenclature 22:101.

HARDWICK, D.F. 1965b. The corn earworm complex. Memoirs of the Entomological Society of Canada 40: 1-247.

HARDWICK, D.F. 1970. A generic revision of the North American Heliothidinae (Lepidoptera: Noctuidae). Memoirs of the Entomological Society of Canada 73: 1-59, figs. 1-114.

HEINRICH, C. 1939. The proper scientific name for the com ear worm. Journal of Economic Entomology. 32: 595-596.

HEMMING, F. 1935. A note on Jacob Hubner's Erste Zutrage zur Sammlung exotischer Schmetterlinge of 1808. Stylops 4.38-48.

HEMMING, F. 1937. Hubner 1. London: Royal Entomological Society of London. 605 pp.

ICZN (International Commission on Zoological Nomenclature). 1926. Opinion 97. Did Hubner's Tentamen, 1806, create monotypic genera? Smithsonian Miscellaneous Collections 73(4):19-30.

ICZN (International Commission on Zoological Nomenclature). 1954. Opinion 278. Addition to the "Official List of Generic Names in Zoology" of the names of ten genera of the suborder Rhopalocera of the order Lepidoptera (Class Insecta), species of which were cited in the undated leaflet commonly known as the "Tentamen", prepared by Jacob Hiibner, which is believed to have been distributed to correspondents in 1806, a leaflet rejected in "Opinion 97". Opinions and Declarations Rendered by the International Commission on Zoological Nomenclature 6:137-177.

ICZN (International Commission on Zoological Nomenclature). 1964. Page 176 *in* International Code of Zoological Nomenclature, 2nd ed. London, UK: International Trust for Zoological Nomenclature.

ICZN (International Commission on Zoological Nomenclature). 1966. Opinion 789. Rejection of the pamphlet by J. Hiibner, 1808, entitled Erste Zutrage zur Sammlung exotischer Schmetterlinge. Bulletin of Zoological Nomenclature 23: 213-220.

ICZN (International Commission on Zoological Nomenclature). 1979. Opinion 1120. *Noctua armigera* Hubner, [1808] (Lepidoptera) conserved. Bulletin of Zoological Nomenclature 35: 221 -222.

NYE, I.W.B. 1964. Application for the rejection for nomenclatorial purposes of the pamphlet by J. Hubner entitled *Erste Zutrage zur Sammlung exotischer Schmetterlinge* printed in 1808. Bulletin of Zoological Nomenclature 21: 58-80.

NYE, I.W.B. 1980. *Heliothis* Ochsenheimer, 1816 (Insecta, Lepidoptera): proposal to designate gender and stem. Bulletin of Zoological Nomenclature 37: 186-189.

OCHSENHEIMER, F. 1808. Die Schmetterlinge von Europa 4. Leipzig. 226 pp.

SAMOUELLE, G. 1819. The entomologist's useful compendium. London. 496 pp.

STEYSKAL, G.C. 1971. On the grammar of the name *Heliothis* Ochsenheimer (Noctuidae). Journal of the Lepidopterists' Society 25: 264-266.

STEYSKAL, G.C. 1972. Application for correction of certain names on the Official List of Family-Group Names in Zoology. Bulletin of Zoological Nomenclature 29:26-27.

TODD, E.L. 1955. The distribution and nomenclature of the corn earworm. Journal of Economic Entomology 48: 600-603.

TODD, E.L. 1978. A checklist of species of *Heliothis* Ochsenheimer (Lepidoptera: Noctuidae). Proceedings of the Entomological Society of Washington 80:1 -14.

WARREN, W. 1914. *In* Die Gross-Schmetterlinge der Erde, ed. A. Seitz, Stuttgart. 511 pp. 75 plates.

Heliothis: a Global Problem

W. Reed and C.S. Pawar*

Abstract

The geographical distribution of the major pests, Heliothis armigera, H. zea, *and* H. virescens, *and the crop losses caused by these are reviewed. Although it is generally considered that the destruction of natural enemies by pesticide use and changes in cropping patterns and management have promoted these insects to major pest status, there are areas where* H. armigera *is a serious pest, although traditional agriculture is still practiced, and no pesticides are used. The dangers of a further increase in losses to* Heliothis spp *by breeding more susceptible crops are described. There is a need tor a more imaginative and holistic approach to research directed towards the management of these pests.*

Résumé

Heliothis, ***un problème global:*** ***La communication fait le point sur la répartition géographique des ravageurs importants que sont*** **Heliothis armigera, H. zea *et* H. virescens**, ***ainsi que les pertes culturales qui leur sont dues. En général, on considère que la destruction des prédateurs naturels, due à une utilisation de pesticides et des changements dans les modes de culture et de gestion, a permis que ces insectes s'élèvent au rang de ravageurs importants. Cependant, on trouve des régions où l'on pratique une agriculture traditionnelle, sans application de pesticides, et où*** **H. armigera** ***pose de graves problèmes. Les dangers d'une augmentation éventuelle des dégâts imputables à*** **Heliothis spp**, ***suite à une sélection de plantes plus sensibles à cet insecte, sont décrits. Il faudrait adopter une approche plus imaginative et globale dans la recherche sur la lutte contre ces ravageurs.***

The Pests and Their Distribution

Of the many recorded *Heliothis* spp (Todd 1978), only a few are of major importance as crop pests. However, the polyphagous nature and wide geographical spread of some of these (Hardwick 1965) merit their consideration at an international level.

Here at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), we are mainly concerned with *Heliothis armigera* (Hb.), a species that has been recorded as damaging 60 cultivated plant species and at least 67 other plant species in 39 families across Africa, Asia, and Australasia. It is likely that this recorded list of host plants is only a fraction of the total number of plants on which this insect can, and does, feed. A systematic study of the host range is long overdue, for this could give information concerning the chemical and physical attributes of plants that determine their attraction and edibility. The geographical range of *H. armigera* extends from the Cape Verde Islands in the Atlantic, through Africa, Asia, and Australasia, to the South Pacific Islands, and from Germany in the north to New Zealand in the south. It causes most damage in the semi-arid tropics, however, and so is of prime interest to ICRISAT.

Until the middle of this century, this insect had been considered to be identical to the cotton bollworm or corn earworm of the USA, which is now known as *Heliothis zea* (Boddie), thus accounting for the common name, American bollworm, that is still used to describe *H. armigera* through much of the Old World. Subsequently, however, Common (1953) working in Australia and Forbes (1954) in the USA, concluded that there were specific differences between these insects. It has been generally accepted that these two species, which are very similar in all aspects, between them circle the earth, with *H. zea* across the Americas and *H. armigera* stretching across all the other tropical

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and subtropical countries, with no geographic overlap.

This tidy and simple distribution has not gone unquestioned, however, and there have been many suggestions that there is subspecies differentiation, and even differences that merit the erection of species among what are now regarded populations of *H. armigera* across the wide geographical range. Here in India, Bhattacherjee and Gupta (1972) distinguished two species from within the commonly accepted *H. armigera.* They considered that collections from different plant hosts showed consistent differences in taxonomy that merited specific separation. Subsequently, Bhatnagar (ICRISAT 1976) studied the range of the cited taxonomic characters of insects collected from those host plants and concluded there was continuous variability within populations and no consistent differences associated with the collections from the different hosts. However, we frequently encounter puzzling differences in apparent host-plant preferences of *H. armigera* across and between areas and cannot rule out the existence of at least subspecific differences between populations. For example, in southern India, at Coimbatore, *H. armigera* seldom reaches pest status on cotton, but many moths of this species are caught in light traps through the cotton season, and this insect is a major pest on the legumes and other crops in this area. A few miles to the south and a few hundred miles to the north, *H. armigera* is a very damaging pest of cotton in most years.

We have much to learn from such puzzles, through the discovery of the reasons why *Heliothis* is not a pest on some crops and in some areas. Unfortunately, we concentrate all of our efforts on crops and areas where *Heliothis* is a major problem and await a brave, farseeing research supervisor who will direct his staff and funding to do otherwise!

The third most important species is *Heliothis virescens* (F.), which burst into prominence as a major pest on cotton in the Americas in the middle of this century. Its common names, tobacco budworm and tomato budworm, reflect the crops on which it caused most concern in both North America and the West Indies in the early part of this century. Although this species had been recorded on cotton in the Virgin Islands by Wilson (1923) it did not merit concern on this crop until the 1930s, when it was recognized as having become a major pest of cotton in some areas of South America, particularly in Peru (Wille 1940). Hambleton (1944) reviewed the pest status of this insect and noted the association of the use of arsenical dusts and the increased attacks by this pest. He recorded that in 1942-43 a general recommendation to farmers not to dust their cotton led to a sharp decline of this pest, largely through the resultant increase of its natural enemies, particularly in an area with a wide range of host plants.

The spectacular rise to infamy of *H. virescens* in North America is so well known that we need not devote much time to this. *Heliothis virescens* had been recorded as a pest of cotton in Louisiana in the mid-1930s (Folsom 1936), but it was the widespread use of DDT and other chemical pesticides from 1950 to 1970, primarily to control *Anthonomis grandis* Boheman, the boll weevil on cotton, that forced *H. virescens* into prominence (Adkisson 1971). The elimination of its natural enemies and the resistance of the pest to all available pesticides allowed it to cause so much destruction that it closed down cotton growing in very large areas and so caused enormous economic upheaval. The publicity given to these events induced a widespread realization that chemical insecticides could not be relied upon to insulate farmers from insect pests, gave a tremendous boost to integrated pest management, and so led Adkisson to comment that *H. virescens* had become a beneficial insect!

In addition to the "big three" *Heliothis* spp, there are others of localized or of minor-crop importance. *Heliothis punctigera* (Wallengren) is a pest of a wide range of crops in Australia. *Heliothis peltigera* (Schiff) is widely distributed across Europe, Africa, and Asia, causing some damage to cotton and safflower. *Heliothis assulta* (Guenee) is widespread through Asia and Australasia, with a different subspecies occurring in Africa (Hardwick 1965), and causes some damage to solanaceous crops. *Heliothis viriplaca* (Hfn.), which earlier featured in the literature as *H. dipsacea,* merits pest status on several crops, including cotton and several legumes, from southwest Asia well into USSR.

Losses Caused by *Heliothis* Spp

As with many other pests, there are few well-researched estimates of losses caused by the *Heliothis* spp. It has been generally assumed that the losses are greatest on cotton, for it is on this crop that these pests have received most attention. On cotton and other crops, *Heliothis* spp form only a part, but often a major part, of the pest complex, and so it is difficult to apportion the losses, even where the total losses are known. Losses to *H. zea* in the United States have been estimated to reach "hundreds of millions of dollars," and the losses to *H. virescens* through the 1960s and into the 1970s must have reached similar sums. The cost of chemicals used on cotton to suppress *Heliothis* spp were estimated by Ignoffo (1973) to be in excess of $50 million per year.

In Australia, Alcock and Twine (1980) estimated that *Heliothis* spp cost over $16 million in the state of Queensland alone each year, with major losses on sorghum, cotton, tomatoes, tobacco, and safflower, and with substantial losses on 11 other crops. These estimates included both the cost of protection designed to reduce crop loss and the residual losses. Elsewhere in Australia, the destruction of natural enemies and resistance of *Heliothis* spp to insecticides (Wilson 1974) led to a situation in the Ord scheme where the pests could no longer be controlled, and cotton-growing had to be discontinued, so leading to large losses and the need for a substitute crop that was not susceptible to *Heliothis* and could be grown profitably. In Africa, there appear to be no recent estimates of losses in cash terms. It is not difficult to estimate, however, that the loss of cotton to *H. armigera* in Tanzania alone must amount to more than $20 million in most years, a loss that may appear small in the developed countries, but is a massive sum when related to the economy of that developing nation. In Sudan, this pest is now costing the Gezira and other cotton schemes enormous sums both in yield losses and in pesticide costs.

In India, there are no published estimates of losses caused by *H. armigera,* but calculations based upon ICRISAT surveys of farmers' fields indicate that the annual loss of the two major pulses, chickpea and pigeonpea, may exceed $300 million per year, and losses in other legumes, cotton, cereals, and other crops must add substantially to that total. Such estimates certainly justify the increased research attention that is now being paid to this pest.

What Promotes *Heliothis* Spp to Pest Status?

The *H. virescens* saga in the USA convinced some scientists that the pest status of *Heliothis* spp has been almost entirely pesticide-induced. Consequently all *Heliothis* spp have recently been regarded as "upset pests" that can be easily relegated to minor status by measures—including a reduction in pesticide use—that will allow the natural control elements to decimate the populations. This simplistic approach has undoubted merit in some cases, particularly in relation to *H. virescens,* but certainly not in the case of *H. armigera* in many of its endemic areas.

Heliothis zea was a major pest of several crops, including maize and cotton, well before the widespread use of pesticides. At the turn of the century it was considered to be of sufficient importance to merit a 149-page USDA Bulletin (Quaintance and Brues 1905), and Hyslop (1927) considered this to be the third most destructive pest in the USA.

Heliothis armigera has been the dominant and primary pest of cotton in some countries of Africa, including Tanzania, both before and after pesticides became widely used. In India it is the dominant pest on cotton in some areas and on several other crops, particularly pigeonpea and chickpea, in most areas. On both the major pulse crops, *H. armigera* commonly destroys more than half the yield, yet even now less than 10% of the farmers use any pesticides on these or other crops on which this pest is particularly damaging. In such circumstances, the pest status cannot be attributed to man's misuse of pesticides and the answer is certainly not a reduction of pesticide use.

It is commonly considered that *Heliothis* spp are becoming an increasing problem, this being associated with improving agriculture. Quantitative evidence of increasing intensity or extension of the areas of attack is available from only a few areas, however, for there are usually no base data of quantitative records of populations or losses.

There is little doubt that *Heliothis* spp increased in importance in the United States largely because of pesticide use, but partly also because of a general improvement in cropping, leading to higher yields through the use of inputs such as fertilizer and irrigation. We know that *H. armigera* has increased in importance in Sudan and Egypt, apparently for similar reasons. In northern Nigeria, *H. armigera* was a rarity in the late 1950s, but has since become a pest; this increase was perhaps associated with the introduction of maize and tomatoes in irrigated schemes. In India, the pest populations are at present greatly reduced each year by the hot dry summers in the south and the cold winters in the north. We fear that an increase in the use of irrigation in the south is leading to an increase in the availability of plant hosts through the dry season and a subsequent increase in pest populations. We also suspect that there are substantial long-range migrations of the moths, so the north may face increasing populations as a result of developments in the south.

Scientists in the USA have demonstrated that the factors regulating populations of *H. zea* are fairly well understood, for computer programs combining these factors now permit the forecasting of populations across areas with reasonable accuracy (Hartstack et al. 1976). For *H. armigera,* however, our knowledge of what promotes differing populations across areas and years is woefully inadequate.

Perhaps the most important observation towards understanding *H. armigera* populations was made by Coaker (1959), while working in southern Uganda. He noted that *H. armigera* was not a serious pest of cotton in that area, but within 200 miles, both to the north in Uganda and to the south in Tanzania, this pest was severe on cotton. He concluded that in southern Uganda, the insect did not achieve pest status because the climate allowed both the insect and its natural enemies to thrive throughout the year. In northern Uganda and in Tanzania, however, there are prolonged dry seasons during which few host plants provide food for the insects, so populations of the pest and its natural enemies are reduced to very low levels each year. In the rainy season, *H. armigera* population increases outpace those of its natural enemies. By the time the natural enemy populations build up to influential levels, the damage to crops has already been done.

Given such evidence, we may be totally wrong in fearing that an increase in the availability of hosts through the dry season may give India increasing *Heliothis* spp problems. Here at ICRISAT we insist upon a closed season during which no crops may be grown, in an attempt to control some pests, including *Atherigona soccata,* the sorghum shoot fly. There is at least a possibility that such closed seasons could lead to an increase in *H. armigera* populations as a result of a reduction of the natural enemies. We may be providing a disruption of the natural control and so promoting the pest, just as pesticide use has done. We now have to consider whether we can find evidence that will determine whether a closed season is beneficial or harmful to the pest status of *H. armigera* in any area. It is unlikely that we will be able to contrive a replicated experiment that will allow us to test this in our fields, so we may have to rely upon computer simulations, if we can determine the meaningful inputs, including the incidence and extent of moth migration.

Disruption of the natural control elements of *H. armigera* can also occur during migrations from area to area and during shifts from one host to another in the same area. This latter effect has been clearly shown (Bhatnagar et al.: these Proceedings) in the case of sorghum and pigeonpea, for on these crops the pest transfers from one to the other, but many of the natural enemies do not.

Although most blame for increases in *Heliothis* problems has been attributed to the destruction of natural control by pesticides, there is some evidence that plant breeders have also contributed. Progress in breeding for resistance to *Heliothis* in the major host crops has been slow, and there are few instances of new cultivars particularly selected for their resistance or tolerance to *Heliothis* being released to farmers. Most breeding and subsequent testing of Heliothis-susceptible crops, particularly in the developing countries, are carried out in pesticide-protected fields, with yield as the main selection criterion. We have some evidence from trials at ICRISAT that such selection is likely to lead to increased losses to *Heliothis* and other pests. Good examples of this are (1) the determinate type pigeonpeas, which can yield well under pesticide protection but yield virtually nothing in unprotected fields in southern India, and (2) the tight-head sorghums, which do well under protected conditions but are much more severely attacked by *Heliothis* and other pests than the open-head types of sorghum in farmers' fields (Doggett 1954). Here at ICRISAT we appear to be unique among research stations in retaining large areas of land that are pesticide-free, and these are being increasingly utilized not only by the entomologists but also by our breeders and other scientists.

The Future

In the past, a great deal of research effort was expended upon *Heliothis* spp, but usually on single crops, particularly cotton, and within small areas, sometimes within research station boundaries. Much of the research has been directed towards single elements of pest management and the literature is rich in such information. In spite of all this work, however, we have little to offer farmers in the semi-arid tropics of the developing countries in the way of practical reduction of Heliothis-caused losses on their crops, other than to advise them to use one or two pesticide applications. We are nowhere near a situation where we can provide practical integrated pest management on a national, area, or even field basis, that can compete with the immediate economic advantage of using DDT

Our failure may be a result of the restriction of most research to individual crops or fields. We need a more holistic approach, with emphasis upon *Heliothis* populations over areas and over time. ICRISAT is ideally placed to encourage such research across India and has already embarked upon this in cooperation with scientists of the Indian Council for Agricultural Research and those working in other national and state institutes. In Australia, there is a team in Queensland that has been concentrating upon *Heliothis* management and their work may well act as a model for other areas. In Africa, there appears to be no well-funded or multidisciplinary team effort to fight *Heliothis,* except in the Sudan. In the United States there have been some magnificent individual contributions to the understanding and management of *Heliothis* spp, but even there greater progress could have been made if there had been integration of effort on an area, rather than on a crop, basis.

We hope that this workshop will promote not only the interchange of information and ideas between scientists working on different aspects, on different crops, and in different countries, but will also stimulate a reappraisal of research policies that will result in more coordination of individual and localized research. If such a reappraisal is not made, there is a danger that there will be another workshop 80 years in the future, discussing similar problems and prospects. Those who have studied Quaintance and Brues' (1905) report will realize that much of the *Heliothis* research today is doing little more than rediscovering what was reported at the beginning of this century!

References

ADKISSON, P.L. 1971. Objective use of insecticides in agriculture. Pages 43-51 *in* Proceedings, Symposium on Agricultural Chemicals—Harmony or Discord for Food, People and the Environment (ed. J.E. Swift). University of California, USA.

ALCOCK, B., and TWINE, P.H. 1980. The cost of *Heliothis* in Queensland crops. Presented at the Workshop on Biological Control of *Heliothis* spp. 23-25 Sept 1980, Queensland Department of Primary Industries, Toowoomba, Queensland, Australia.

BHATNAGAR, V.S., LATEEF, S.S., PAWAR, C.S., SITHANANTHAM, S., and REED, W. 1982. Research on *Heliothis* at ICRISAT. These Proceedings.

BHATTACHERJEE, N.S., and GUPTA, S.L. 1972. A new species of *Heliothis* Ochsenheimer (Noctuidae, Lepidoptera) infesting cotton and tur *(Cajanus indicus)* in India with observations on the three other common species of the genus. Journal of Natural History 6:147-151.

COAKER, T.H. 1959. Investigations on *Heliothis armigera* (Hb.) in Uganda. Bulletin of Entomological Research 50: 481 -506.

COMMON, I.F.B. 1953. The Australian species of *Heliothis* (Lepidoptera: Noctuidae) and their pest status. Australian Journal of Zoology 1: 319-344.

DOGGETT, H. 1954. *In* Progress Report for the season 1952-53, Tanganyika Territory, Lake Province. Empire Cotton Growing Corporation. London U.K.

FOLSOM, J.W. 1936. Notes on little known cotton insects. Journal of Economic Entomology 29(2): 282-285.

FORBES, W.T.M. 1954. Lepidoptera of New York and neighbouring states. III. Noctuidae. Cornell Agricultural Experiment Station Bulletin 329, Ithaca, NY, USA. 433 pp.

HAMBLETON, E.J. 1944. *Heliothis* virescens as a pest of cotton, with notes on host plants in Peru. Journal of Economic Entomology 37(5): 660-666.

HARDWICK, D.F. 1965. The corn earworm complex. Memoirs of the Entomological Society of Canada 40, Ottawa, Canada. 247 pp.

HARTSTACK, A.W., WITZ, J.A., HOLLINGSWORTH, J.P., RIDGWAY, R.L., and LOPEZ, J.D. 1976. MOTHZV-2: A computer simulation of *Heliothis zea* and *Heliothis virescens* population dynamics. Users manual. U.S. Department of Agriculture ARS-S-127, Washington DC, USA.

HYSLOP, J.A. 1927. A monthly survey report. Journal of Economic Entomology 20: 717-725.

ICRISAT. 1976. Pages 178-180 *in* ICRISAT Annual report 1975-76. Patancheru, A.P., India: ICRISAT.

IGNOFFO, C.M. 1973. Development of viral insecticide concept to commercialisation. Experimental Parasitology 33: 380-406.

QUAINTANCE, A.L., and BRUES, C.T. 1905. The cotton bollworm. U.S. Department of Agriculture. Bureau of Entomology, Bulletin 50, Washington, DC, USA. 149 pp.

TODD, E.L. 1978. A checklist of species of *Heliothis* Ochsenheimer (Lepidoptera: Noctuidae). Proceedings of the Entomological Society of Washington 80(1):1 -14.

WILLE, J.E. 1940. Observations sobre *Heliothis virescens* F. como plaga del algodonero en el Peru (Lep). Revista de Entomologia (Rio de Janeiro) 11(1-2): 584-588.

WILSON, A.G.L. 1974. Resistance of *Heliothis armigera* to insecticides in the Ord Irrigation Area, North Western Australia. Journal of Economic Entomology 67:256-258.

WILSON, C.E. 1923. Insect pests of cotton in St. Croix and means of combatting them. Virgin Isles Agricultural Experiment Station Bulletin 3, Virgin Isles.

Session 1

Biology, Behavior, and Ecology of *Heliothis* Spp

Chairman: E.G. King
Cochairman: R.C. Patel

Rapporteurs: S.S. Lateef
S. Sithanantham

Biological and Ecological Studies of *Heliothis*

S. Jayaraj*

Abstract

The previous work on the biology and ecology of Heliothis spp *is reviewed and recent work in South India is reported.* Heliothis armigera *laid* 50.6% eggs *on the upper surface of cotton leaves on the upper half of the plant. Squares were the other preferred site, with a mean of 31.7% eggs. Temperature and host plant affected the development of* Heliothis *considerably.*

The preferred host plants for oviposition by H. armigera *were found to be, in descending order, pigeonpea, field bean, chickpea, tomato, cotton, chillies, mung bean, and sorghum. Feeding preference was, in descending order, pigeonpea, field bean, cotton, sunflower, sorghum, chickpea, mung bean, urd bean, and tomato. Chillies were not selected tor feeding. A mean of* 76.9 *larvae per three plants was observed on pigeonpea grown as a border crop around cotton, but a mean of only 4-05 larvae was found on the main cotton crop.*

Consumption index (fresh weight) had significant correlation with innate capacity for increase in numbers and finite rate of increase; growth rate was significantly correlated with the net reproductive rate, weight of pupae, and percentage of pupae and moths formed.

Résumé

*Etudes biologiques et écologiques sur l'*Heliothis: *La recherche passée sur la biologie et l'écologie d'*Heliothis *spp est revue et les travaux de recherche récents faits au sud de l'Inde sont décrits.* Heliothis armigera *a déposé 50,6% de ses oeufs sur la face supérieure des feuilles du cotonnier à la moitié supérieure du plant. Les fleurs encore recouvertes des bractées (squares) ont été l'autre site choisi, avec une moyenne de 31,7% des oeufs. La température et la plante-hôte ont beaucoup affecté le développement de l'*Heliothis.

Pour l'oviposition les plantes-hôtes préférées ont été, par ordre décroissant, le pois d'Angole, Lablab purpureus, *le pois chiche, la tomate, le cotonnier, les piments,* Vigna radiata *et le sorgho. La préférence alimentaire a été, par ordre décroissant, le pois d'Angole,* Lablab purpureus, *le cotonnier, le tournesol, le sorgho, le pois chiche,* Vigna radiata, Vigna mungo *et la tomate. Les piments n'ont pas été choisis pour l'alimentation. Une moyenne de 16,9 larves par trois plants a été observée sur le pois d'Angole qui servait de culture de bordure autour du cotonnier, mais une moyenne de 4,05 larves seulement a été trouvée sur la culture principale, soit celle du coton.*

L'indice de consommation (poids frais) a été en corrélation significative avec la capacité intrinsèque de croissance et le taux fini de croissance; le taux de croissance était en corrélation significative avec le taux reproductif net, le poids des pupes et le pourcentage de pupes et papillons formés.

Heliothis spp are major pests on many important crops, *H. zea* (Boddie), *H. armigera* (Hiibner), and *H. virescens* (F.) being the most devastative. In India, the three species—*H. armigera, H. peltigera* Schiff, and *H. assulta* Guenee—occur frequently, and *H. armigera* is by far the most important. A great deal of information is available on *Heliothis* spp because of their wide distribution in many parts of the world; the literature pertaining to the biology and ecology of the important species is briefly reviewed in this paper.

Annual Cycle

Heliothis armigera passes through four generations in the Punjab, India: one on chickpea during

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March; two on tomato, from the end of March to May; and one on maize and tomato in July-August (Singh and Singh 1975). Light-trap catches also showed the occurrence of four broods. Moths of the first brood appeared in March; of the second in April; of the third in May; and of the fourth in July-August. Bhatnagar (1980) reported that seven to eight generations of *H. armigera* are present each year in Andhra Pradesh, India.

Oviposition usually starts in early June, with the onset of premonsoon showers, adults possibly emerging from diapausing pupae and also from larvae that had been carried over in low numbers on crops and weeds during the summer. Reproductive moths were recorded throughout the year ovipositing on the host crops and weeds with flowers. The pest multiplied on weeds, early-sown corn, sorghum, mung bean, and groundnut before infesting pigeonpea in October-November and chickpea in November-March. Field surveys have indicated that the larvae of *H. armigera axe* present on some crop or weed host in every month of the year. Host plants flowering in summer and weed hosts are a source of carryover. Hsu et al. (1960) observed three generations of *H. armigera* each year in China. The pest bred four complete and a partial fifth generation in Hunan Province of China (Anonymous 1977). Reed (1965) reported that the pest completed four generations from September to March under western Tanganyika conditions.

The literature on seasonal abundance of *H. zea* and *H. virescens* has been reviewed by Lincoln (1972). Development of the bollworm, *H. zea,* has been found to be continuous, at least at a low level, throughout most years in southern Louisiana (Brazzel et al. 1953) and in the lower Rio Grande Valley (Fife and Graham 1966). At more northerly locations, *Heliothis* survived the winter as diapausing pupae in the soil and there were then six generations in the year. The first generation in the spring was found on a variety of weed and legume hosts; larvae were generally exposed to parasites and predators, because the fruiting bodies of the hosts were too small for larvae to bore into. The second generation in early and mid-June was passed primarily on whorl-stage corn, tomato, tobacco, alfalfa, okra, and cotton. Two generations were passed on corn, which silks continuously from mid-June to late July, depending on the planting date. From early August, with the loss of corn as a suitable host, the fifth generation turned to a series of hosts, and cotton, groundnut, alfalfa, and tobacco were all found to support large populations. This generation was extremely important from an economic standpoint. The final generation in late September and early October was also found on these plants.

Cotton was infested in mid-July, and infestations were more or less continuous until the crop was removed in September-October. Soybeans often supported heavy populations in late August and early September. Diapause populations developed in October, mostly on regrowth cotton.

Like the bollworm, the tobacco budworm, *H. virescens,* is found on a variety of weed hosts and legumes in the first generation. Tobacco is the favored host for the second and later generations, but in the absence of tobacco, cotton is the principal summer host. Tomato, okra, and alfalfa may be locally important, but corn and grain sorghum are seldom infested (Lincoln 1972).

Generalizations about seasonal abundance must, however, be limited to areas with similar climate, crops, and wild hosts.

Life History and Habits

Moth Activity

Details of the life history and habits given for *H. armigera* appear to be broadly similar to those given for *H. zea* (Pearson and Darling 1958).

Although emergence of *H, armigera* moths has been found to take place in the evening any time after 1600 hr, the peak emergence being between 2000 and 2200 hr (Singh and Singh 1975; Roome 1975). There was no emergence during the day. Roome (1975) observed that from 0200 to 0400 hr the males flew above the crop while the females were stationary and released a pheromone. During this period of high male and low female activity, assembly of males around females and copulation were observed in caged as well as field conditions. Inseminated female *H. armigera were* collected in crops that were at a suitable stage for oviposition, while light traps away from crops or near mature crops collected mainly virgin females. Loganathan (1981) observed peak mating activity at 0400 hr.

The preoviposition period ranged from 1 to 4 days, oviposition period 2 to 5 days, and postposition period 1 to 2 days (Patel et al. 1968; Singh and Singh 1975). Moths continued to oviposit for 10 to 23 days in South Africa, depending on the time of year, averaging 730 eggs each, with a maximum of 1600, and a maximum in one night of 480. In Southern Rhodesia, the total number of eggs laid over a period of 2 months ranged up to 1729, and the average per egg-laying night up to 276. In the USA, one moth laid a maximum of about 3000 eggs. Oviposition on maize by *H. zea* mostly took place at the time of silking, but by *H. armigera* at the time the tassels appear. On cotton, oviposition rarely took place in quantity until flower buds were formed (vide Pearson and Darling 1958).

Eggs

The eggs of *Heliothis armigera* are nearly spherical, with a flattened base, giving a somewhat dome-shaped appearance, the apical area surrounding the micropyle smooth, the rest of the surface sculptured in the form of longitudinal ribs; at first yellow-white, glistening, changing to dark brown before hatching; diameter 0.4 to 0.55 mm.

The eggs are laid singly, late in the evening, mostly from after 2100 hr to midnight. On many host plants, the eggs are laid on the lower surface of the leaves along the midrib. Eggs are also laid on the buds, flowers, and in between the calyx and fruit (Continho 1965; Singh and Singh 1975). *H. zea* in the United States, when laying eggs on maize, prefers the silks, but *H. armigera* in South Africa lays very few eggs on the silks and about half on the stalks. On cotton, *H. armigera* eggs were found mostly on the upper surfaces of leaves and on the squares, while *H. zea* laid one-third on the squares and the remainder scattered about the plant (vide Pearson and Darling 1958).

Beeden (1974) observed that eggs of *H. armigera were* laid on cotton uniformly over the field throughout the season. A significant correlation was found between the number of sympodial nodes and the number of eggs per plant throughout the season. The favored oviposition sites changed from vegetative parts of plants, notably leaf surfaces and stems, early in the season to bolls and peduncles later in the season.

The percentage of oviposition by *H. armigera* on cotton was found to vary on the surfaces of leaves in the upper and lower halves of the plant in the early, peak, and late flowering phases. A mean of 50.6% eggs was observed on the upper surface of leaves on the upper half of the plant. Cotton squares formed the other preferred site, with a mean of 31.7% eggs (Table 1). The lower surface of leaves on the lower half of the plant was the least preferred site (Vijayakumar and Jayaraj 1981). A study of within-plant distribution of *H. zea* on cotton revealed that the average location of eggs was approximately one-third of the distance in nodes from the terminal. The main-stem leaves were the preferred oviposition sites. Older larvae were found lower on the plant than younger ones, and early first-instar larvae were detected in squares by the presence of trass and flaring of the bracts.

Patel et al. (1974), found that, irrespective of the color (yellowish green or deep-green) of the cotton plants, *H. armigera* preferred the upper half of the plant to the lower, the upper leaf surfaces to the lower, and tender leaves to medium and old leaves for oviposition. In the yellowish green fields, more eggs were laid on the occasional deep green plants than on yellowish ones, but number of eggs per 50 leaves was still greater in the wholly deep green fields, indicating that ovipositing females were attracted to deep green.

The incubation period of the eggs is longer in cold weather and shorter in hot weather, being 2 to 8 days in South Africa and 2.5 to 17 in the United States (Pearson and Darling 1958), and 2 to 5 days in India (Srivastava and Saxena 1958; Singh and Singh 1975) and Western Tanganyika (Reed 1965). The viability of eggs varies from 63 to 90%.

Larvae

There are normally six instars in *H. armigera,* but exceptionally, during the cold season, when larval development is prolonged, seven instars were regularly found in Southern Rhodesia (Pearson and Darling 1958). The newly hatched larva is translucent and yellowish white in color, with faint yellowish orange longitudinal lines. The head, thoracic and anal shields, and legs are brown, and the setae dark brown (Neunzig 1964; Singh and Singh 1975). The full-grown larva is about 35 to 42 mm long; general body color is pale green, with one broken stripe along each side of the body and one line on the dorsal side. Short white hairs are scattered all over the body. Head is reddish brown, thoracic and anal shields and legs are brown. Setae are dark, prothorax is slightly more brownish than meso- and meta-thorax. Crochets are arranged in a biordinal symmetry on the prolegs. The underside of the larva is uniformly pale. The general color is extremely variable; and the pattern may be in shades of green, straw yellow, and pinkish to reddish brown or even black.

The young larva of *H. armigera* on emerging usually eats some or all of its empty eggshell before feeding on the plant. It wanders about nibbling various parts of the plant until it finds a flowerbud or

Table 1. Oviposition pattern of *H. armigera* on cotton during early, peak, and late flowering phases (mean of three observations).

Place of oviposition	Percentage eggs laid during: Early flowering (August - September)	Peak flowering (October - November)	Late flowering (December)	Mean
Squares	28.4 (32.3)	33.3 (35.4)	33.4 (35.3)	31.7 (34.3)
Leaves: Upper half of plant				
Upper surface of leaf	45.9 (42.0)	53.7 (47.2)	52.1 (46.3)	50.6 (45.2)
Lower surface of leaf	17.2 (24.6)	9.3 (17.8)	14.6 (22.2)	13.7 (21.5)
Leaves: Lower half of plant				
Upper surface of leaf	7.7 (16.1)	3.6 (10.7)	0.0 (1.8)	3.8 (9.5)
Lower surface of leaf	0.8 (4.2)	0.0 (1.8)	0.0 (1.8)	0.3 (2.6)

LSD (P=0.05)

Stage of flowering	1.62**
Place	2.08**
Stage of flowering x place	3.60**

** Significant at 1% level

(Figures in parentheses are arcsin percentage values)

Source: Vijaykumar and Jayaraj (1981).

flower; a bud will be hollowed out, leaving an empty shell. Young larvae rarely attack bolls; older larvae prefer buds and young bolls. The full-grown larva is of considerable size and it habitually feeds with only the front portion of its body inside the hole it has made. Cotton buds and bolls that have been attacked by *Heliothis* thus commonly show an accumulation of larval faeces between the surface and the enclosing bracteoles. This habit must render the larva more prone to attack by natural enemies. The larvae often move about the plant and usually attack each other if they meet; the victor, if not mortally wounded, will devour its opponent.

Temperature affects the development of the larva considerably. The larval duration varied from 21 to 40 days in California, 18 to 51 days in Ohio (Wilcox et al. 1956), and 8 to 12 days in the Punjab, India (Singh and Singh 1975) on the same host, tomato. The length of larval life is recorded as 15 to 32 days in South Africa, 14 to 70 in the United States, and 18 to 35 in Nyasaland. In Southern Rhodesia, the larval period and the temperature in an insectary averaged approximately 18 days (22.5°C) in November and 51 days (17.5°) in June-July. The temperature limits determined in the USSR were 14 and 36°C; the optimum temperature, 27 to 28°C at 100% relative humidity for the early instars and 25 to 26°C at 80 to 90% for the late instars (vide Pearson and Darling 1958).

Nikishina (1980) reported that temperature also regulates feeding activities of *H. armigera* larvae that give rise to overwintering pupae in Tadzhikistan, USSR. The larvae fed on fruiting forms, irrespective of the amount present of the sex hormone vitamin E (tocopherol), but the proportions of pupae entering diapause varied with the forms on which the larvae fed. Third-generation larvae in fields of early cotton fed mainly on squares and 10-day-old bolls containing in all 74.7 mg of vitamin E/100g and later on buds and squares containing 47.5 mg /100g. Diapausing pupae in the two cases were 18.5% and 24.5% respectively.

The rate of development of *H. armigera* is also affected by the type of food. The larval stage lasted for 21 to 28 days on chickpea (Srivastava and Saxena 1958); 21.8 days on maize silk; 33.6 days on sunflower corolla (Coaker 1959); and 20 to 21 days on cotton (Hsu et al. 1960; Reed 1965).

The full-grown *H. armigera* larva leaves the plant, sometimes by dropping to the ground, and burrows into the soil to a depth of 2.5 to 17.5 cm. In the case of *H. zea,* the larva then works upward by a different route, forming a curved tunnel with smooth walls of well-packed earth, thinly covered with silk. This burrow stops just below the surface, and the larva then retires to the lower end where it pupates (vide Pearson and Darling 1958). In sandy soil the burrow is deeper when the soil is dry; in heavy soil it is shallow, and if the soil is very dry, the larva may not be able to penetrate it and uses a crack instead.

Pupae

The pupa is 14 to 18 mm long, mahogany-brown, smooth-surfaced, and rounded both anteriorly and posteriorly, with two tapering parallel spines at the posterior tip.

Harrell et al. (1979) studied the effects of two levels of temperature (25 and 29°C), two of relative humidity (50 and 70%), and five of air velocity (10, 75,150, 200, and 300 cm/sec) on development of *H. zea.* Relative humidity influenced the development more than air velocity. The higher temperature shortened pupation time. Air velocities did not affect development at high humidity but did at low humidity.

The pupa of *H. armigera* undergoes a facultative diapause. Only nondiapause pupae are formed during much of the year, but during cold weather, a large proportion of the pupae formed undergo diapause and thus have a considerably extended pupal period. Not all pupae, however, enter diapause, even in the coldest months, although the duration of the pupal period of such nondiapause individuals is lengthened by the low temperature. It is also possible to find out, by inspection with a hand lens, whether a pupa is in diapause or not. The fat body of the newly formed pupa is composed of firm, rounded lobes, and remains unchanged in this condition throughout diapause. In the developing pupa, histolysis starts on the second day and the fat body disintegrates into a mass of minute, free granules; these start to re-form, about half-way through the life of the developing pupa, into the adult fat body, which is in the form of digitate lobes lying along the trachea (vide Pearson and Darling 1958).

The nondiapause pupal period for *H. armigera* was recorded as 14 to 40 days in the Sudan Gezira, 14 to 57 in Southern Rhodesia, 12 to 25 in Tanganyika, 14 to 37 in Uganda, 15 to 25 in Nyasaland, and 5 to 8 days in India; for *H. zea,* this period was recorded as 14 to 40 days in the United States. Experiments conducted at controlled temperatures in the United States gave 10.3 days as the pupal period of *H. zea* at 32°C and 26.7 days at 20°C. Experiments in the USSR, in which the pupal stage of *H. armigera* took from 13 days at 25°C to 36.6 days at 17.1°C, suggested 11°C as the threshold of development, although larvae bred at 27 to 28°C produced only a few moths, some of them deformed, when the pupae were kept at 14 to 15°C.

The date of emergence of adults from diapause pupae in southern Africa is more or less independent of the date of formation of the pupae, those formed in March to June contributing impartially to an emergence broadly covering August to mid-October. According to Pearson and Darling (1958), this suggests that diapause development is accomplished in two parts, with different temperature requirements, the first having a relatively low requirement, so that all diapause pupae complete it during the winter months and are then arrested, pending the onset of higher temperatures that enable the second part to be accomplished by all pupae more or less concurrently, the later formed ones having by then caught up with those formed earlier.

Diapause in *H. armigera* is most pronounced in South Africa and Southern Rhodesia. It also occurs in the Eastern Province of what was formerly Tanganyika, but is not as pronounced as further south, and in Uganda, on the Equator, no definite diapause occurs. In the Sudan Gezira, a succession of short-term generations occurs between August and January, and in each generation an increasing proportion of the pupae formed appear to enter diapause from which they do not emerge until the following rainy season.

Adults

The female *H. armigera* is a stout-bodied moth, 18 to 19 mm long, with a wing span of 40 mm. The male is smaller, wing span 35 mm. Forewings are pale brown with marginal series of dots; black kidney-shaped mark present on the underside of forewing; hind wings lighter in color with dark-colored patch at the apical end. Tufts of hairs are present on the tip of the abdomen in females.

The female moth is the longer lived. In the United States, the average figures for H. *zea* are 7.5 to 14.0 days for males and 9.25 to 18.0 for females, the longest lived male surviving for 19.5 days and the female for 38 days. In South Africa, males lived for 1 to 23 days (average 8.7) and females 5 to 28 (average 13.5). The length of life is greatly affected by the availability of food, in the form of nectar or its equivalent; in its absence, the female fat body is rapidly exhausted, and the moth dies when only 3 to 6 days old. This explains why moth activity is largely confined to the flowering phase of the crops.

The moths copulate about 1 to 4 days after emergence from the pupa, but only if they have fed on nectar. They may lay infertile eggs before mating, but mating stimulates oviposition. The moths normally remain inactive on the plants during the day; most activity is usually between sundown and dark, when they begin by feeding from nectaries or insect honeydew or drops of moisture on their host plants.

Host Plants

Heliothis can breed on a wide range of plants, and cotton is not the most favored. The crops attacked in many countries are maize, sorghum, oats, barley, pearl millet, chickpea, pigeonpea, cowpea, peas, various beans, cotton, sunflower, safflower, tobacco, tomato, brinjal, cucurbits, sweet potato, groundnut, flax, citrus, lucerne, sunnhemp, cape gooseberry, potato, etc.

There are various wild host plants recorded in South Africa, of which the most important are *A calypha segatalis* (Euphorbiaceae) *Amaranthus thunbergii* (Amaranthaceae), *Malvastrum tricuspidatum* (Malvaceae), *Nicandra physaloides* (Solanaceae), *Sonchus oleraceus* and *xanthium pungens* (Compositae). In Tanganyika, *Portulaca oleracea* (Portulacaceae) and *Tridax procumbens* (Compositae) are mentioned as important wild hosts; in the Sudan, *Ipomoea cordofana* (Convolvulaceae).

Bhatnagar and Davies (1978) recorded 50 species of crop plants and 48 species of wild and weed species of plants for *H.armigera* at Patancheru, Andhra Pradesh, whereas 96 crops and 61 weeds and wild species have been recorded elsewhere in India. The most important carryover weed hosts in the hot summer season are *Datura metel, Acanthospermum hispidum,* and *Gynandropsis gynandra* for *H. armigera, H. assulta,* and *H. peltigera.*

Preference for Oviposition and Feeding

The preferred host plants for oviposition by *H. armigera* were studied by Vijayakumar and Jayaraj (1981) and found to be, in descending order, pigeonpea, field bean, chickpea, tomato, cotton, chillies, mung bean, and sorghum. A mean of 40.3 eggs per plant was observed on pigeonpea (Table 2). Reddy (1973) and Loganathan (1981) reported similarly that pigeonpea was the preferred host for oviposition. Hillhouse and Pitre (1976) reported that *H. zea* and *H. virescens* preferred cotton for oviposition, while Parsons et al. (1937) reported that chickpea was most attractive for oviposition.

The feeding preference of *H. armigera* was, in descending order, pigeonpea, field bean, cotton, sunflower, sorghum, chickpea, mung bean, urd bean, and tomato. Chillies were not selected for feeding in the multiple-choice test (Table 2). A mean of 16.9 larvae per three plants was observed on pigeonpea grown as a border crop around cotton, but the cotton recorded only 4.05 larvae (Table 3) during the September-February season (Vijayakumar and Jayaraj 1981).

Food Consumption and Utilization

From an ecological point of view, the rates of digestion and conversion of food by the most destructive instars might serve as a reasonably precise estimate of food utilization during the whole larval period (Waldbauer 1968). Dhandapani and Balasubramanian (1980a) studied the food utilization of *H. armigera* from the third to the last instar larvae, using chickpea, pigeonpea, lablab, cotton, tomato, sorghum, maize, and sunflower as hosts. Total food consumed was most in cotton and least in sun-

Table 2. Oppositional and feeding preference of H. armigera In multiple-choice last of host plants (mean of three observations).

Most plant	No. of eggs laid/plant	% of oviposition	No. of larvae feeding	% of larvae feeding
Cotton	17.0 (4.3)[a]	10.7	3.7 (2.0)	18.4
Pigeonpea	40.3 (6.3)	25.5	6.7 (2.7)	33.3
Field bean	30.0 (5.5)	19.0	4.0 (2.1)	20.0
Tomato	19.3 (4.4)	12.2	0.3 (0.9)	1.7
Mung bean	8.7 (3.0)	5.5	1.0 (1.2)	5.0
Chillies	11.0 (3.2)	7.0	0.0 (0.7)	0.0
Chickpea	24.0 (4.9)	15.2	1.0 (1.2)	5.0
Sorghum	8.0 (2.6)	5.1	1.3 (1.3)	6.7
Urd bean			0.7 (1.0)	3.3
Sunflower			1.3 (1.3)	6.7
LSD (P=0.05)	0.73		0.30	

Source: Vijayakumar and Jayaraj (1981).

a. Numbers in parentheses are square-root transformations.

flower. Approximately 80% of the larval food was consumed during the last instar stage and was again most in cotton and least in sunflower. However, larval weight was maximum in lablab.

Consumption Index

The fresh-weight consumption index (CI) is generally taken as a measure of the behavioral response of insects towards the food (Waldbauer 1968). In the case of *H. armigera,* this index was highest in cotton and least in chickpea. Dhandapani and Balasubramanian (1980a) observed, in general, a direct correlation between the succulence of host plants and the feeding rate of the larvae (Spearman's rank correlation coefficient [rs]= 0.6666*). The dry-weight CI was higher in maize, probably because of more dry matter. The CI calculated based on dry weight of food and fresh weight of larva was highest in maize. This finding is of nutritional interest, since this index measures the rate at which nutrients enter the digestive system. Several earlier workers have found that the dry-weight CIs were always higher than the corresponding fresh-weight CIs, because the insects contained a lower percentage of dry matter than their food. On each host plant, the CI values, both on dry-weight and fresh-weight basis, were highest in the third-instar larvae and gradually decreased in each subsequent larval stage, indicating that the nutritional requirement of the earlier instars is probably higher.

Growth Rate

The relative growth rate of *H. armigera* was maximum in sunflower and minimum in sorghum (Dhandapani and Balasubramanian 1980a). As observed by Premkumar et al. (1977), more food consumed does not necessarily give highergrowth rates. On a fresh-weight basis, the CI was maximum in cotton,

Table 3. Population of *H.armigera* larvae on pigeonpea border crop around main crop of cotton (mean of three observations).

Period		Mean larval population on		
Month	Week	Pigeonpea	Cotton	Mean
October	3	7.0 (2.6)[a]	2.3 (1.5)	4.7 (2.1)
October	4	11.7 (3.4)	5.3 (2.3)	8.5 (2.9)
November	1	12.0 (3.5)	4.3 (2.1)	8.2 (2.8)
November	2	27.3 (5.2)	9.0 (3.0)	18.2 (4.1)
November	3	18.3 (4.3)	5.3 (2.3)	11.8 (3.3)
November	4	20.3 (4.5)	4.7 (2.2)	12.5 (3.4)
December	1	17.0 (4.1)	4.0 (2.0)	10.5 (3.1)
December	2	25.3 (5.0)	3.3 (1.8)	14.3 (3.4)
December	3	24.7 (5.0)	3.0 (1.7)	13.8 (2.6)
December	4	17.7 (4.2)	2.0 (1.4)	9.8 (2.8)
January	1	4.7 (2.1)	1.0 (1.0)	2.8 (1.5)
Mean		16.9 (4.0)	4.0 (1.9)	
LSD	$(P=0.05)$			
Period	0.32			
Crop	0.14			
Period x Crop	0.46			

Source: Vijayakumar and Jayaraj (1981).

a. Figures in parentheses are square-root transformations.

but the growth rate was lower. This may be due to the presence of aldehydes and cyclopropenyl fatty acids in cotton (Chan et al. 1978). The dry-weight CI was higher on maize, but this does not guarantee a nutrient intake qualitatively or quantitatively adequate to support growth at the normal rate. The dry matter ingested may be deficient in a nutrient or may be less digestible than the usual food (Waldbauer 1962).

Digestibility

For *H. armigera,* the approximate digestibility (AD) of tomato was higher than that of sunflower on a dry-weight basis; however, on a fresh-weight basis, approximate digestibility was maximum in sunflower-reared and minimum in maize-reared larvae (Dhandapani and Balasubramanian 1980a). Soohoo and Fraenkel (1966) reported that plants with thick structural carbohydrates encompassing the individual cells are less digestible because of the physical barrier to mechanical and enzymatic activity within the insect. The lower digestibility might also be due to a nutrient deficiency or nutrient imbalance (Waldbauer 1962).

Tomato was well digested by the larvae, but resulted in poor growth, probably because the rate of ingestion was so low that most of the food was used for body maintenance rather than growth. In maize, on a dry-weight basis, the rate of consumption was high whereas the digestibility was comparatively low, resulting in low utilization. Possibly the combination of low protein and high dry matter accounts for the low utilization. In general, the AD value was highest in third-instar larvae and gradually decreased in each subsequent larval stage. The decrease might have been due to the fact that young larvae are more selective feeders and choose more digestible, nutritious parenchymatous tissues of the food than older larvae, which apparently feed more indiscriminately.

Utilization of Food

The efficiency of conversion of ingested food (ECI) was highest in pigeonpea and lowest in sorghum on a dry-weight basis, while on fresh-weight basis, it was maximum in sunflower and minimum in cotton (Dhandapani and Balasubramanian 1980a). The ECI values did not remain constant during larval development, but varied among instars. The changes among instars might be influenced by the digestibility of food, its nutritional value, and the level of nutrient intake. The dry-weight ECI possibly reflected better the balance of energy than the fresh-weight ECI. In cotton, the ECI declined with larval age, both on a dry and fresh-weight basis. The indiscriminate feeding of older larvae and the greater energy spent for maintenance could account for this.

The efficiency of conversion of digested food (ECD) was maximum in pigeonpea and minimum in sorghum on a dry-weight basis; on a fresh-weight basis, it was highest in maize and lowest in lablab. As reported by Soohoo and Fraenkel (1966) in the case of *Prodenia eridania,* the high ECD might be due to the high nutritional value of the food and faster growth of the larvae. The fresh-weight ECD for sorghum, maize, and sunflower was two to three times higher than the corresponding dry weight ECD. This probably reflects a high rate of retention of the small amount of water taken in with the food and the storage of metabolic water obtained by the oxidation of carbohydrates as reported in many insects (Waldbauer 1968).

In general, the ECD values were low during the third instar and gradually increased in the last instar. This increase of ECD during larval development has an inverse relationship to the approximate digestibility (AD). As noted earlier, young *H. armigera* larvae digested their food better than older larvae, but since the respiratory rate of younger insects is generally higher per unit bodyweight than it is in later stages, a smaller portion of the digested food is channeled into tissue growth, more of.it being used in maintenance. However, older larvae have a lower metabolic rate than younger ones, and hence more of the digested food is available for conversion to body tissue.

Effect of Host Plant on Development and Reproduction

Dhandapani and Balasubramanian (1980b) studied the effect of eight species of host plants on the biology and reproduction of *H. armigera. The* egg stage ranged from 2.9 to 4.3 days on different food plants. This is in agreement with the duration (2 to 5 days) reported by Ewing et al. (1947), Srivastava and Saxena (1958), Hsu et al. (1960), Reed (1965), Continho (1965), and Singh and Singh (1975). The larval period ranged from 17 to 20 days. The minimum and maximum were with pigeonpea and tomato, respectively (Dhandapani and Balasubramanian 1980b). According to Minanandana (1964), it was 19 and 16 days on pigeonpea and tomato. Singh and Singh (1975) observed 8 to 12 days on tomato and they reported that the deviation in larval period might be due to the climatic conditions. In maize and cotton, larval period was 18 and 18.3 days. Pretorius (1976) has also noted 17.4 and 18.2 days in maize and cotton respectively. The total larval duration was 21, 15, 24, and 19 days when larvae were fed on cotton, soybean, tomato, and corn respectively (Doss 1979). The weight of the sixth-instar larvae was significantly higher on cotton (700 mg) than on sunflower, field bean, pigeonpea, chickpea, and maize, which ranged from 598 to 626 mg. The weight was reduced considerably when larvae were reared on tomato (376 mg) and sorghum (390 mg) (Vijayakumar and Jayaraj 1981). The difference in larval period and weight observed among hosts might be due to differential nutritional status of the host.

The pupal stage ranged from 10.5 to 13.6 days, being minimum on pigeonpea and maximum on sorghum, maize, and sunflower. The weight of the pupae and percentage of pupae and moths formed were higher with cotton food material, lower with sorghum (Pretorius 1976; Dhandapani and Balasubramanian 1980b; Vijayakumar and Jayaraj 1981).

H. armigera adults from larvae fed on soybean and cotton lived longer than those fed on tomato and corn. The preoviposition period ranged from 2.5 to 3.4 days on different hosts; the oviposition period, from 6.5 to 9.8 days. According to Sharma (1978) the fecundity ranged from 584 to 1501 eggs in pigeonpea. Ewing et al. (1947), Christidis and Harrison (1955), and Hsu et al. (1960) recorded that a female laid 500 to 3000 eggs with an average in excess of 1000 eggs. A maximum of 1265 and 1251 eggs were observed on cotton by Pretorius (1976) and Vijayakumar and Jayaraj (1981). The number of eggs per female ranged from 387 to 1346 eggs on different hosts (Dhandapani and Balasubramanian 1980b). The fecundity varied because of nutritional qualities of various diets. Pretorius (1976) found that the ratio of total female births in two successive generations was greater on cotton food material. Based on percentage and weight of pupae and number of moths formed, Pretorius (1976) concluded that cotton leaves were the most suitable host. Of the hosts tested by Dhandapani and Balasubramanian (1980) cotton bolls were found to be the most suitable for reproduction and development; sorghum and tomato, the least suitable. However, the presence or absence of secondary plant substances that act as feeding deterrents or stimulants were not studied by these authors to determine the behavioral mechanism that decides the host selection.

Life Tables

Life tables were worked out for *H. armigera on* eight different hosts under laboratory conditions (Dhandapani and Balasubramanian 1979,1980c, 1981 a, 1981b). The highest survival from egg to adult emergence was noted on cotton (84 adults) and lowest on sorghum (70 adults). Survival of insects on a food is commonly used as an indication of nutritional adequacy of the food for the insect. Mortality in the larval stage occurred due to virus diseases. The highest mortality was observed during pupal formation, when the larvae struggled to escape from their larval skins, the delicate cuticle broke open, exposing their internal organs, and the insects subsequently died. On some hosts such as tomato and chickpea, mortality was observed in early sixth-instar larvae.

The first female mortality after emergence occurred early (on the seventh day) on pigeonpea and late (tenth day) on cotton and maize. The maximum net reproductive rate (537.0), innate capacity for increase in numbers (0.15), finite rate of increase in numbers (1.16), and weekly multiplication (2.81 times) were recorded for cotton, and minimum values (140.6, 0.12, 1.13, and 2.80 respectively) were observed for tomato-reared insects. The mean length of the generation was highest in sunflower (43.2 days) and lowest in pigeonpea (38.1 days).

On all hosts, the population on reaching a stable age distribution, was comprised approximately of 99% of immature stages. Thus the maximum contributon towards the stable age distribution was made by the immature stages.

Significant correlations existed with the following: consumption index (fresh-weight) with innate capacity for increase in numbers (rm) and finite rate of increase (λ); growth rate with the net reproductive rate (Ro), weight of pupae, and percentage of pupae and moths formed. A positive correlation was found between weight of the pupae and innate capacity for increase; percentage of moths and innate capacity for increase; net reproduction rate and innate capacity for increase; ECI and ECD on a dry-matter basis; and moisture percentage of host plant and fresh-weight consumption index (Dhandapani and Balasubramanian 1980b).

Bilapate et al. (1979), studying the population dynamics of *H. armigera* on sorghum, pigeonpea, and chickpea, found that pupal mortality was high (24%) because of parasitism and unknown causes in sorghum during August-September. The positive value of the trend index (4.5) indicated that the mortality factors operating during this period were not effective in causing decline in population. Pupal mortality resulting from failure to complete development or inability of the adult to emerge was 45% in pigeonpea during October-November, but the mortality factors during this period were ineffective in suppressing the pest population in pigeonpea. A larval parasite *Campoletis chlorideae* was alone responsible for reducing the population on chickpea during November-December. The negative value of the trend index (0.051) indicated that the mortality factors during winter were dominant in reducing the pest population in chickpea.

References

ANONYMOUS. 1977. Studies on the occurrence and control of cotton boll worms in the region of Honon province. Acta Entomologica Sinica 20:141-146.

BEEDEN, P. 1974. Boll worm oviposition of cotton in Malawi. Cotton Growing Review 5:52-61.

BHATNAGAR. V.S. 1980. A report on research on the *Heliothis* complex at ICRISAT (India) 1974-79. Presented at the All India Workshop on Consolidation of Pest Management Recommendations and Guidelines of Research. 24-26 Apr 1980, Udaipur, India.

BHATNAGAR, V.S., and DAVIES, J.C. 1978. Factors affecting populations of gram pod borer, *Heliothis armigera* (Hubner) in the period 1974-77 at Patancheru (Andhra Pradesh). Presented at the Oriental Entomology Workshop on Population Ecology in Relation to Insects of Economic Importance, 18-20 Jan 1978, Bangalore, India.

BILAPATE, G.G., RAODEO, A.K., and PAWAR, V.M. 1979. Population dynamics of *Heliothis armigera* Hubner in sorghum, pigeonpea and chickpea in Marathwada. Indian Journal of Agricultural Sciences 49:560-566.

BRAZZEL, J.R., NEWSOM, L.D., ROUSSEL, J.S., LINCOLN, C., WILLIAMS, F.J., and BARNER, G. 1953. Bollworm and tobacco budworm as cotton pests in Louisiana and Arkansas. Louisiana Agricultural Experiment Station Technical Bulletin 482, Baton Rouge, La, USA.

CHAN, B.G., WAISS, A.C., BINDER, R.G., and ELLIGER, C.A. 1978. Inhibition of lepidopterous larval growth by cotton constituents. Entomologia Experimentalis et Applicata 24:94-100.

CHRISTIDIS, B.G., and HARRISON, G.J. 1955. Cotton growing problems. New York and London. McGraw-Hill. 633 pp.

COAKER, T.H. 1959. Investigations *on Heliothis armigera* (Hb.) in Uganda. Bulletin of Entomological Research 50:487-505.

CONTINHO, S.A. 1965. Polyphagous larvae—*Heliothis armigera* and *Heliothis peltigera* in the Cape Verde Islands. Garcia de Orta 11.593-599.

DHANDAPANI, N., and BALASUBRAMANIAN, M. 1979. Life tables for the gram pod borer, *Heliothis armigera* Hubner (Lepidoptera, Noctuidae) on cotton. Journal of Entomological Research 3:186-190.

DHANDAPANI, N., and BALASUBRAMANIAN, M. 1980a. Consumption and utilization of different food plants by *Heliothis armigera* (Hubner) (Noctuidae, Lepidoptera). Entomon 5:99-103.

DHANDAPANI, N., and BALASUBRAMANIAN, M. 1980b. Effect of different food plants on the development and reproduction of *Heliothis armigera* (Hbn.) Experientia 36:930-931.

DHANDAPANI, N., and BALASUBRAMANIAN, M. 1980c. Life table for the gram pod borer, *Heliothis armigera* Hbn. on three pulse crops. Proceedings, Indian Academy of Sciences (Animal Science) 89:575-578.

DHANDAPANI, N., and BALASUBRAMANIAN, M. 1981a. Growth of population of *Heliothis armigera* Hbn. on maize and sorghum. Indian Journal of Ecology (In press).

DHANDAPANI, N., and BALASUBRAMANIAN, M. 1981b. Life table studies of gram pod borer, *Heliothis armigera* (Hubner) on tomato. Indian Journal of Entomology (In press).

DOSS, S.A. 1979. Effect of host plants on some biological aspects of bollworm, *Heliothis armigera* (Hubner) Lepidoptera, Noctuidae. Zeitschrift fur Pflanzenkrankheiten und Pflanzenschutz 86:143-147.

EWING, K.P., PARENCIA, C.R., and IVY, E.E. 1947. Cotton insect control with benzene hexachloride, alone or in mixture with DDT. Journal of Economic Entomology 40:374-381.

FIFE, L.C., and GRAHAM, H.M. 1966. Cultural control of overwintering bollworm and tobacco budworm. Journal of Economic Entomology 59:1123-1125.

HARRELL, E.A., PERKINS, W.D., and MULLINIX, B.G. 1979. Effects of temperature, relative humidity, and air velocities on development of *Heliothis zea.* Annals of the Entomological Society of America 72:222-223.

HILLHOUSE, T.L., and PITRE, H.N. 1976. Oviposition by *Heliothis* on soybeans and cotton. Journal of Economic Entomology 69: 144-146.

HSU, MING-SHIA, CHANG, GUANG-SHIO, and CHU HUNG-FU. 1960. A study on cotton boll worm, *Heliothis armigera* (Hubner) (Lepidoptera: Noctuidae). Acta Oeconomico Entomologica Sinica 1:18-30.

LINCOLN, C. 1972. Distribution, abundance and control of *Heliothis* species in cotton and other host plants. Southern Cooperative Series Bulletin 19. 92 pp.

LOGANATHAN, M. 1981. Studies on ecology and effect of host plants on the susceptiblity of larvae of *Heliothis armigera* (Hubner) to insecticides. M.Sc. (Ag.) Thesis, Tamil Nadu Agricultural University, Coimbatore, India.

MINANANDANA, N. 1964. Studies on biology and host range of *Heliothis armigera* (Hubner) (Lepidoptera: Noctuidae). M.Sc. (Ag.) thesis, Madras University, Madras, India.

NEUNZIG, H.H. 1964. Wild host plants of the corn earworm and the tobacco bud worm In Eastern North Carolina. Journal of Economic Entomology 56:135-139.

NIKISHINA, E.S. 1980. The diapause of the cotton bollworm and the phenology of cotton. Zashchita Rasteni 6: 37.

PARSONS, F.S., HUTCHINSON, H., and MARSHALL, J. 1937. Progress reports from experimental stations, season 1936-37. Empire Cotton Growing Review 8, London, UK. 129 pp.

PATEL, R.C., PATEL, J.K., PATEL, P.B., and SINGH, R. 1968. Mass breeding of *Heliothis armigera* .Hbn. Indian Journal of Entomology 30: 272-280.

PATEL, R.C., PATEL, R.M., MADHUKAR, B.V.R., and PATEL, R.B. 1974. Oviposition behavior of *Heliothis armigera* in cotton hybrid-4. Current Science 43:588-589.

PEARSON, E.O., and DARLING. R.C.M. 1958. The insect pests of cotton in tropical Africa. London, UK: Empire Cotton Growers and Commonwealth Institute of Entomology. 355 pp.

PREMKUMAR. M., DALE, D., and NAIR, M.R.G.K. 1977. Consumption, digestion and utilization of food by larvae of *Spodoptera litura* F. (Lepidoptera: Noctuidae). Entomon 2: 7-10.

PRETORIUS, L.M. 1976. Laboratory studies on the developmental reproductive performance of *Heliothis armigera* on various food plants. Journal of the Entomological Society of South Africa 39: 337-343.

REDDY, K.V.S. 1973. Studies on the gram caterpillar, *Heliothis armigera* (Hb.) (Lepidoptera, Noctuidae) with special reference to its biology, host preference and estimation of loss in redgram. Ph.D. Thesis, University of Agricultural Sciences, Bangalore, India.

REED, W. 1965. *Heliothis armigera* (Hb.) (Noctuidae) in Western Tanganyika. I. Biology with special reference to the pupal stage. II. Ecology and natural and chemical control. Bulletin of Entomological Research 56:117-125.

ROOME, R.E. 1975. Activity of adult *Heliothis armigera* with reference to the flowering of sorghum and maize in Botswana. Bulletin of Entomological Research 65: 523-530.

SHARMA, S.K. 1978. Studies on the biology and extent of damage of gram pod borer, *Heliothis armigera* (Hubner) (Lepidoptera, Noctuidae). M.Sc. (Ag.) Thesis, Haryana Agricultural University, Hissar, India.

SINGH, H., and SINGH, G. 1975. Biological studies on *Heliothis armigera* (Hubner) in the Punjab. Indian Journal of Entomology 37:154-164.

SOOHOO, C.F., and FRAENKEL, G. 1966. The consumption, digestion and utilization of food plants by polyphagous insect, *Prodenia eridania* (Cramer). Journal of Insect Physiology 12: 711 -730.

SRIVASTAVA, A.S., and SAXENA, H.P. 1958. Tissue borers and problems of their control. Pages 109-114 *in* Proceedings, Entomology Research Workers Conference, Simla, India.

VIJAYAKUMAR, A., and JAYARAJ, S. 1981. Studies on the food plant ecology of *Heliothis armigera* (Hubner) (Lepidoptera, Noctuidae). Indian Journal of Agricultural Sciences (In press.)

WALDBAUER, G.P. 1962. The growth and reproduction of maxillectomized tobacco hornworms feeding on normally rejected non-solanaceous plants. Entomologia Experimentalis et Applicata 5:147-158.

WALDBAUER, G.P. 1968. The consumption and utilization of food by insects. *In* Advances in Insect Physiology 5 (ed. M. Rockstein). New York, USA: Academic Press.

WILCOX, J., HOWLAND, A.F., and CAMPBELL, R.E. 1956. Investigations on the tomato fruit worm, its seasonal history and methods of control. U.S. Department of Agriculture Bulletin 1147, Washington DC, USA. 47 pp.

Studies on the Biology of *Heliothis* Spp in Sudan

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Abstract

Tethered flight behavior of female Heliothis armigera *(Hb)* was *studied in the laboratory, using methods adapted for moths or a novel automated technique. Flight performance increased from day 1 to day 4, and feeding had the effect of stimulating oviposition and flight, though long flight was inhibited shortly after feeding. Full flight performance occurred in 4-day-old females under conditions suggesting the presence of a reproductive delay; 49% of a group of 122 females flew for more than 2 hours. Ovipositing females tended not to fly persistently. Factors affecting the duration of the prereproductive period were probably larval diet and temperature in the early adult stage. These phenomena are consistent with* H. armigera *being a facultative migrant. Diapause occurred in* H. armigera *pupae when larvae, prepupae, and pupae were exposed to cool (22°C). short-day (12 h light) conditions in the laboratory. After a suitable period at low temperature, certain pupae remained undeveloped after.transfer to high temperature (34° C) for 80 days, and then developed and emerged in response to a drop in temperature. This could provide a mechanism to bridge the dry season and emerge after the first rains.* H. fletcheri *(Hdwck) underwent prolonged diapause, from the end of the rainy season until the following rains. The implications of these findings tor management of* Heliothis *are discussed, and suggestions made for further study.*

Résumé

Etudes sur la biologie d'Heliothis *spp au Soudan: Le comportement de vol attaché de femelles* Heliothis armigera *(Hb) a été étudié en laboratoire, en utilisant des méthodes adaptées aux papillons ou une nouvelle technique automatisée. La performance de vol a augmenté entre le premier et le quatrième jour, et l'alimentation a eu un effet de stimulation sur l'oviposition et le vol, bien que les longs vols aient été inhibés peu après l'alimentation. Une complète performance de vol est survenue chez des femelles de quatre jours dans des conditions suggérant la présence d'un retard reproductif; 49% d'un groupe de 122 femelles ont volé pendant plus de deux heures. Les femelles en état de pondre n'ont pas eu tendance à voler d'une manière persistante. Le régime alimentaire des larves et la température au début du stade adulte ont été probablement les facteurs qui ont affecté la durée de la période de pré-reproduction. Ces phénomènes semblent confirmer qu'*H. armigera *soit un migrateur facultatif. La diapause est survenue chez la pupe* H. armigera *lorsque la larve, la pré-pupe et la pupe ont été exposées à une température fraîche (22°C) et des jours courts (12 h de lumière), en laboratoire. Après une période appropriée à une basse température, certaines pupes sont demeurées non développées après avoir été placées à une température élevée (34°C) pendant 80 jours; puis grâce à une baisse de la température, elles se sont développées et ont émergé. Ceci peut être un mécanisme permettant de franchir la saison sèche et émerger après les premières pluies.* H. fletcheri *(Hdwck) a eu une diapause prolongée, de la fin de la saison des pluies aux pluies suivantes. Les conséquences découlant de ces découvertes sont examinées dans le contexte de la lutte contre l'*Heliothis *et des recommandations sont faites afin de poursuivre la recherche.*

Recently a large part of the Gezira cotton pest complex, chiefly consisting of *Heliothis armigera* (Hubner) and white fly *Bemisia tabaci* (Gennadius), has been successfully controlled by nonpersistent insecticide. In order to kill susceptible hatching larvae of *Heliothis,* it has been necessary to scout the cotton crop frequently and respond with sprays when and where necessary (Joyce 1978). Research effort has been put into studying patterns of oviposition and the origin of *Heliothis* adults, emphasis being given to the mobility of insects in

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wind systems (Bowden and Gibbs 1973; Joyce 1976; Schaefer 1976; Topper 1978; Haggis 1978, 1981).

Migratory flight in many insects is a prereproductive phenomenon (Johnson 1969), and therefore some workers have dissected light-trap catches of *H. armigera* in order to detect changes in age and reproductive state of females that could indicate migration (Bowden and Gibbs 1973; Morton et al. 1981; Roome, unpublished[1]). Similar assumptions have been made for *Heliothis zea* (Boddie), e.g. Callahan et al. (1972). The current study investigated changes in the flight behavior of *H. armigera* females in the laboratory in relation to age and reproductive state, which may indicate when migration may occur.

A cotton closed season is enforced in the Gezira from April to June, and the area of alternative host plants for *H. armigera* in this dry season is quite restricted. Observations by Balla (1970, 1973) in Sudan suggest that very low proportions of pupae diapause at the end of the growing season. This contrasts with earlier work by Cowland (1935) in which high percentages of diapause occurred from October onwards. This paper summarizes work undertaken for a doctoral study on diapause and flight in *Heliothis* in Sudan (Hackett 1980).

Materials and Methods

Flight Studies

H. armigera adults were derived from larvae collected in the field, chiefly from sorghum, and allowed to feed on sorghum or on artificial diet. Alternatively, insects were derived from first-generation insects in culture on artificial diet. Ages of moths refer to the night of emergence as night zero. Insects at Bangor were kept under 26°C, 70% RH, and 13-hour light conditions; those in Sudan were kept under ambient conditions either in a laboratory without airconditioning or a netting-walled insectary. Where mating was necessary, females were caged on night 3 with males 2 to 7 days old and dissected after flight testing.

Two techniques involving tethering were developed for use with *H. armigera* females. The first, termed static tethered flight, was based on the method of Dingle (1965). After CO_2 anesthetization of each moth, a small foil bracket on the tip of a wire was cemented to the thorax with melted beeswax in the period from 1 hour to 0.5 hours before dusk or lights off. Flight testing of moths of different ages was conducted in the period 0.5 hours after lights off or dusk until 2 hours later. The test consisted of supporting the wire mountings on a horizontal bar, initiating flight by removing tarsal contact, and timing flight duration until wing beating stopped or was much reduced in amplitude. Each moth was tested for 30 minutes or over five successive flights, whichever occurred sooner. The duration of the longest flight within the 30-minute test period was recorded. Observations were carried out under dim red light to keep disturbance to a minimum.

The second technique, termed the flight swing technique, was based on the first, except that flight started spontaneously in the dark, and flight duration was measured automatically. The moth was tethered by a harness to a wire support connected to a pivot. A mercury switch or photocell activated by the swing signaled an event recorded when flight started or stopped. When inactive, the moth rested on a foam plastic ball or paper-covered roller, which allowed eggs laid overnight to be counted.

Diapause Studies

More than 1000 pupal periods of *H. armigera* in the field in Sudan were measured from August until the end of November in 1976,1977, and 1978. Pupae were derived from larvae collected from or reared on groundnut, sorghum, cotton, or artificial diet, and were held in a Stevensons screen or netting-walled insectary. In 1978, insect material collected from sesame resulted in a high percentage of diapause in the first generation, in late September. The species identified from the nondiapause insects was *Helicoverpa (Heliothis)* fletcheri (Hardwick) (Hackett and Gatehouse 1979). As field infestations of *H. armigera* were difficult to secure from November onwards, insects were cultured under 26°C, 75% RH, and 13-hour daylength conditions. Since diapause in *H. armigera* has been found to be induced by low temperatures and short day lengths (Komarova 1959; Roome 1979), possible induction conditions (22°C and 11.5 hr daylength) were modeled on January in the Gezira, which is the coldest month with the shortest daylength.

The dry-season conditions after January become hotter, and then temperatures drop when the rainy season begins. Initially, insects resulting

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***R.E. Roome, 1972, Report of the Drylands Farming Research Team, Botswana, Entomologists' Report (or 1971 -1972.**

from induction conditions were transferred to 26°C to demonstrate their ability to remain undeveloped at higher temperatures. Subsequently, pupae after more than 2 months in diapause were subjected to a high temperature (34°C) and then to a lower one (26°C) to simulate passing the dry season. The criterion for determining diapause was the presence of larval eyespots, as used by Wilson et al. (1979), for example. Nondiapause pupae lost their eyespots on day 2 at 26°C (control conditions). Pupae formed at 22°C were examined daily to note the loss of eyespots. Diapause pupae could be separated safely from nondiapause pupae on day 12 at this temperature.

Results

Flight Studies

Effect of Age on Flight in Female Moths

Short flights of 1 minute or more were taken by females of all ages (Table 1); however, there was a tendency for lower proportions of young females 1 and 2 days old to take flights of longer duration, such as > 5 minutes and >30 minutes. A very low proportion of females took flights of > 120 minutes duration on the flight swing. The rather higher proportion of females taking flights > 30 minutes in experiment 1 may have been due to different larval diet or environmental conditions during the tests.

Effect of Food on Flight in Sexually Immature Females

In these experiments 1 - and 2-day-old moths were supplied with 10% sugar or honey as food on each night in static tethered flight and on alternate nights between flight-swing tests. Since other workers had shown that feeding stimulates reproduction in *Heliothis* and that oviposition would be heavy by night 4, an experiment was set up to examine the effect of starvation on flight by 1 - and 2-day-old female moths.

The study was carried out in two parts. In part A, starved moths were flown on night 1 only, night 2 only, or fed 10% sucrose on night 1 and then flown on night 2. In part B, a group of moths fed to repletion at 1600 hours on day 2, just before attachment to the flight swing, was compared with a starved group of the same age. Feeding on night 1 or on the afternoon of day 2 had no significant effect on flight performance on night 2, though there was some indication that a small increase in long flight occurred in fed moths (Table 2). However, a further indication of an increase in long flight on night 2 compared with night 1 was detected. The timing of long flight (>60 min) during night 2 was examined from part B. In starved moths, the majority of flights

Table 1. The effect of age on flight in *H. armigera* females.

	Percentage of moths showing continuous flight for											
	>1 min			>5 min			>30 min			>120 min		
	Experiment			Experiment			Experiment			Experiment		
Age of moths	1	2	3	1	2	3	1	2	3	1	2	3
1 day	86			48a			13					
2 days	91	59	100	84b	53	71	22y	0	16			4
4 days	100	100	100	90	100	73	62z	15	36			9
6 days	100	100	100	94	100	70	77	27	24			0

Experiment 1. Static tethered flight using unmated moths collected from sorghum in Sudan (n=23, 37, 21, and 17, for 1-, 2-, 4-, and 6-day-old females, respectively).

Experiment 2. Static tethered flight using unmated moths from F_1 generation on artificial diet at Bangor (n= 17, 20, and 18, for 2-, 4-, and 6-day-old females respectively).

Experiment 3. Flight swing, using mated and unmated moths from artificial diet in Sudan (n=25, 44, and 17, for 2-, 4-, and 6-day-old females respectively).

Values followed by different letters indicate where significant differences occur (P<0.05).

Table 2. Effect of feeding on flight in 1- and 2-day-old *H.* armigera females.

Part of experiment		Age	Feeding	Percentage of months showing flight duration of			
				>5 min	>30 min	>60 min	>120 min
A	(n=45)	1 day	Starved	89	33	8a	0
A + B[a]	(n=62)	2 days	Starved	91	53	27b	9
A	(n=24)	2 days	Fed night 1	96	58	29	20
B	(n= 39)	2 days	Fed at 1600 hr on night 2	97	59	41	18

Values followed by different letters indicate where significant differences occur (P<0.05).

a. Flight data for 2-day-old starved females from parts A and B (described in the text) were pooled, as no significant differences in any flight-duration category existed.

Table 3. Effect of feeding on timing of flight in 2-day- old *H.* armigera females.

Experiment	Percentage of moths showing flight duration of	
	>60 min, starting before 2400 hr	>60 min. starting after 2400 hr
Starved (n= 40)	30	10a
Fed 10% sucrose at 1600 hr on night 2 (n= 39)	11	31b

Values followed by different letters indicate where significant differences occur (P<0.05).

started before midnight; in the group fed at 1600 hours, fewer moths flew for long periods before midnight, but the situation was reversed after midnight (Table 3).

Effect of Feeding on Oviposition in 2-Day-Old Females

The flight-swing apparatus allowed eggs laid overnight to be counted. Feeding on night 1 significantly (P <0.01) increased the proportion of females ovipositing on night 2 (43.5%, n=23),compared with starved moths (14.3%, n=63) or those fed at 1600 hr on night 2 (9.2%, n=39). These results indicate that feeding affected subsequent oviposition, although in the short term there was no effect.

Relationship between Mating, Oviposition, and Flight

Mated and unmated females were tested on the flight swing in 1977 and 1978 in Sudan. Adults were derived from larvae reared on artificial diet (1977) or collected and fed to pupation on sorghum (1978). Moths were caged with males on night 3 only, and flight-tested on nights 4 and 6 (1977) or night 4 only (1978). The proportion of moths mating was significantly different (P < 0.025) in the 2 years: 42.6% (n=61) in 1977 and 24.4% (n=164) in 1978. There was also a large difference in the pattern of oviposition between the two years, both in the proportion of females ovipositing and in the number of eggs laid (Table 4). There were significant differences (Mann-Whitney U test) in the numbers of eggs laid by ovipositing 4-day-old mated versus unmated females in 1977 (P < 0.01) and in 1978 (P < 0.05). By night 6, however, unmated and mated females in 1977 were laying similar numbers of eggs. Both mated and unmated females laid more eggs in 1977 than in 1978.

In 1978, the lower percentage of females mating and ovipositing and the fewer eggs laid suggest that there was a delay in reaching reproductive maturity. This conclusion was supported by a small number of unmated females subjected to the same feeding regime as those flight-tested, but kept individually in cages. The proportion of these moths ovipositing rose from 11% on night 4 to 89% on night 6; i.e., the insects were able to oviposit, but it took longer for them to start.

Table 4. Oviposition by 4-and 6-day-old mated and unmated *H. armigera* females on flight-swing apparatus In 1977 and 1978.[a]

Year and age		Mated status[b]	Percentage ovipositing	Mean number of eggs laid
1977	4 days	Mated	100 (20)[c]	296 (20)[c]
	4 days	Unmated	96 (26)	62 (25)
	6 days	Mated	90 (10)	223 (9)
	6 days	Unmated	91 (11)	196 (10)
1978	4 days	Mated	57 (33)	44 (19)
	4 days	Unmated	36 (89)	9 (32)

[a] Proportions of 4-day-old mated females ovipositing were found significantly different (*P<0.05*) between years, as were proportions of unmated ovipositing females (P <0.01)

[b] Determined by subsequent dissection.

[c] n = numbers in parentheses.

Table 5. Flight performance of 4-day-old *H.armigera* females In relation to mating.

Year and status	Percentage of moths showing flight duration of			
	>5 min	>30 min	>60 min	>120 min
1977				
Mated (n=19)	74	37	27	10
Unmated (n=25)	72	36	24	8
1978				
Mated (n=33)	97	81	63	48
Unmated (n = 89)	97	76	59	49

Since the percentage of mating in 1977 was greater than in 1978 and mating affected oviposition during night 4, flight data for mated and unmated females were treated separately (Table 5). No significant differences were found between mated and unmated females within years in any flight-duration category; however, comparison between years showed mated females to be significantly different in the > 30-minute (P< 0.05) and> 120-minute (P< 0.025) categories. Unmated females were similarly compared and found to be significantly different (P< 0.05) in the long-flight categories (> 30 minutes). Mating therefore did not significantly affect flight, but large differences in long-flight categories existed between years.

Since the proportion of moths ovipositing (and numbers of eggs laid) was greater in 1977 than in 1978, the incidence of long flight was analyzed from 1978 data on 4-day-old females with respect to whether the moth oviposited or not. Similar data were not available from 1977, as nearly all moths oviposited. A significantly smaller proportion of ovipositing moths (31 %, n=51) gave flights of > 120 minutes duration compared with moths not ovipositing (71 %, n=71; P < 0.05). The duration of the longest flight by the 60 moths that flew for >120 minutes was examined. Again ovipositing moths tended to fly for a shorter time than those not ovipositing (Table 6).

Diapause Studies

Less than 1 % of *H. armigera* pupae formed under field conditions in Sudan had an extended pupal period. The few slow-developing pupae that occurred were formed in cooler weather in November. The study was continued under controlled conditions (Table 7).

Under the control conditions of 26°C and 13 hours daylength, no diapause occurred (Treatment 1). Control temperature and short (11.5 hr) daylength also produced no diapause (Treatment 2). When the feeding part of the larval stage was maintained under low-temperature (22°C) short-day conditions, and insects were transferred to control temperatures at the prepupal stage, a very low percentage (ca 5%) of pupae diapaused (Treatment 3). The incidence of diapause was increased to over 30% in pupae produced from larvae reared under control temperature and daylength and transferred to 22°C at the prepupal stage (Treatment 4). When larvae as well as prepupae and pupae were reared under low-temperature, short-day conditions (Treatment 5), diapause increased to over 60%. When daylength was increased from 11.5 to 12 hours (Treatment 6), incidence of diapause further increased. Adults emerged earlier from pupae which had diapaused in treatment 4 than in treatment 5 or 6, indicating a lower diapause intensity in treatment 4.

Table 6. Flight duration of 4-day-old tomato *H.armigera* In relation to opposition.

	Percentage of moths showing flight duration of	
	2-5 hr	> 5 hr[a]
Not ovipositing (n = 44)	47	53
Ovipositing (n=16)	81	19

a. The longest recorded flight was 719 minutes.

Pupae in diapause 80 to 82 days after median pupation from treatments 5 and 6 were subjected to further treatments designed to test responses to rising soil temperatures such as occur during the dry season in the Gezira. A group of 33 pupae was taken from 22°C and subjected to a rising temperature regime to 34°C over a period of 5 days. A control group of nine pupae was transferred at the same time to a different incubator at 22°C.

The rising temperature regime stimulated 64% of the pupae to break diapause, develop, and emerge 9 to 22 days after the temperature rise started. Twelve pupae remained in diapause, but one broke diapause and emerged on day 155 after pupation. The remaining pupae were examined on day 164 and all were found to be still in diapause. On day 165, 79 days after first being exposed to 34°C, the pupae were transferred to 26°C to simulate a drop in the soil temperature at the start of the rainy season in the field. All pupae broke diapause within 3 days and emerged 14 to 17 days after transfer.

Control pupae transferred from 22°C to the different incubator at 22°C all broke diapause and emerged 22 to 36 days after transfer. The close association of the period of emergence with the

Table 7. Occurrence of diapause In *H. armigera* pupae undar controlled conditions.

	Conditions of treatment				Pupal period range (days)			
	Larva		Prepupa/pupa					
Treatment	Temp (°C)	Daylength (hours)	Temp <°C)	Daylength (hours)	Nondia-pause	Diapause	Day pupae inspected	Percent diapause[a]
1 A (42)[b]	26	13	26	0	11-14		3	0
B (27)	26	13	26	13	13-17		4	0
2 (44)	26	11.5	26	11.5	13-14		4	0
3 A (22)	22	11.5	26	0	13.14		4	0
B (47)	22	11.5	26	0	12-17	50-80	6	6.4
							8	4.3
C (49)	22	11.5	26	0	13-18	83	4	6.1
4 (25)	26	13	22	11.5	21-26	34-79	12	32
B (76)	22	11.5	22	11.5	20-28	36-93[c]	12	60.5
6 (61)	22	12	22	12	29	39-91[c]	12	97.6

a. Presence of larval eyespots denoted diapause.

b. Figures in parentheses denote number (n) in each treatment.

c. Upper limit not given as pupae subjected to further treatments.

transfer to different incubators suggested that some factor associated with the equipment provided a stimulus for diapause termination.

An intended fourth treatment in which pupae in diapause were to be exposed to 34°C by means of a more gradual rise in temperature failed to give results because of equipment malfunctioning.

Diapause in *H. fletcheri*

Observations on *H. fletcheri* were confined to insects maintained under field conditions in Sudan. Pupae from larvae on sorghum or artificial diet were held in a Stevensons screen throughout. Ninety-three pupae were formed in the last week of September 1978. Twenty-four adults emerged from 1 October to 8 October, but the remaining 69 insects diapaused until 1979, when 61 adults successfully emerged over the period from 13 June to 6 August. This gave a median diapause pupal period of over 9.5 moths.

Discussion

Tethered flight tests indicated that there was an increase in ability of insects to fly for a long duration, correlated with age up to day 4. Several examples of other Lepidoptera showing development of flight ability were given by Johnson (1969) and more recently by Sharp et al. (1975) and Leppla et al. (1979).

Feeding in young moths tended to inhibit long flight soon afterwards, but promoted flight and oviposition later. Feeding has been shown to promote flight (to exhaustion on flight mills) in other Noctuids (Koerwitz and Preuss 1964; Hwang and How 1966; Kishaba et al. 1967); stimulation of mating and oviposition by food in *Heliothis* spp has also been reported (Parsons and Marshall 1939; Callahan 1958). In many insects, factors that stimulate reproduction inhibit migration and vice versa (Kennedy 1961). In bugs, reductions of quantity or quality of food delay oviposition and stimulate migration (Dingle and Arora 1973; Kehat and Wyndham 1973; Rankin and Riddiford 1977). It is likely, therefore, that feeding could affect migration in *Heliothis* through this mechanism, and further experiments with controlled feeding of older adults are required.

In this study, nonovipositing females 4 days old showed the highest incidence of flight of more than 2 hours' duration. This was associated with a lower percentage of mating on night 3 and with lower oviposition on the night of testing. On the hypothesis that the lower incidence of mating occurring in 1978 was due to environmental conditions, the results *on* mating from both years were analyzed with respect to mean temperature calculated from 2-hourly thermograph readings over the first 2 days of the adult lives of each group of females. The calculated mean temperature range was then divided into five 1.6°C classes and the incidence of mating associated with each class calculated (Table 8). The data suggest that temperature significantly affected the proportion of females mating (X^2=25.73; 4 d.f. $P< 0.05$). The response was an inverted U shape about the central temperature groups C and D 27.2°C to 30.39°C. Isely (1935) working on *H. zea* had also found a U-shaped response to temperature in the pre-oviposition

Table 8. Effect of temperature In early adult life on mating In *H.* armigera females and pre-oviposition period in H. zes.

Heliothis armigera females[a]			*Heliothis zea* females[b]		
Temperature class (°C)	Number of females in class	Percent mating on night 3	Temperature (°C)	Number of females	Pre-oviposition period (days)
A <25.59	92	19	23	11	4.3
B 25.6-27.29	28	18	25	41	3.1
C 27.2-28.79	48	35	28	20	2.1
D 28.8-30.39	30	63	30	8	3.6
E >30.4	27	18	31	13	5.6

a. Source: Hackett (1978).
b. Source: Isely (1935)

period of females, with a minimum at 28°C. The length of the pre-oviposition period in many insects is of decisive importance in determining the extent to which migration will take place (Caldwell 1974; Gatehouse and Hall 1976; Dingle 1978). The reason for the higher incidence of mating and oviposition (and reduced flight) in females in 1977 could then have been due to more favorable temperatures, since data from this year, all fell in the central classes B, C, and D.

Other factors, such as larval diet, could have caused the differences in the insects between the 2 years, as in 1977, insects were derived from artificial diet, and in 1978 from sorghum. Callahan (1962) suggested that larval diet affected fat composition and possibly reproduction in *H. zea,* and Gross and Young (1977) found the pre-oviposition period in *H. zea* was affected by larval diet.

Long-duration flight, therefore, appears to be possible in *H. armigera* females under conditions which delay reaching reproductive maturity. It is quite likely that at the end of the rainy season moth movement into the Gezira is feasible, as is movement southwards (Joyce 1976; Haggis 1978) when environmental conditions become less suitable for reproduction with the approach of cool or excessively hot weather.

Tethered flight techniques using suitable apparatus on Noctuid moths may enable a model of migration to be developed, this aspect of biology being otherwise inaccessible. If migrating insects could be characterized physiologically, then trapped specimens in the field could be dissected or kept alive for observation, to distinguish migrants from locally produced insects.

Diapause in *H. armigera* was found to be facultative, and would occur in cold weather in irrigated crops. A possible mechanism for passing the hot dry season and synchronizing emergence with the start of the rainy season was suggested. The sensitivity of the prepupae to moderate temperatures (averting diapause) may explain why Balla (1970, 1973) obtained low proportions of diapause pupae. However, not all pupae entered diapause in any treatment, and so continous breeding on vegetables in the dry season in the Sudan no doubt also occurs.

The phenology of diapause in *H. fletcheri* suggested that this insect is adapted to survive In rainfed conditions, since September to October is the end of the rainy season in central Sudan. The recent finding of *H. fletcheri* as part of the Gezira pest complex verifies Hardwick's (1965) suggestion that Cowland (1935) was, in fact, looking at this species. The species composition of *Heliothis* in the irrigated and rainfed areas of Sudan requires further investigation.

On the basis of the current study, which suggested that migration and diapause in *H. armigera* are facultative, it would be unwise to define the life-history strategy of the insect in oversimplified terms. The contribution of diapause pupae versus continuous generations to bridge the dry season will have to be investigated in more detail in the field, paying particular attention to soil temperatures. It may well be that both strategies are followed to spread risk. The same may apply to adult migration; local as well as distant immigrants may occur in crops in a dynamic balance. Ovipositing females or those already mated may also be relatively mobile under some conditions, which could affect future monitoring or mating-suppression techniques.

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References

BALLA, A.N. 1970. American bollworm in the Gezira and Managil. Pages 281-292 *in* Cotton growth in the Gezira environment (eds. W.A. Siddig and L.C. Hughes). Gezira Research Station Symposium 1969, Wad Medani, Sudan.

BALLA, A.N. 1973. Some aspects of the ecology, biology and control of American bollworm in the Sudan Gezira and Managil. Presented at the CIBA-GEIGY Conference, February 1973, Gezira Agricultural Research Station, Wad Medani, Sudan.

BOWDEN, J., and GIBBS, D.G. 1973. Light trap and suction trap catches of insects in Northern Gezira, Sudan in the season of southward movement of the Intertropical Front. Bulletin of Entomological Research 62: 571 -579.

CALDWELL, R.L. 1974. A comparison of the migratory strategies of two milkweed bugs, *Oncopeltus fasciatus* and *Lygaeus kalmii.* Pages 304-316 *in* Experimental analysis of insect behavior (ed. L. Burton-Browne). Berlin: Springer-Verlag.

CALLAHAN, P.S. 1958. Behavior of the imago of the corn earworm *Heliothis zea* (Boddie). Annals of the Entomological Society of America 51: 271 -283.

CALLAHAN, P.S. 1962. Techniques for rearing the corn earworm *Heliothis zea* (Boddie). Journal of Economic Entomology 55: 453-457.

CALLAHAN, P.S., SPARKS, A.N., SNOW, J.W., and COPELAND, W.W. 1972. Com earworm. Vertical distribution in nocturnal flight. Environmental Entomology 1: 497-503.

COWLAND, J.W. 1935. American bollworm *Heliothis obsoleta.* Pages 113-118 *in* Annual Report, 1934-1935, Agricultural Research Division, Sudan.

DINGLE, H. 1965. The relation between age and flight activity in the milkweed bug *Oncopeltus fasciatus.* Journal of Experimental Biology 42: 269-283.

DINGLE, H. 1978. Migration and diapause in tropical, temperate and island milkweed bugs. Pages 254-275 *in* Evolution of insect migration and diapause (ed. H. Dingle). Berlin: Springer-Verlag.

DINGLE, H., and ARORA, C. 1973. Experimental studies of migration of the bugs of the genus *Dysdercus.* Oecologica 12: 119-140.

GATEHOUSE, A.G., and HALL, M.J.R. 1976. The effect of isolation on flight and on the pre-oviposition period in unmated Dysdercus superstitiosus. Physiological Entomology 1: 15-19.

GROSS, H.R., and YOUNG, J.R. 1977. Comparative development and fecundity of corn earworm reared on selected wild and cultivated early season hosts common in the Southeastern U.S. Annals of the Entomological Society of America 70: 63-65.

HACKETT, D.S. 1980. Biology of *Helicoverpa armigera* in the Sudan Gezira. Ph.D. thesis, University of Wales, Cardiff, U.K.

HACKETT, D.S., and GATEHOUSE, A.G. 1979. New records of *Helicoverpa fletcheri* Hardwick from the Sudan Gezira and observations on diapause in the 'American bollworm'. Pesticides Articles and News Summaries 25: 316-317.

HAGGIS, M.J. 1978. Distribution of American bollworm eggs in the Sudan Gezira: spatial and temporal changes and their relation to weather. Pages 34-67 *in* Proceedings, Third Seminar for Cotton Pest Control in the Sudan, CIBA-GEIGY, Basel, Switzerland.

HAGGIS, M.J. 1981. Spatial and temporal changes in the distribution of eggs of *Heliothis armigera* (Hubner) (Lepidoptera: Noctuidae) on cotton in the Sudan Gezira. Bulletin of Entomological Research 71:183-193.

HARDWICK, D.F. 1965. The corn earworm complex. Memoirs of the Entomological Society of Canada 40, Ottawa, Canada. 247 pp.

HWANG, G.H., and HOW, W.W. 1966. Studies on the flight of the Armyworm moth *Leucania separata* (Walker). I. Flight duration and wingbeat frequency. Acta Entomologica Sinica 15: 96-104. (Chinese, with English summary.) Review of Applied Entomology, Series A 55:88-89.

ISELY, D. 1935. Relation of hosts to the abundance of cotton bollworm. University of Arkansas Agricultural Experiment Station Bulletin 320:1-30.

JOHNSON, C.G. 1969. Migration and dispersal of insects by flight. London, UK: Methuen. 763 pp.

JOYCE, R.J.V. 1976. Insect flight in relation to problems of pest control. Pages 135-155 *in* Insect flight (ed. R.C. Rainey). Symposia of the Royal Entomological Society of London 7. Oxford, UK: Blackwell.

JOYCE, R.J.V. 1978. Yield response of *Gossypium barbadense* in the Sudan Gezira to aerial spraying at ULV rates with Nuvacron 40 . Pages 229-242 *in* Proceedings, Third Seminar on Strategy for Cotton Pest Control in the Sudan, CIBA-GEIGY, Basel, Switzerland.

KEHAT, M., and WYNDHAM, M. 1973. The relation between food, age and flight in the Rutherglen bug *Nysius vinitor* (Hemiptera: Lygaeidae). Australian Journal of Zoology 21: 427-434.

KENNEDY, J.S. 1961. A turning point in the study of insect migration. Nature (London) 189: 785-791.

KISHABA, A.N., HENNEBERRY, T.J., HANCOCK, P.J., and TOBA, H.H. 1967. Laboratory technique for studying flight of Cabbage looper moths and the effect of age, sex, food and tepa on flight characteristics. Journal of Economic Entomology 60: 359-366.

KOERWITZ, F.L., and PRUESS, K.P. 1964. Migratory potential of the Army cutworm. Journal of the Kansas Entomological Society 37: 234-239.

LEPPLA, N.C., HAMILTON, E.W., GUY. R.H., and LEE, F.L. 1979. Circadian rhythms of locomotion in six Noctuid species. Annals of the Entomological Society of America 72: 209-215.

MORTON. R., TUART, L.D., and WARDHAUGH, K.G. 1981. The analysis and standardisation of light-trap catches of *Heliothis armiger* (Hubner) and *H. punctiger* Wallengren (Lepidoptera: Noctuidae). Bulletin of Entomological Research 71; 207-225.

PARSONS, F.S., and MARSHALL, J. 1939. Investigations on the American bollworm. Progress Reports, Experiment Stations, Empire Cotton Growing Corp., South African Cotton Experiment Station, Barberton, Season 1937-1938:28-35.

RANKIN, M.A., and RIDDIFORD, L.M. 1977. The hormonal control of migratory flight in *Oncopeltus fasciatus:* The effects of the corpus cardiacum, corpus allatum and starvation on migration and reproduction. General and Comparative Endocrinology 33: 309-321.

ROOME, R.E. 1979. Pupal diapause in *Heliothis armigera* (Hubner) (Lepidoptera: Noctuidae) in Botswana: its regulation by environmental factors. Bulletin of Entomological Research 69: 149-160.

SCHAEFER, G.W. 1976. Radar observations on insect flight. Pages 157-197 *in* Insect flight (ed. R.C. Rainey). Symposia of the Royal Entomological Society of London 7. Oxford, UK: Blackwell.

SHARP, J.L., MCLAUGHIN, J.R., ASHLEY,, T.R., and BENNETT, D.R. 1975. Flight activity of *Trichoplusia ni* in the laboratory. Annals of the Entomological Society of America 68: 755-758.

TOPPER, C. 1978. The incidence of *Heliothis armigera* larvae and adults on groundnuts and sorghum and the prediction of oviposition on cotton. Pages 17-33 *in* Proceedings, Third Seminar on Strategy for Cotton Pest Control in Sudan. CIBA-GEIGY, Basel, Switzerland.

WILSON, A.G.L., LEWIS, T., and CUNNINGHAM, R.B. 1979. Overwintering and spring emergence of *Heliothis armiger* (Hubner) (Lepidoptera: Noctuidae) in the Namoi Valley, New South Wales. Bulletin of Entomological Research 69: 97-109.

The Potential Contribution of Moth Behavior Research to *Heliothis* Management

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Abstract

Recently several tools and techniques have been developed for, or adapted to, the study of the nocturnal behavior ot Heliothis spp. *As a result, a great deal of information has been collected on the nocturnal behavior of certain species, such as the tobacco budworm,* Heliothis virescens *(F.). For instance, their diet patterns of emergence, feeding, oviposition, sex pheromone secretion, male searching behavior, pheromone trap response behavior, mating, resting, and, to some extent, their in-field movement have been partially described. Along with other knowledge ot their biology, this information also allows the typing of populations as to their age structure, mating status, and generation dynamics. This paper reviews the status of knowledge relevant to the nocturnal behavior of* Heliothis spp, *references current methods for obtaining that knowledge, and describes its current uses and some potential ones for the management of* Heliothis *spp populations.*

Résumé

Contribution potentielle de la recherche sur le comportement du papillon dans la lutte contre Heliothis: *Récemment, plusieurs outils et techniques ont été mis au point ou adaptés pour permettre l'étude du comportement nocturne d'*Heliothis *spp. Ainsi, plusieurs informations ont été obtenues sur le comportement nocturne de certaines espèces, telle* Heliothis virescens *(F.). Par exemple, leur mode d'émergence journalier, alimentation, oviposition, sécrétion de phéromone sexuelle, comportement de recherche du mâle, réponse au piège à phéromone, accouplement, période de repos et, dans une certaine mesure, leur mouvement dans la nature ont été partiellement décrits. Grâce à d'autres informations sur leur biologie, il a été possible de classer les populations par structure d'âge, statut d'accouplement et dynamique des générations. Cette communication fait le point sur l'état de notre connaissance sur le comportement nocturne d'*Heliothis *spp, fournit des références sur les méthodes actuelles permettant de mieux connaître cet insecte et décrit leur utilisation actuelle et potentielle dans la lutte contre les populations d'*Heliothis *spp.*

The adults of *Heliothis* spp are primarily active at night, and very little is Known about their nocturnal behavior. This is somewhat surprising when one considers that the adult female essentially controls the food supply of her progeny by placement of eggs. The resulting larvae *are* not highly mobile and are therefore largely restricted to the food supply selected by the adult female. In contrast, the adults are highly mobile (Hardwick 1965; Callahan et al. 1972; Hendricks et al. 1973; Haile et al. 1975; Schaefer 1976; Phillips 1979; Raulston 1979; Sparks 1979; Lingren and Wolf 1982), and the females oviposit on a wide range of host plants (Brazzel et al. 1953; Hardwick 1965; Neunzig 1969; Teitz 1972; Martin et al. 1976; Pretorius 1976). This promotes, or even ensures, survival of *Heliothis* spp individuals over a broad range of environmental conditions. The difficulties of protecting crop plants from such polyphagous pests are apparent; however, adequate knowledge of the dynamics of *Heliothis* spp populations in relation to their various host plants (Adkisson 1971; Knipling 1979) and their nocturnal behavior in these plant ecosystems may provide the basis for an attack on the weakest

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links in their population cycles (Lingren 1978; Lingren et al. 1982; Lingren and Wolf 1982).

In this paper we will review some of the biology of *Heliothis* spp in relation to their nocturnal behavior, which we feel is important to the management of populations. We will deal primarily with adults, but nocturnal behavior of larvae is also important and will be discussed. Our discussion will be mostly limited to our experience with the tobacco budworm, *Heliothis virescens* (F.) and the bollworm, *Heliothis zea* (Boddie). Selected references will be used to provide historical background and to direct the reader to sources of information that are important to an overall understanding of our philosophy. Much of this presentation will be of a qualitative nature and may thus be considered somewhat speculative. Qualification is, however, a major prerequisite to quantification, and is thus very important to the understanding of biological organisms that are by nature highly variable.

A recent bibliography on the tobacco budworm and bollworm (Kogan et al. 1978) provides an excellent reference to past work, and accounts of the biology of the two species from various areas of their distribution can be found in Quaintance and Brues (1905); Brazzel et al. (1953); Wilcox et al. (1956); Hardwick (1965); Lincoln et al. (1967); Neunzig (1969); and Mongrut-Olivares (1971). One outstanding aspect of the biology of these species is that a female of either species can produce over 1000 eggs. However, there is a great deal of variation in the numbers of eggs produced per female, depending on the individual (Proshold et al. 1982), the species (Brazzel et al. 1953; Wilcox et al. 1956), and the larval food source (Lukefahr and Martin 1964; Neunzig 1969; Mongrut-Olivares 1971). If we assume that one female per acre (0.4 ha) produces 1000 eggs and that half of those eggs produce larvae that live to even the fourth instar, then the economic threshold has been surpassed on a high cash value crop such as lettuce. Five females per acre could potentially produce enough progeny to surpass the economic threshold on a lower cash value crop such as cotton (Adkisson 1964; Ridgway 1969). Indeed, economic thresholds may be somewhat misleading, since control procedures aimed at the larvae seldom result in more than 85% mortality, and the crop sustains considerable damage even while under a control program that is considered to be economically sound.

Why then have we aimed a majority of our control efforts at the larval stage, whose density can be 500 to 1000 times that of its parent and can cause significant damage to crops even under current control procedures? The answer to this question is not simple; however, a paramount reason for the current approach is a lack of knowledge of adult behavior. This information may result in development of efficient suppression techniques of the adult life stage, but the literature shows that until the last decade, little effort has been made to obtain such behavioral information. Of the many reasons for this lack of effort, we consider the following to be among the more important: (1) general diurnal human behavioral patterns; (2) lack of good night vision in humans; (3) severe restrictions by the scientific community on the publication of qualitative information resulting from our inability to reduce the variability of biological systems to quantitative measures; (4) large labor and insect-density requirements for gathering adequate information; and (5) profitability of larval control procedures using pesticides. However, despite these restrictions, a beginning has been made toward an understanding of the nocturnal behavior of the tobacco budworm and bollworm, and, in our opinion, this knowledge offers great potential to increase the efficiency of current control technology and for the development of new control procedures.

Tools and Techniques for Studying Nocturnal Behavior

Several tools are available for studying various aspects of the nocturnal behavior of *Heliothis* spp, such as head lamps, monocular and binocular night-viewing devices, pheromone traps, malaise traps, mating tables, actographs, and radar. Several recent papers describe these tools and some of their uses (Raulston et al. 1975, 1979; Mitchell et al. 1976; Schaefer 1976; Lingren et al. 1976, 1979, 1980, 1982; Sasaki and Ohguchi 1978; Sparks et al. 1979a, 1979b; Greenbank et al. 1980; Lingren and Wolf 1982). Obviously, this list of references indicates that a great deal of work has been done on the nocturnal behavior of certain *Heliothis* spp, but their nocturnal behavior as a group is still not well understood.

Historically, one of the major constraints to collection of data on the nocturnal behavior of *Heliothis* spp has been the lack of use or misuse of visible light in the form of head lamps, flashlights, and lanterns. Early workers assumed that little valid information could be gathered on nocturnal behavior of the species since the insects reacted to the wavelengths emitted in white light. Consequently, they covered their lights with red filters, which greatly restricted their field of view. Although *Heliothis* spp do respond to visible light, either in a negative (escape response) or positive (attraction) manner, many of these responses can De avoided by first locating the insect with a bright beam of light and then covering the beam with a red filter or by averting the beam so that the insect is located in the outer fringes of the beam. Moreover, insects in various modes of behavior, such as newly emerged adults or mating pairs, are unable to escape from the beam of light even if they react to it. Similarly, the adults that are deeply involved in a particular mode of behavior, such as calling or feeding, may show an initial reaction to the light beam, but they will generally continue their original activity within a short time even in the presence of the light. Therefore, white light is still one of our better tools for gathering information on many types of nocturnal insect activity.

Nocturnal Behavior of Tobacco Budworm and Bollworm

A description of the nocturnal behavior of adult tobacco budworms is given in several recent papers (Lingren et al. 1977a, 1977b, 1978, 1979, 1982; Raulston et al. 1975, 1976, 1979, 1980; Sparks et al. 1979b; Lingren and Wolf 1982). Initial nocturnal activity begins about 1 hr after sundown, with a spurt of flight that is generally oriented downwind (Lingren and Wolf 1982). This activity lasts for about 10 min, and then large numbers of moths of both sexes can be observed moving upwind and feeding on plant nectaries and other sources of sugar (Lingren et al. 1978). Oviposition activity is heavily interspersed with the feeding activity (Lingren et al. 1979). The major part of feeding and oviposition activity occurs within a 3-hr period, but intermittent feeding and oviposition continues throughout the night, followed by an intense spurt of activity about an hour prior to daylight (Lingren et al. 1977a, 1979). An inactive period occurs for about 15 to 30 min after major feeding and oviposition activity subsides. This inactivity has also been observed in laboratory studies on the bollworm (Agee 1969a, 1969b). Near the end of the inactive period, males begin a fast flight movement oriented crosswind (Lingren et al. 1982), and mating pairs are normally observed about 30 min after initiation of the fast flight activity. Secretion of the sex pheromone by laboratory-reared females (positioned near the top of the plants) released in the field usually begins about 15 min after the beginning of the fast flight activity of the males. We have observed very few native females calling in the field, except when the population was exposed to disruption efforts with their sex pheromone. Even then the disruption of mating was only temporary, lasting about a couple of hours.

Mating activity in the field generally begins about 4 hr after sundown and continues for about 4 hr with a majority of the activity taking place between midnight and 0200 hr. Temperature and daylength modulate the time that mating takes place. On cool nights and short days, the mating, as well as the whole sequence of nocturnal activity, occurs earlier in the evening than on warm nights and long days. Tobacco budworm adults dark-adapted in the laboratory generally start mating about 4 hr after being placed in the dark, but they begin their sequence of nocturnal activity in 15 to 30 min. Agee (1969a, 1969b) reports similar activity for the bollworm.

Tobacco budworm (Lingren et al. 1982) and bollworm (Callahan 1958) adults emerge at night and it is likely that other species of *Heliothis* follow a similar pattern. Peak emergence of the tobacco budworm occurs between 2300 hr and midnight, after which they crawl to the top of the plants and remain very docile and relatively inactive for about 4 hr. Bollworm emergence also occurs at night, but appears to occur earlier. Tobacco budworms do not mate on the night of emergence, but both sexes are capable of mating the following night. Following an initial mating, females generally do not mate for 2 or 3 days (Raulston et al. 1975); however, males can mate every night, so as a populaton ages an excess male mating potential is created. In other words, at some period during each generation cycle, males are available and searching for mates, but few females are receptive to mating (Lingren et al. 1982). A delay in the initial mating greatly reduces the numbers of eggs produced by females (Proshold et al. 1982). A knowledge of the emergence patterns is very important to the use of nocturnal observation techniques in assessing population age structure and generation dynamics, as well as adult control with pesticides (Lingren et al. 1982; Raulston et al. 1979)

An account of the nocturnal behavior of the bollworm can be gleaned from laboratory studies (Callahan 1958; Agee 1969a, 1969b); however, field studies on the nocturnal behavior of this species are extremely limited, and it was 1962 before an observation of mating in the field was reported (Phillips and Whitcomb 1962), in which case three pairs were observed after 80 nights of observation. A primary reason for this lack of information may be that the researchers were concerned that white visible light would disturb the adults, so they used red filters, which restricted their range of view to only a few feet.

Since 1962, we have observed thousands of mating pairs of bollworms in the field and collected some information of their diel patterns of feeding, oviposition, resting, pheromone secretion, pheromone-trap response activity (Sparks et al. 1979a), and in-field mating. The only major differences observed in the nocturnal behavior of the bollworm and tobacco budworm have been the timing, the activities of the bollworm occurring somewhat earlier.

Interestingly, bollworm males have been observed responding to pheromone traps baited with virgin female tobacco budworms and their seven-component synthetic pheromones. Also, male bollworms have been observed mating with tobacco budworm females in nature. We have observed no other mating combinations between the two species. Indeed, these observations are not surprising, since the tobacco budworm pheromone contains all four components that constitute the pheromone of the bollworm (Klun et al. 1979; Sparks et al. 1979a, 1979b). Nevertheless, the matings that we have observed between the two species were not viable. Hardwick (1965) has reported viable offspring in only one case out of many interspecific crosses between *Heliothis* spp; however, interspecific hybrids have been produced from crosses between the tobacco budworm and *Heliothis subflexa* (Guenee) (Laster 1972), and males produced from a backcross between the hybrid female and native males produce sterile males and fertile females. A backcross of this hybrid is currently being tested as a population-suppression procedure for tobacco budworm on the island of St. Croix, U.S. Virgin Islands.

The larvae of the tobacco budworm leave the cotton fruit during the night and move to the top of the plants to molt (Lingren and Wolf 1982). After molting, they eat their cast skins, and appear to remain on the tops of the plants until their exoskeletons are cured. Also, Neunzig (1969) reported that tobacco budworm larvae moved from tobacco plants during the night. We do not know if the bollworm or other *Heliothis* spp exhibit similar behavior, but such behavior is extremely important to the timing and placement of materials for larval control. The main problem with control of *Heliothis* spp larvae is that we know very little about their behavior. Although a limited amount of information has been reported on the behavior of larvae of the tobacco budworm (Mistric and Smith 1969) and bollworm (Barber 1941), to our knowledge, the behavior of a *Heliothis* spp larva has never been described from hatch to pupation. Nor have we seen an account of the behavior of any insect larva throughout its larval cycle. This seems deplorable, since a majority of our chemical control procedures have been aimed at larvae, and it is well known that many of their biological activities are of a circadian nature (Minis and Pittendrigh 1967). Therefore it is highly likely that larvae of *Heliothis* spp eclose, molt, rest, feed, and pupate in rhythmic cycles. Full knowledge of these cycles is extremely important in effective and efficient use of population-suppression procedures for the species.

Potential Uses of Information on Nocturnal Behavior of *Heliothis*

A relatively good account of the present and potential uses of nocturnal behavior information against *Heliothis* spp populations is available in two recent papers (Lingren et al. 1982; Lingren and Wolf 1982). Therefore, we will deal with this topic in a rather general manner and make an effort to expand on previous coverage of the subject as well as point out additional potential uses.

Population Age Structure and Generation Cycling

The sequence of nocturnal activities described for tobacco budworm and bollworm indicates that adults (newly emerged, calling females, mating pairs, and resting singles) and larvae (molting) occupy the terminal portions of plants during specific periods of the night. In natural populations most of these forms exhibit no major movement activity and are therefore rather easily observable at night. This allows collection of adults and typing of the population in terms of its generation age structure (Raulston et al. 1979) and mating potential (Lingren et al. 1982). Barber (1937) reported that four to six generations of the tobacco budworm occurred annually in eastern Georgia, and that these generations were distinct and separated by periods in which larvae were not found. Our experience from coast to coast throughout the southern USA suggests similar population trends. This suggests that populations emerge and age in a rather predictable manner. We have shown that night-observation techniques can be used to type these populations according to their generation age structure (Lingren et al. 1982). The adults of a given generation do emerge rather rapidly, mate, and age in a potentially predictable manner (Raulston et al. 1979). The age structure of the overall population presents different levels of pressure on control procedures (Lingren et al. 1982); therefore, the density and the age structure of a population should determine the type of suppression to be used, as well as the timing, dosage, and numbers (parasites, predators, and sterile releases), of a specific procedure.

According to Barber (1937), generations of the bollworm tend to overlap. This may be due in part to a developmental period that is 2 to 3 days longer than that of the tobacco budworm. However, unpublished data that we have collected overtime indicate that a majority of a generation emerges and mates over a 9-day period. Therefore, their generation cycles on cotton appear to be somewhat similar to that of the tobacco budworm during the major fruiting period of the crop. Alternative host plants and their relative maturity would influence these cycles, which would therefore probably be somewhat different for each major ecosystem.

Immature forms of some *Heliothis* spp are much more difficult to control with pesticides than others; therefore, immediate knowledge of the species composition within an area is necessary for efficient application of an effective control procedure and for accurate evaluation of the effect of control procedures such as sex pheromones. This is especially true when egg and larval counts are used as a measure of efficacy. However, the immature forms of most *Heliothis* spp are difficult to separate, while the adult forms are sometimes distinctly different (for example, bollworm vs. tobacco budworm). Knowledge of the nocturnal behavior of adults along with night observations offer an immediate solution to this problem and relative density assessments can be obtained. In other words, an observer can go into the field at night and collect adults for species comparisons. Density assessments can be obtained from relative captures per unit area or time period.The capture of native males in live traps (Raulston et al. 1980) also allows mark-release and recapture of native insects. Comparisons of the capture-recapture ratios of native males, along with comparative mating interactions of the marked and unmarked males, appear to offer a relatively good means for density determination (unpublished data).

Population Forecasting

Knowledge of the population age structure and generation dynamics obtained by night-observation techniques, along with other information on the developmental and mating biology of the tobacco budworm, should allow us to forecast the time of occurrence of future generations. We have observed that temperatures generally are optimum for development during the primary fruiting period of the plants and cycles occur al about 28-day intervals. We have been able to use the projection in our research and many of the pest-control advisors in the western United States commonly use our verbal projections for timing of pesticide applications. Moreover, the senior author feels, on the basis of several field trials, that the potential density of future generations (at least the next generation) on cotton in the western USA can be predicted with relatively good accuracy from nocturnal studies.

Adult and Larval Suppression from Nocturnal Applications of Insecticides

Good kill of adult tobacco budworms has been accomplished through nighttime applications of insecticides timed to take advantage of an emerging population and adult activities on the terminal portion of the plant (Lingren et al. 1982). Also, observations indicate that larvae of the tobacco budworm move to the top of the plant to molt (Lingren and Wolf 1982), thus becoming exposed to direct contact from sprays applied at night. A more thorough knowledge of this larval behavior could be very advantageous to the more efficient use of microbials (Bell and Kanavel 1978) formulated with feeding adjuvants, especially when the crop canopy has overlapped the rows. Under this situation, nighttime control applications should be more effective than daytime applications. Indeed, nighttime applications of insecticides for larval and adult control have become much more prevalent in the southwestern USA during the past few years.

Nocturnal Predation

Whitcomb and Bell (1964) have observed several species of nocturnal predators feeding on one or more of the life stages of the bollworm and tobacco budworm. In our nocturnal studies we have observed that earwigs, assassin bugs, and spiders are the foremost arthropod predators of *Heliothis* spp. The earwigs appear to be the most important of this group. However, in one test we released 2400 tobacco budworm adults in cotton and 17% of the adults were captured on the first night by the green lynx spider, *Peucatia viridins* (Hentz). On numerous occasions, the senior author has observed moths hovering around several species of spiders as if they were attracted to them. This phenomenon generally occurs during the sexually active period of the moths. Collections of moths captured by these spiders show that some species capture primarily males, while others capture primarily females. Eberhard (1977) has shown that the bolas spiders use chemical mimicry to attract and capture adult male fall armyworms. Therefore, an intensive investigation into the means that certain spiders use for obtaining their prey could lead to the identification of new attractants or more effective use of these predators as biological control agents.

Evaluation of Population-Suppression Programs Involving Mating

In the past, most investigations aimed at population suppression through mating interaction or mating suppression were evaluated by indirect methods, such as pheromone traps, light traps, or subsequent production of immature forms. Use of such evaluation procedures is rather tenuous, unless one knows their relationship to the behavior being altered. Nocturnal observation techniques can be used to directly measure the impact on mating or mating interaction that is occurring in the field (Raulston et al. 1975, 1976; Lingren et al. 1979, 1982). Establishment of relationships between direct and indirect methods of evaluation of mating depressants or interactions is a prerequisite to proper program evaluation.

Chemical Communication

It is interesting to note that molecular vibrations produce frequencies that correspond to wavelengths in the far infrared (Wright 1980) and that optically inactive isomers will exhibit circular dichroism when placed in an optically active solvent (Wright 1977). This activity is also observable in the far infrared. Wright (1954, 1977, 1980) suggests that these phenomena are very important to odor stimulus-receptor interaction, and are probably the means by which insects respond to various stimuli. Callahan (1965a) also advocates a far infrared electromagnetic theory of communication and sensing by the corn earworm (Callahan 1965b, 1969) and other night-flying moths (Callahan and Lee 1974). The concepts of these two scientists may lead to a major advancement in an understanding of insect communications. If so, and if moths do locate their host plants through far infrared emissions, then major new approaches to insect suppression are on the horizon. A better understanding of the nocturnal behavior of moths and their flight activities will play a major role in the development of these new suppression procedures.

The Future

We feel that the information developed on the nocturnal behavior of *Heliothis* spp can potentially be used for more rapid or better technological advancement in: (1) in-field speciation, (2) impact of most types of control programs, (3) population density assessments, (4) population age structure determinations, (5) population emergence forecasting, (6) trap design and efficiency, (7) nocturnal predation, (8) population movement determination, (9) target selection in terms of life stage, (10) identification of possible new attractants, (11) more effective and efficient use of current control procedures, and (12) design of new and more effective control procedures.

The degree and speed of such advances will depend a great deal on the number of observers, their observational ability, and their capacity for communicating primarily qualitative information. Adequate observations of the nocturnal behavior of *Heliothis* spp—or, as far as that goes, any species—are labor-intensive and dependent on the density of the target. Therefore, countries or organizations with adequate supplies of relatively cheap trained technical personnel can contribute substantially to future advancements in the control or *Heliothis* spp.

References

ADKISSON, P.L. 1971. Weak links in the population dynamics and diapause of *Heliothis zea* (Boddie) which might be exploited by the sterile-insect release technique. Pages 355-364 *in* Sterility principle for insect control or eradication. International Atomic Energy Agency, Vienna, Austria.

ADKISSON, P.L., HANNA, R.L., and BAILEY, C.F. 1964. Estimates of the numbers of *Heliothis* larvae per acre in cotton and their relation to the fruiting cycle and yield of the host. Journal of Economic Entomology 57:657-663

AGEE, H.R. 1969a. Response of flying bollworm moths and other typmanate moths to pulsed ultrasound. Annals of the Entomological Society of America 62:801 -807.

AGEE, H.R. 1969b. Mating behavior of bollworm moths. Annals of the Entomological Society of America 62:1120-1122.

BARBER, G.W. 1937. Seasonal availability of food plants of two species of *Heliothis* in eastern Georgia. Journal of Economic Entomology 30:150-158.

BARBER, G.W. 1941. Observations on the egg and newly hatched larva of the corn ear worm on corn silk. Journal of Economic Entomology 34:451 -456.

BELL, M.R., and KANAVEL, R.F. 1978. Tobacco budworm: development of a spray adjuvant to increase effectiveness of a nuclear polyhedrosis virus. Journal of Economic Entomology 71:350-352.

BRAZZEL, J.R., NEWSOM, L.D., ROUSSEL, J.S., LINCOLN. C., WILLIAMS, F.J., and BARNER, G. 1953. Bollworm and tobacco budworm as cotton pests in Louisiana and Arkansas. Louisiana Agricultural Experiment Station Technical Bulletin 482, Baton Rouge, Louisiana, USA. 47pp.

CALLAHAN, P.S. 1958. Behavior of the imago of the corn earworm, *Heliothis zea* (Boddie), with special reference to emergence and reproduction. Annals of the Entomological Society of America 51:271 -283.

CALLAHAN, P.S. 1965a. Intermediate and far infrared sensing of nocturnal insects. Part I. Evidences for far infrared (FIR) electromagnetic theory of communication and sensing in moths and its relationship to the limiting biosphere of the corn earworm. Annals of the Entomological Society of America 58:727-745.

CALLAHAN, P.S. 1965b. Far infrared emission and detection by night flying moths. Nature 207:1172-1173.

CALLAHAN, P.S. 1969. The exoskeleton of the corn earworm moth *Heliothis zea* Lepidoptera: Noctuidae with special reference to the sensilla as polytubular dielectric arrays. Pages 5-105 *in* University of Georgia Agricultural Experiment Station Research Bulletin 54,Tifton, Ga, USA.

CALLAHAN, P.S., and LEE, F. 1974. A vector analysis of the infrared emission of night flying moths, with a discussion of the system as a directional homing device. Annals of the Entomological Society of America 67:341 - 355.

CALLAHAN, P.S., SPARKS, A.N., SNOW, J.W., and COPELAND, W.W. 1972. Corn earworm moth: vertical distribution in nocturnal flight. Environmental Entomology 1:497-503.

EBERHARD, W.G. 1977. Aggressive chemical mimicry by a bolas spider. Science 198:1173-1175.

GREENBANK, D.O., SCHAEFER, G.W., and RAINEY, R.C., 1980. Spruce budworm (Lepidoptera: Tortricidae) moth flight and dispersal: new understanding from canopy observations, radar, and aircraft. Memoirs of the Entomological Society of Canada 110, Ottawa, Canada. 49 pp.

HAILE, D.G., SNOW, J.W., and YOUNG. J.R. 1975. Movement by adult *Heliothis* released on St. Croix to other islands Environmental Entomology 4:225-226.

HARDWICK, D.F. 1965. The corn earworm complex. Memoirs of the Entomological Society of Canada 40, Ottawa, Canada. 247 pp.

HENDRICKS, D.E., GRAHAM, H.M.. and RAULSTON, J.R. 1973. Dispersal of sterile tobacco budworms from release points in northeastern Mexico and southern Texas. Environmental Entomology 2:1085-1088.

JOYCE, R.J.V. 1981. The control of migrant pests. Pages 209-229 *in* Animal migration. Society for Experimental Biology seminar series 13. Cambridge, UK: Cambridge University Press.

KLUN, J.A., PLIMMER, J.R., BIERL-LEONHARDT, B.A., SPARKS, A.N., and CHAPMAN, O.L. 1979. Trace chemicals: the essence of sexual communication systems in *Heliothis* species. Science 204:1328-1330.

KNIPLING, E.F. 1979. The basic principles of insect population suppression and management. USDA Agricultural Handbook 512, Washington, DC, USA. 659 pp.

KOQAN, J., SELL, D.K., STINNER, R.E., BRADLEY, J.R., Jr., and KOGAN, M. 1978. The literature of arthropods associated with soybeans: V. A bibliography of *Heliothis zea* (Boddie) and *H. virescens* (F.) (Lepidoptera: Noctuidae). INTSOY Series 17. Champaign-Urbana, Ill., USA: International Agricultural Publications. 242 pp.

LASTER, M.L. 1972. Interspecific hybridization of *Heliothis virescens* and *H. subflexa.* Environmental Entomology 1: 682-687.

LINCOLN, C. et al. 1967. The bollworm-tobacco budworm problem in Arkansas and Louisiana. University of Arkansas Agricultural Experiment Station Bulletin 720, Fayetteville, Ark, USA. 66 pp.

LINGREN, P.D. 1978. Tobacco budworm nocturnal behavior—an aid in pest management. Pages C1-3 *in* Proceedings, Sixth Desert Cotton Insects Symposium, University of California Cooperative Extension Service, El Centra, Calif, USA. 42 pp.

LINGREN, P.D., and WOLF, W.W. 1982. Nocturnal activity of the tobacco budworm and other insects. Pages 205-222 *in* The role of biometeorology in integrated pest management, eds. J.L. Hartfield and I.J.Thomason. New York, NY, USA:Academic Press. 500 pp. (In press).

LINGREN, P.D., GREENE, G.L., DAVIS, D.R., BAUMHOVER, A.H., and HENNEBERRY, T.J. 1977a. Nocturnal behavior of four lepidopteran pests that attack tobacco and other crops. Annals of the Entomological Society of America 70:161-167.

LINGREN, P.D., RAULSTON, J.R., andSPARKS, A.N. 1977b. Interception of native male tobacco budworm by barriers of released laboratory-reared sterile females. Environmental Entomology 6:217-221.

LINGREN, P.D., SPARKS, A.N., RAULSTON, J.R., and WOLF, W.W. 1978. Applications for nocturnal studies of insects. Bulletin of the Entomological Society of America 24:206-212.

LINGREN, P.D., RAULSTON, J.R., SPARKS, A.N., and PROSHOLD, F.I. 1979. Tobacco budworm. nocturnal behavior of laboratory-reared irradiated and native adults in the field. USDA/SEA, Oakland, Calif, USA. ARR-W-5.17 pp.

LINGREN, P.D., BURTON, J., SHELTON, W., and RAULSTON, J.R. 1980. Night vision goggles: for design, evaluation, and comparative efficiency determination of a pheromone trap for capturing live adult male pink bollworms. Journal of Economic Entomology 73:622-630.

LINGREN, P.D. RAULSTON, J.R., SPARKS, A.N., and WOLF, W.W. 1982. Insect monitoring technology for evaluation of suppression via pheromone systems. Chapter 6 *in* Insect suppression using controlled release pheromone systems, Volume I, eds. G. Zinerg, A.F. Kydonieus, and M. Beroza. Boca Raton, Florida: CRC Press.

LUKEFAHR. M.J., and MARTIN, D.F. 1964. The effects of various larval and adult diets on the fecundity and longevity of the bollworm, tobacco budworm, and cotton leafworm. Journal of Economic Entomology 57:233-235.

MARTIN, P.B., LINGREN, P.D., and GREENE, G.L. 1976. Relative abundance and host preferences of cabbage looper, soybean looper, tobacco budworm, and corn earworm on crops grown in northern Florida. Environmental Entomology 5:878-882.

MINIS, D.H., and PITTENDRIGH, C.S. 1967. Circadian oscillation controlling hatching: its ontogeny during embryogenesis of a moth. Science 159:534-536.

MISTRIC.W.J., Jr., andSMITH, F.D. 1969. Behavior of tobacco budworm larvae on flue-cured tobacco and possibilities of improving the effectiveness of insecticidal treatment applied mechanically for control. Journal ot Economic Entomology 62:16-21.

MITCHELL, E.R., BAUMHOVER, A.H., and JACOBSON, M. 1976. Reduction of mating potential of male *Heliothis* spp and *Spodoptera frugiperda* in field plots treated with disruptants. Environmental Entomology 5:484-486.

MONGRUT-OLIVARES, C.A. 1971. Temperature, humidity, and light effects on the reproductive potential of *Heliothis zea* (Boddie) adults in the laboratory. Ph. D. dissertation, University of California, Riverside, Calif, USA. 186 pp.

NEUNZIG, H.H. 1969. The biology of the tobacco budworm and the corn earworm in North Carolina. North Carolina Agricultural Experiment Station Technical Bulletin 196, Raleigh, NC, USA. 76 pp.

PHILLIPS. J.R. 1979. Migration of the bollworm, *Heliothis zea* (Boddie). Pages 409-411 *in* Movement of highly mobile insects: Concepts and methodology in research, eds. R.L. Rabb and G.G. Kennedy. Raleigh, NC, USA: University Graphics. 456 pp.

PHILLIPS, J.R., and WHITCOMB, W.H. 1962. Field behavior of the adult bollworm, *Heliothis zea* (Boddie). Journal of the Kansas Entomological Society 35:242-246.

PRETORIUS, L.M. 1976. Laboratory studies on the developmental and reproductive performance of *Heliothis armigera* (Hubn) on various food plants. Journal of the Entomological Society of South Africa 39:337-343.

PROSHOLD, F.I. KORPENKA, C.P., and GRAHAM, C.K. 1982. Egg production and oviposition in the tobacco budworm. Annals of the Entomological Society of America. (In press.)

QUAINTANCE, A.L., and BRUES, C.T. 1905. The cotton bollworm. USDA Bureau of Entomology Bulletin 50, Washington, DC, USA. 155 pp.

RAULSTON, J.R. 1979. *Heliothis virescens* migration. Pages 412-419 *in* Movement of highly mobile insects: Concepts and methodology in research, eds. R.L. Rabb and G.G. Kennedy. Raleigh, NC, USA: University Graphics, 456 pp.

RAULSTON, J.R., SNOW, J.W., GRAHAM, H.M., and LINGREN, P.D. 1975. Tobacco budworm: Effect of prior mating and sperm content on mating behavior of females. Annals of the Entomological Society of America 68:701 - 704.

RAULSTON, J.R., GRAHAM, H.M., LINGREN, P.D., and SNOW, J.W. 1976. Mating interaction of native and laboratory-reared tobacco budworms released in the field. Environmental Entomology 5:195-198.

RAULSTON, J.R., LINGREN, P.D., SPARKS, A.N., and MARTIN, D.F. 1979. Mating interaction between native tobacco budworms and released backcross adults. Environmental Entomology 8:349-353.

RAULSTON, J.R., SPARKS, A.N., and LINGREN, P.D. 1980. Design and comparative efficiency of a wind-oriented trap for capturing live *Heliothis* spp. Journal of Economic Entomology 73:586-589.

RIDGWAY, R.L. 1969. Control of the bollworm and tobacco budworm through conservation and augmentation of predaceous insects. Pages 127-144 *in* Proceedings, Tall Timbers Conference on Ecological Animal Control by Habitat Management, Tallahassee, Fla, USA. 244 pp.

SASAKI, M., and OHGUCHI, Y. 1978. Female-searching flight rhythm of the male cucumber looper, *Anadenidia peponis* (Lepidoptera: Noctuidae). Bulletin of the Faculty of Agriculture, Tamagamo University 18:8-15.

SCHAEFER, G.W. 1976. Radar observations of insect flight. Pages 157-197 *in* Insect flight, ed. R.G. Rainey. London, UK: Blackwell.

SPARKS, A.N. 1979. An introduction to the status, current knowledge, and research on movement of selected Lepidoptera in southeastern United States. Pages 382-385 *in* Movement of highly mobile insects: Concepts and methodology in research, eds. R.L. Rabb and G.G. Kennedy. Raleigh, NC, USA: University Graphics. 456 pp.

SPARKS, A.N., CARPENTER, J.E., KLUN, J.A., and MULLINIX, B.G. 1979a. Field responses of male *Heliothis zea* (Boddie) to pheromonal stimuli and trap design. Journal of the Georgia Entomological Society 14: 318-325.

SPARKS, A.N., RAULSTON, J.R., LINGREN, P.D., CARPENTER, J.E., KLUN, J.A., and MULLINIX, B.G. 1979b. Field responses of male *Heliothis virescens* to pheromonal stimuli and traps. Bulletin of the Entomological Society of America 25: 268-274.

TEITZ, H.M. 1972. An index to the described life histories, early stages, and host of the macro-lepidoptera of the continental United States and Canada. A.C.Allyn, Allyn Museum of Entomology, Sarasota Fla, USA. 1041 pp.

WHITCOMB, W.H., and BELL, K. 1964. Predaceous insects, spiders, and mites in Arkansas cotton fields. Arkansas Agricultural Experiment Station Bulletin 690, Fayetteville, Ark, USA. 83 pp.

WILCOX, J., HOWLAND, A.F., and CAMPBELL, R.E. 1956. Investigations of the tomato fruitworm, its seasonal history and methods of control. USDA Technical Bulletin 1147. Washington, DC, USA. 47 pp.

WRIGHT, R.H. 1954. Odor and chemical constitution. Nature 173:831.

WRIGHT, R.H. 1977. Odor and molecular vibration: optical isomers. Chemical Senses and Flavor 3:35-37.

WRIGHT, R.H. 1980. Odor and molecular vibration. Pages 123-141 *in* Odor quality and chemical structure, eds. H.R. Moskowitz and C.B. Warren. American Chemical Society Symposium series 148.

Note: This paper reports tne results of research only. Mention of a pesticide does not constitute recommendation for use by the USDA, nor does it imply registration under FIFRA as amended. Mention of a commercial product does not constitute an endorsement of the product by the USDA.

Discussion — Session 1

Dr. Jayaraj explained that his laboratory studies were conducted mainly to determine the suitablity of different species of host plants for the development and reproduction of *H. armigera.* He agreed that such studies may not reflect the actual suitability of the crops in the field. Further field studies would be needed to determine the key mortality factors that would operate on pest populations.

Dr. Jayaraj was asked whether there are genetic differences between geographical populations in their tendency to enter diapause or whether diapause was purely a function of the environment. He replied that he had no knowledge of any work on such genetic differences.

Dr. Hackett, answering a question on the long flights of mated females in his tests, agreed that this may have been due to the absence of host odor. However, in the USA, mated females have been caught on a TV tower at a height of more than 300 m, from a population that was thought to be migrating, so the mated females observed in Dr. Hackett's tests could well have been behaving naturally.

When asked whether there was any indication that the previous larval history had affected the flight behavior of the moths, Dr. Hackett said that there was. Moths tested in 1977 were fed an artificial diet; these did not fly much and oviposited heavily on the fourth day. This was in sharp contrast to the moths studied in 1978, which were from a field crop of sorghum.

Dr. Lingren said that one of the benefits resulting from nocturnal observations of *Heliothis* moth behavior was the more efficient insecticide spraying at night. Such spraying is now common practice in the western USA, and many operators are spraying at specific times of the night to take advantage of particular behavioral traits, which have been determined by nocturnal observation of the pests.

Dr. Lingren confirmed that he regarded release-recapture methods as useful and reasonably efficient in studies of *Heliothis* moths. Studies of moth flight have indicated both short and migratory flight. In newly emerging populations it was observed that the majority of moths left the emergence area during the early evening and early morning. Night-vision goggles, radar, and radio have been used to observe the flight of *Heliothis* moths from near the crop canopy to several meters above. Although strong winds can affect moth behavior, it is suspected that the behavioral mode of the insect at any time will markedly influence its flight activity in relation to the wind. The *Heliothis* spp moths are known to be strong fliers, and good responses of males to virgin females have been observed in winds in excess of 35 mph (56 kmph).

The seven-component synthetic pheromone of *H.virescens* has been shown to be much more attractive to males than were virgin females in traps in field tests in three major climatic zones. However, the synthetic formulation began to break down after about 2 hours, after which male behavioral patterns similar to those induced by the two major components were noticed. These two components are highly attractive, but the males stop before they reach the point source. The alcohol appears to be the component that separates matings between *H. zea* and *H. virescens.*

Dr. Lingren knew of no studies concerning the conditioning effect of larval food upon mating behavior, except that larval diet has been shown to affect reproductive maturity and mating aggressiveness. The larger welt-fed insects are not always the most aggressive. He was unable to offer a good speculative answer to the question why *H. armigera* has recently become a major pest on cotton in India. However, he pointed to the similar adaptation of *H. virescens,* which has developed as a major pest of cotton in the USA over the last three decades. Possible reasons for *H. armigera* adaptation to cotton may be changes in varieties, cropping systems, and cropping practices. There may also have been a mutation in the species.

Session 2

Surveillance, Forecasting, and Modeling of *Heliothis* Populations

Chairman: R.J.V. Joyce

Cochairman: Zile Singh

Rapporteurs: C.S. Pawar

H.C. Sharma

Modeling and Forecasting *Heliothis* Populations in the USA

A.W. Hartstack*

Abstract

Heliothis spp *modeling in the USA has made considerable* progress *in the past decade; however, there are still many unanswered questions and unknowns in the population dynamics of both* species *of economic importance. The MOTHZV model, developed in Texas, has been used successfully in the field by the state's Agricultural Extension Service for 6 years. The model* was used *to predict the timing of oviposition one to two generations ahead; this information was used by pest managers to time scouting programs, irrigation applications, and insecticide treatments. The MOTHZV model lacks many of the physiological process algorithms necessary to predict the number of insects; therefore its predictions are limited to timing only. The paper also reviews other models used to evaluate management strategies tor the pest and identifies some of the areas in which research is needed for building more sophisticated models.*

Résumé

*Modèles et prévisions sur les populations d'*Heliothis *aux Etats-Unis: Aux Etats-Unis, des progrès considérables ont été faits au cours de la dernière décade dans l'élaboration de modèles propres à* Heliothis *spp. Cependant, il reste à éclaircir plusieurs questions sur la dynamique des populations des deux espèces d'importance économique. Le modèle MOTHZV, mis au point à Texas, a été utilisé avec succès sur le terrain par le Service de vulgarisation agricole de l'état pendant six ans. Le modèle a servi à prédire le moment de l'oviposition une ou deux générations à l'avance; cette information a permis aux responsables de la défense des cultures de programmer la surveillance, les irrigations et les traitements insecticides. Le modèle MOTHZV omet plusieurs des algorithmes du processus physiologique requis pour prévoir le nombre d'insectes; aussi ce modèle ne prévoit que le temps. La communication fait également état d'autres modèles servant à évaluer les stratégies de lutte contre le ravageur et identifie certains domaines de recherche devant permettre l'élaboration de modèles plus sophistiqués.*

There have been dramatic changes in the control of cotton insect pests during the last 10 to 15 years, brought about by insect resistance to pesticides, changes in government programs, and reductions in potential profits. Recently, the increasing cost of energy and concern over environmental quality have accentuated the need for alternative approaches to cotton-pest control. Several new production systems have been proposed and tested, based on cotton varieties with early, more rapid fruiting characteristics, complemented by efficient use of fertilizer and water, judicious use of insecticides, and maximum reliance on naturally occurring insect-control factors.

An important realization in the search for alternatives was that no single method of control can be expected to provide an acceptable solution to all insect problems. The entire cotton-production system must be examined to decide what techniques are likely to be feasible and practical for a given pest (Knipling 1979). In most cases, more detailed knowledge of the ecology and behavior of the insect is required. The new discipline of integrated pest management has been built on this philosophy

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of total system consideration and multiple control techniques.

The Systems Approach

The integrated pest management approach can be enhanced by the use of systems analysis and computer models. Systems modeling has emerged from man's need to study and control larger and more complex systems. The NASA moon exploration program is a prime example of the systems approach, where multidisciplinary teams with specialized knowledge worked together with the aid of sophisticated computers and equipment to solve complex problems (Witz 1973). DeMichele and Bottrell (1976) discuss in considerable detail the systems approach to cotton-pest management, stating that this approach is especially useful in unifying and guiding research and in understanding interactions in the system and the consequences of the control tactics applied.

The systems or modeling approach usually begins with simple mental models (Witz 1973). "Watch out for the July 4th bollworm egglay." "Full moon occurs on July 10, so there will be large *Heliothis* spp egglays about 2 to 4 days later." "Those summer showers will really bring on the boll weevil." Every person formulates such simple models, based on experience.

When these mental models or images are transformed to a flowchart, a set of equations, or a computer program, they then become a tangible model that can be communicated to and used by other people. Such models may then be combined into more complex models through the use of the computer and systems analysis techniques (Witz 1973).

Models may be constructed at various levels of detail. The level used in a given situation must be determined from the intended purpose of the model as well as the current knowledge available for a given system. The possible levels of detail establish a hierarchy of knowledge on a given subject. An animal or plant, for example, may be subdivided into the basic physiologic processes, which in turn are composed of various organs and components. Each organ may be studied from the cellular level, the biochemical level, and possibly down to the molecular and atomic levels. Detailed models at one level can often be simplified and made useful for application at a higher level where less precision is required.

Review of *Heliothis* Modeling in the USA

A generalized framework for insect population dynamics as a function of temperature was developed by Watson (1973). This model has been used by entomologists for studying the development rate and population dynamics of many insects, including *Heliothis* spp, pink bollworm, and *Lygus.*

Stinner et al. (1974) described a *Heliothis* model for North Carolina conditions. The model included a spatial grid of fields and crop types. Each crop was modeled on a field basis, using a measure of the attractance of the crop for *Heliothis.* While no yield prediction was possible, this approach allowed study of the movement of the insect population; however, the use of this model was limited to the area of North Carolina where it was developed.

As part of a multidisciplinary effort at Mississippi State University, Brown et al. (1979) and Jones et al. (1980) have developed a model of the cotton crop and its major pests, the boll weevil and *Heliothis* spp. The model brings together previous work on the cotton crop (McKinion et al. 1975), the boll weevil (Jones et al. 1977), and *Heliothis* (Hartstack et al. 1976a), and is being used to improve pest-management strategies, such as timing of insecticide applications, variable economic threshold levels of pests, and various pest-control strategies, including boll weevil eradication.

A considerable amount of *Heliothis* modeling has been done in Arizona (Butler and Hamilton 1976), mostly based on laboratory studies of insect development at various temperatures (Butler 1976; Butler et al. 1979). The models use an algorithm described by Stinner et al. (1974) on a degree-day concept for development due to temperature.

Light traps have been used for many years to monitor *Heliothis* moth populations. Hartstack et al. (1973) developed a model for estimating the number of moths per hectare from these light-trap catches, to evaluate the possible use of light traps for controlling *Heliothis* spp. In the last few years, pheromone traps (Hartstack et al. 1979) have replaced light traps as moth-monitoring devices. Models are also being developed (Hartstack et al. 1976b; Hartstack and Witz 1981) to sort out the various factors affecting pheromone trap catches.

An important event in the population dynamics of *Heliothis* spp is diapause. Recently a number of models describing the emergence of diapausing pupae in the spring have been reported (Logan et al. 1979; Potter et al. 1981; Wilson et al. 1979). A major effort is under way at College Station, Texas, to construct a diapause emergence model that can be used in a study of early spring migration of *Heliothis* into Texas from Mexico (Hartstack et al. 1982a, 1982b; Lopez et al. unpublished[1]). Eger (1981) reported a model that predicts the overwinter mortality of diapausing pupae due to low temperature. These models will eventually permit the prediction of numbers of surviving overwintering pupae and the timing of emergence.

Heliothis Population Model: MOTHZV

Hartstack et al. (1973) reported the concept of a simple model of the *Heliothis* spp (Fig. 1). Hartstack and Hollingsworth (1974) converted this model concept to mathematical equations, and with the use of a computer were able to make predictions of the number and timing of future adults. Development times, using a degree-day concept, were calculated as total generation lengths (adult to adult) rather than being divided into various life stages. Rates of increase were input as constants for each day, based on light-trap data collected at College Station over a 3-year period. Moonlight was the only other factor that affected rate of increase. Predictions of timing and size of future generations were very accurate for College Station, but this regression-type model lacked the versatility needed for use at other locations.

MOTHZV-2

Hartstack et al. (1976a) presented a detailed description of MOTHZV-2, a descendant of the original MOTHZV, which incorporated considerably more detailed population and physiology algorithms (Fig. 2) and included three simple crop models—corn, cotton, and sorghum. The FORTRAN computer program for MOTHZV-2 consisted of a main computer program and 16 subroutines.

Predictions of timing and size of future generations of *Heliothis* spp were made by using expected (long-term average) temperatures and expected or predicted crop phenology. Simulations were initialized with input of either eggs or moths, and the population was carried through as many generations as *occur* during one season. A bookkeeping system recorded the number of eggs, first- to third-instar larvae, fourth- and fifth-instar larvae, pupae, preoviposition adults, and ovipositing adults for each day of the simulation. Each stage of the insect was advanced one calendar day at a time with a degree-day concept, so that daily mortalities (natural, insecticide, parasite, predator) could be applied. The output of MOTHZV-2 was in the form of tables or graphs of the daily numbers of *Heliothis* spp of each stage.

The three crop models were temperature-dependent and used a degree-day concept to predict crop phenology events such as first square, boll, and open boll. These were then used to predict the relative attractance of the crop to females, a factor affecting oviposition. No yield prediction was possible. Each crop required a separate run of the model; however, *Heliothis zea* adults predicted to migrate out of corn or sorghum were held in a vector that could be used as input for a subsequent run of cotton. In this situation, the population of adults migrating into cotton was adjusted by the ratio of hectares of cotton to hectares of corn and sorghum in the region. (For detailed description see Hartstack et al. 1973, 1976a.)

MOTHZV-3

In 1978, MOTHZV-2 was revised. As reported from extensive studies by Quaintance and Brues (1905), Townsend (1973), and by Baldwin et al. (1974), the larval stage of *Heliothis* spp causes the most damage to fruiting cotton. Therefore a *Heliothis* damage model was added to MOTHZV-2, and the original cotton model was replaced by a more dynamic crop model, SIMPLECOT, for cotton fruiting behavior, based on a model developed by Wilson et al. (1972). This revision, MOTHZV-3, allows the user to study changes in cotton yield caused by *Heliothis,* and makes new and more complex studies also possible.

The cotton model can be adjusted for a particular simulation by varying the two input parameters, a variety factor, and yield. A base run with no damage can be made. The effect on yield of various insect populations or pest-management decisions can be studied by comparing subsequent runs with the base run or to each other.

A Statewide Extension Program: BUGNET

BUGNET is a computerized pest-management

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[1] J.D. Lopez, AW. Hartstack, and J A Witz. 1982, Diapause development of the tobacco budworm in Central Texas.

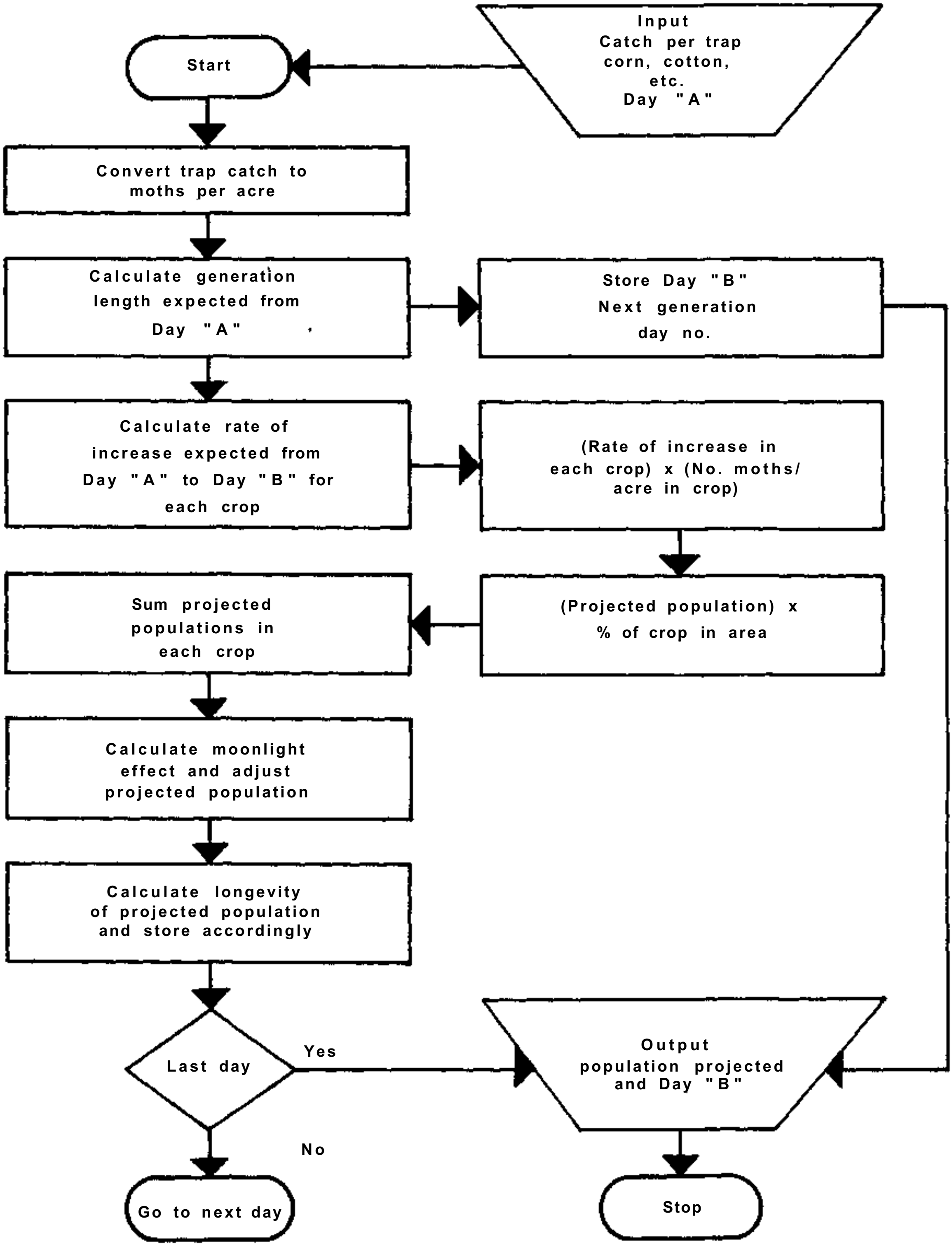

Figure 1. Flowchart of the first version of the MOTHZV model for prediction of Heliothis *spp populations.*

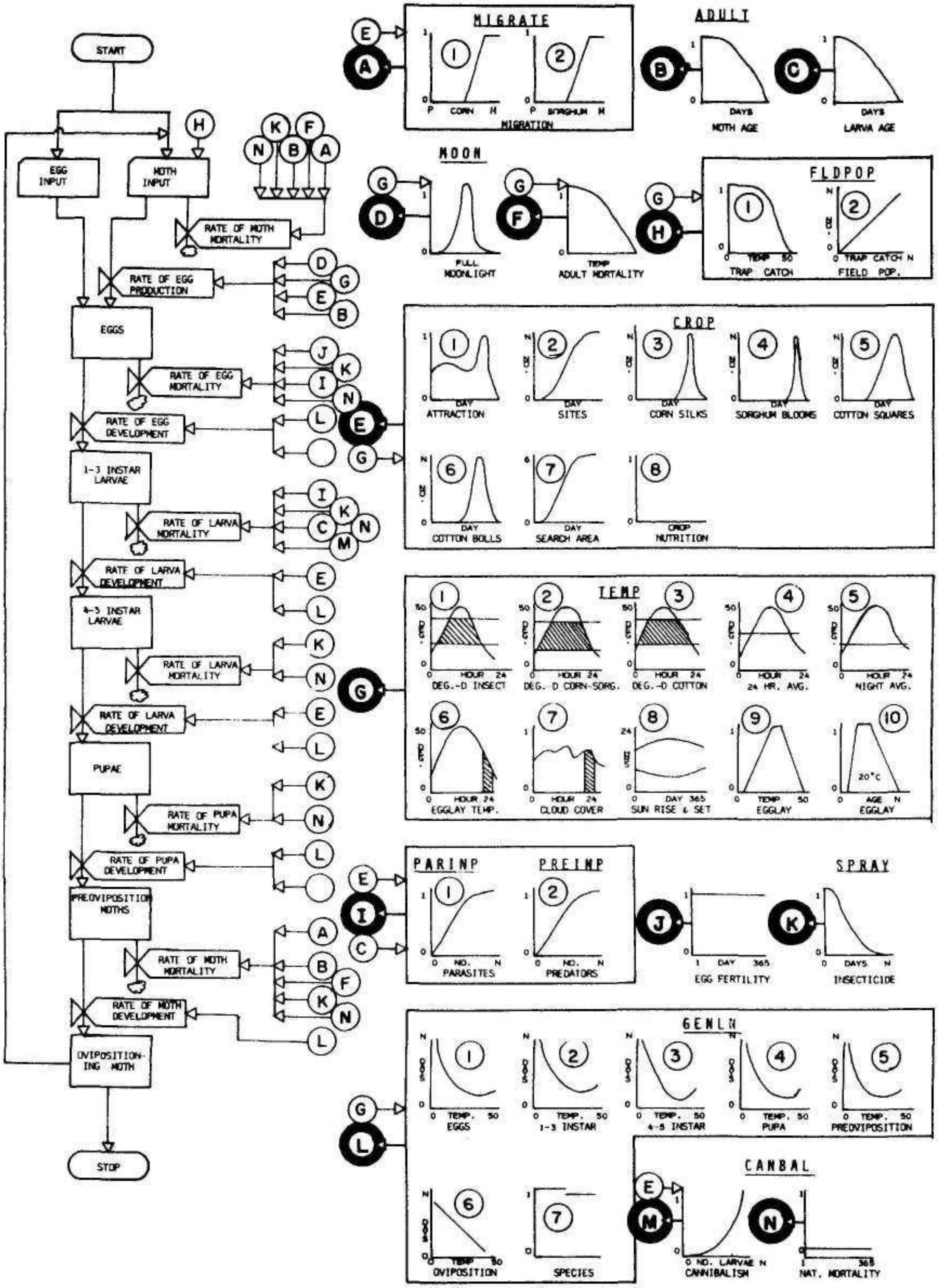

Figure 2. Flowchart showing the complexity of the MOTHZV-2 model.

delivery system in Texas, developed by entomologists of the Texas Agricultural Extension Service and research cooperators, to make computer models available to the personnel of the Extension Service and thereby to the public. The MOTHZV model and the other BUGNET programs are currently being used by producers across the state for pest-control decision-making.

A statewide pest-management plan for Texas (Frisbie and Adkisson 1975) was proposed in 1974; the pilot action programs in 1973,1974, and 1975 proved so encouraging in maintaining the profitability of cotton and sorghum production that the Texas Association of Cotton Producers asked the State's extension service, experiment station, and the Texas Department of Agriculture to implement the plan statewide.

This statewide plan, which began in 1976, consisted of 10 subplans developed by individual subcommittees. Nine of the plans were geographically based on the nine cotton and sorghum-producing areas of Texas. The tenth, TAMU-BUGNET, was involved with the potential of a computer-based system of forecasting insect-pest populations and crop yields. The goal of BUGNET is to aid farmers in making decisions concerning insect control and crop management.

BUGNET Phase One

The BUGNET program was initiated to make various computer applications, including MOTHZV, available to the county extension entomology specialists. To acquire the necessary input information, insect light traps were installed at each location early enough to enable monitoring of moth emergence from the diapausing (overwintered) pupae. This timing varied from February in the Rio Grande Valley to May in the Rolling Plains area. Traps were located within early-season hosts of *H. zea*—corn or sorghum or both—depending on which was the major crop in the area. When cotton began to square or when the corn or sorghum matured, the traps were moved into cotton.

Additional input data gathered by the specialist for the BUGNET version of MOTHZV-2 were: (1) minimum and maximum daily temperature; (2) planting date, emergence date, and date of first fruit (silk, bloom, square, boll) for each of three crops (corn, sorghum, cotton) in the area; (3) the percentage of each of the three crops in the area (one county or more).

The first data were mailed to College Station by the county extension entomologist about 30 days after the traps were installed; thereafter, data were forwarded whenever it seemed necessary to update a forecast, usually every 7 to 14 days. As soon as the data arrived at College Station, they were punched on computer cards, and MOTHZV-2 (stored on-line at the Texas A & M Data Processing Center) was run to forecast the timing and size of the expected egg and larval populations of *H.zea* and *H.virescens* through the season. This output was then marked to the extension entomologist and other interested personnel, with the caution that predictions were to be used only as trend indicators and not as predictions of actual numbers in specific fields.

In 1976, three light traps (Hollingsworth and Hartstack 1972) were installed at each of five test locations. The forecasts in 1976 were within 3 days of the actual peaks in the field. Figure 3 shows a comparison of the June forecast of *H. zea* oviposition with the actual field egg counts in the Hillsboro,

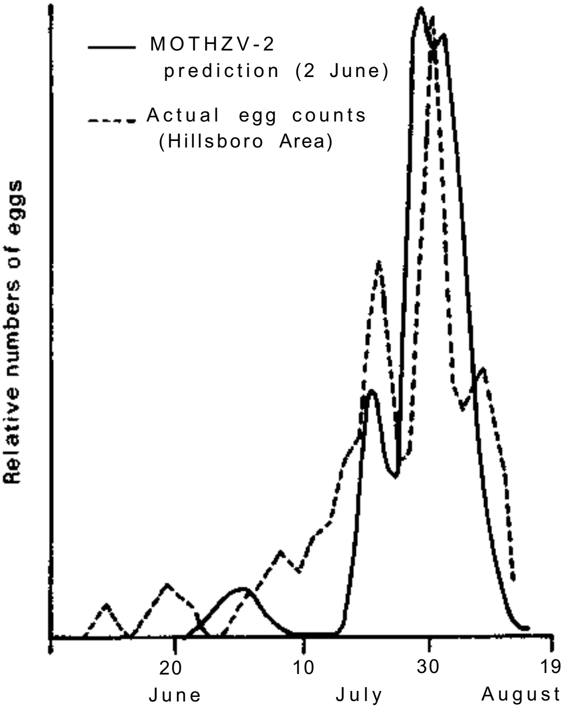

Figure 3. An example of the MO THZV-2 prediction (2 June) compared with actual field counts of **Heliothis** *spp eggs in the Hillsboro area, Texas, USA, 1976.*

Texas, area. The successful results of this program's first year were reported by Hartstack et al. (1977).

In 1977 the BUGNET-MOTHZV program was expanded from 5 to 15 areas. Two or three electric grid traps (Wolf et al. 1972) baited with Virelure (Tumlinson et al. 1975; Hendricks et al. 1977), a synthetic attractant for *H. virescens,* were installed at each location in addition to the light traps. The pheromone-trap catches were used as inputs to MOTHZV-2 for predictions of *H. virescens* oviposition.

In 1978, MOTHZV-2 was replaced by MOTHZV-3; in 1979, the grid traps were replaced by cone traps (Hartstack et al. 1979) that required no electricity and were much more versatile. The program has continued to operate at about 15 locations since 1977.

BUGNET Phase Two

A second phase of the overall BUGNET program, begun in 1977, attempted to put computer power directly into the hands of the county extension specialist. IBM 5100 minicomputers were installed at three locations to test the feasibility of their use by field personnel. MOTHZV-4, a simplified version of MOTHZV-3, written in APL, was sent to the field in 1979, to be used on the minicomputers; although this version lacked much of the versatility of MOTHZV-3, it could successfully predict timing of *Heliothis* spp oviposition.

In 1980, BUGNET added 11 more minicomputers and upgraded the original three. Other software packages have also been made available to users: a Peanut Leaf Feeder Model, Pecan Production Game, Adult Pecan Weevil Mortality, Pecan Weevil Static Threshold Model, Sorghum Midge Static Threshold Model, Insecticide Compatibility Chart, Cotton Production Games, IBM Statistics Pack, and a Boll Weevil Model.

MOTHZV on BUGNET: Results

The first year, forecasts were of limited use to farmers, both because there was doubt about their reliability and because populations were low and of little economic importance except for a few localized outbreaks. But confidence in the model has grown steadily each year since, and over the 3 years 1977-79, the predicted egg peaks were within 4 days of the actual field egg counts about 70% of the time.

Although an insecticide application was never based solely on MOTHZV, the advance knowledge of possible insect infestations alerted producers to intensify scouting efforts. In irrigated areas, such advance knowledge was valuable in timing irrigation (Slosser 1979). Since the rapid plant growth and lush foliage that immediately follow irrigation are extremely conducive to *Heliothis* egg laying, avoiding irrigation at times when insect populations are high can be an effective control measure.

In areas where other pests are problems prior to *Heliothis,* it is important to stop pesticide treatment for early-season pests several weeks *before Heliothis* populations build up. Advance knowledge of probable buildups helps determine the best insecticide cutoff date, to enable beneficial insects to recover from the treatment and reach a level effective for control of *Heliothis.*

A statement issued by the Texas Agricultural Extension Service in 1979 pointed out that MOTHZV had enjoyed widespread use over 3 years; in 1979 alone, 5740 cotton producers in 91 counties had used this tool to help manage 4 069 300 acres (1 646 789 ha) of cotton, for a combined net profit of $4 967 000. In addition, it brought intangible benefits, such as peace of mind, which could not be measured in dollars.

The Future for MOTHZV

Although the value of this work entailing a systems approach remains to be fully tested and evaluated for pest-management applications in cotton, benefits have already been realized in identifying research gaps and priorities. Many improvements need to be made in the model itself. While the predicted timing was close, the numbers predicted were not very accurate.

Increasing emphasis is now being placed on the use of beneficial insects. Natural predators and parasites are being studied to determine their occurrence and ability to control pest species; however, basic biological data available on beneficial species are limited. Methods to manage and increase natural beneficials are being considered. Researchers are also looking at methods of rearing and distributing beneficial species as an alternative pest-control technique (Ridgway et al. 1980). Improved methods of sampling beneficial populations to determine their occurrence and number are required before this method of pest control can become practicable on a large scale.

MOTHZV-3 does not consider the effect of rainfall and soil moisture on the growth of the crop or insect. Because lush crop growth has a marked effect on *Heliothis* oviposition, it affects the timing and size of egg peaks. Mortality of eggs and larvae is also affected by moisture conditions, a factor not considered in the model. However, before these factors can be incorporated and used successfully, better methods of monitoring rainfall and soil moisture are needed. Perhaps remote sensing will be the answer.

One of the most important inputs to the present model is early-season trap catches. Light traps (Hartstack et al. 1971, 1973) have been one of the best ways to monitor *Heliothis* adults; however, each trap requires an electrical power source, which often interferes with field operations. Light-trap catches are also difficult to identify at times. Experience with MOTHZV-BUGNET has shown that at least three, and perhaps five to ten, traps are required to properly monitor *Heliothis* adults in an area. Because operating so many light traps would be very expensive, time-consuming, and troublesome, numbers have usually been sacrificed for convenience. Even locating the traps in the proper crop and place has been difficult because of power requirements, and this inadequacy, plus irregular servicing, has contributed substantially to prediction errors.

New pheromone traps (Hartstack et al. 1979) and synthetic sex pheromones (Klun et al. 1979) for both *H. zea* and *H. virescens* have recently been developed; these should provide the pest manager or producer with a convenient and effective tool for monitoring *Heliothis* adults. The traps are highly efficient, simple to construct, inexpensive, and portable (requiring no power). Only the single species for which the trap is baited is attracted and caught, making identification and counting quick and easy. The pheromones are now commercially available; therefore, the proper array of five to ten traps can be located within the proper crops and should not be difficult to *monitor.* As an added bonus, pheromone traps also detect spring emergence of moths 2 or 3 weeks earlier than light traps, which should give more precision to forecasts.

References

BALDWIN, J.L., WALKER, J.K., GANNAWAY, J.R., and NILES, G.A. 1974. Boltworm attack on experimental semidwarf cottons. Texas Agricultural Experiment Station Bulletin 1144, Texas A&M University, College Station, Tex, USA.

BROWN, L.G., McCLENDON, R.W., and JONES, J.W. 1979. Computer simulation of the interaction between the cotton crop and insect pests. Transactions of the American Society of Agricultural Engineers 22(4): 771 - 774.

BUTLER, G.D. 1976. Bollworm: development in relation to temperature and larval food. Environmental Entomology 5: 520-522.

BUTLER, G.D., and HAMILTON, A.G. 1976. Development time of *Heliothis virescens* in relation to constant temperature. Environmental Entomology 5: 759-760.

BUTLER, G.D., HAMILTON, A.G., and PROSHOLD, F.I. 1979. Development times of *Heliothis virescens* and *H. subtlexa* in relation to constant temperature. Annals of the Entomological Society of America 72: 263-266.

EGER, J.E., Jr. 1981. Factors affecting winter survival of *Heliothis virescens* (Fabricius) and *Heliothis zea* (Boddie) (Lepidiptera: Noctuidae), and subsequent development on wild spring hosts. Ph.D. dissertation, Texas A&M University, College Station, Tex, USA.

DeMICHELE, D.W., and BOTTRELL, D.G. 1976. Systems approach to cotton insect pest management. Pages 107-132 *in* Integrated pest management. New York, USA: Plenum Press.

FRISBIE, R.E., and ADKISSON, P.L. 1975. Summary: Statewide pest management plan. Texas Agricultural Extension Service, Texas A&M University System, College Station, Texas, USA.

HARTSTACK, A.W., Jr., and HOLLINGSWORTH, J.P. 1974. A computer model for predicting *Heliothis* populations. Transactions of the American Society of Agricultural Engineers 17(1): 112-115.

HARTSTACK, A.W., Jr.,and WITZ. J.A. 1982. Estimating field populations of tobacco budworm moths from pheromone trap catches. Environmental Entomology (In press).

HARTSTACK, A.W., Jr., HOLLINGSWORTH, J.P., RIDGWAY, R.L., and HUNT, H.H. 1971. Determination of trap spacings required to control an insect population. Journal of Economic Entomology 64(5): 1090-1100.

HARTSTACK, A.W., Jr., HOLLINGSWORTH, J.P., RIDGWAY, R.L., and COPPEDGE, J.R. 1973. A population dynamics study of the bollworm and the tobacco budworm with light traps. Environmental Entomology 2(2): 244-252.

HARTSTACK, A.W., Jr., WITZ, J.A., and RIDGWAY, R.L. 1975. Suggested applications of a dynamic *Heliothis* model (MOTHZV-1) in pest management decision making. Pages 118-122 *in* Proceedings, Beltwide Cotton Producers Research Conference.

HARTSTACK, A.W., Jr., WITZ, J.A., HOLLINGSWORTH, J.P., RIDGWAY, R.L, and LOPEZ, J.D. 1976a. MOTHZV-2: A computer simulation of *Heliothis zea* and *Heliothis virescens* population dynamics. U.S. Department of Agriculture Users' Manual ARS-S-127, Washington DC, USA. 55 pp.

HARTSTACK, A.W., Jr., WITZ, J.A., HOLLINGSWORTH, J.P., and BULL, D.L. 1976b. SPERM. A sex pheromone emission and response model. Transactions of the American Society of Agricultural Engineers 19(6): 1170-1180.

HARTSTACK, A.W., Jr., HENSON, J.L., WITZ, J.A., JACKMAN, J.A., HOLLINGSWORTH, J.P., and FRISBIE, R.E. 1977. The Texas program for forecasting *Heliothis* spp. infestations on cotton. Pages 151-154 *in* Beltwide Cotton Producers' Research Conference.

HARTSTACK, A.W., Jr., WITZ, J.A., and BUCK, D.R. 1979. Moth traps for tobacco budworm. Journal of Economic Entomology 72(4): 519-522.

HARTSTACK, A.W., Jr., WITZ, J.A., and LOPEZ, J.D. 1982a. Predicting the timing of the spring emergence of overwintered populations of *Heliothis* spp. (In press).

HARTSTACK, A.W., Jr., LOPEZ, J.D., STERLING, W.L., KING, E.G., MULLER, R.A., and WITZ, J.A. 1982b. Long range spring migration of *Heliothis zea* indicated. (In press).

HENDRICKS, D.E., HARTSTACK, A.W., and SHAVER, T.N. 1977. Effect of formulations and dispensers on attractiveness of virelure to the tobacco budworm. Journal of Chemical Ecology 3: 497-506.

HOLLINGSWORTH, J.P., and HARTSTACK, A.W. 1972. Effect of components on insect light trap performance. Transactions of the American Society of Agricultural Engineers 15(5): 924-927.

JONES, J.W., BOWEN, H.D., STINNER, R.E., BRADLEY, J.R., and BACHELER, J.S. 1977. Simulation of boll weevil populations as influenced by weather, crop status, and management practices. Transactions of the American Society of Agricultural Engineers 20(1): 121-125.

JONES, J.W., BROWN, L.G., and HESKETH, J.D. 1980. COTCROP: A computer model for cotton growth and yield. Chapter 10 *in* Predicting photosynthesis for ecosystems models. West Palm Beach, Fla, USA: CRC Press.

KLUN, J.A., PLIMMER, J.R., BIERL-LEONHARDT, B.A., SPARKS, A.N., and CHAPMAN, O.L. 1979. Trace chemicals: The essences of sexual communication system in *Heliothis* spp. Science 204:1328.

KNIPLING, E.F. 1979. The basic principles of insect population suppression and management. U.S. Department of Agriculture Handbook 512, Washington DC, USA. 659 pp.

LOGAN, J.A., STINNER, R.E., and RABB, R.L. 1979. A descriptive model for predicting spring emergence of *Heliothis zea* populations in North Carolina. Environmental Entomology 8: 141 -146.

McKINION, J.M., BAKER, D.N., HESKETH, J.D., and JONES, J.W. 1975. SIMCOT II. A simulation of cotton growth and yield. Pages 27-82 *in* Computer simulation of a cotton production system. U.S. Department of Agriculture User's Manual ARS-S-52, Washington DC, USA.

POTTER, M.F., HUBER, R.T., and WATSON, T.F. 1981. Heat unit requirements for emergence of overwintering tobacco budworm, *Heliothis virescens,* in Arizona. Environmental Entomology 10: 543-545.

QUAINTANCE, A.L., and BRUES, C.T. 1905. The cotton bollworm. U.S. Department of Agriculture Bureau of Entomology Bulletin 50, Washington DC, USA.

RIDGWAY, R.L., ABLES, J.R., GOODPASTURE, C, and HARTSTACK, A.W. 1981. *Trichogramma* and its utilization for crop protection in the United States. *In* Proceedings, Soviet-American Conference on Use of Beneficial Organisms in Control of Crop Pests. St. Paul, Minn., USA: American Phytopathological Society.

SLOSSER, J. 1980. Irrigation timing for bollworm management in cotton. Journal of Economic Entomology 73(2): 346-349.

STINNER, R.E., GUTIERREZ, A.P., and BUTLER, G.D. 1974. An algorithm for temperature-dependent growth rate simulations. Canadian Entomologist 106: 519-524.

STINNER, R.E., RABB, R.L., and BRADLEY, J.R. 1974. Population dynamics of *Heliothis zea* and H. *virescens* in North Carolina: a simulation model. Environmental Entomology 3:163-168.

TOWNSEND, J.R. 1973. Economic Threshold studies of *Heliothis* spp. on cotton. M.S. Thesis, Department of Entomology, Mississippi State University, Miss, USA. 72 pp.

TUMLINSON, J.H., HENDRICKS, D.E., MITCHELL, E.R., DOOLITTLE, R.E., and BRENNAN, M.M. 1975. Isolation, identification and synthesis of the sex pheromone of the tobacco budworm. Journal of Chemical Ecology 1:203-214.

WATSON, F.L. 1973. The optimal control of *Lygus hesperus* on cotton. Unpubl. Ph.D. thesis, University of Arizona, Ariz, USA. 207 pp.

WILSON, A.Q., HUGHES, R.D., and GILBERT, N. 1972. The response of cotton to pest attack. Bulletin of Entomological Research 61: 405-414.

WILSON, A.G.L., LEWIS, T., and CUNNINGHAM, R.B. 1979. Overwintering and spring emergence of *Heliothis armigera* (Hubner) (Lepidoptera: Noctuidae) in the Namoi Valley, New South Wales. Bulletin of Entomological Research 69: 97-109.

WITZ, J.A. 1973. Integration of systems methodology and scientific research. Agricultural Science Review 11: 37-48.

WOLF, W.W., TOBA, H.H., KISHABA, A.N., and GREEN, N. 1972. Antioxidant to prolong the effectiveness of cabbage looper sex pheromone in the field. Journal of Economic Entomology 65:1039-1041.

Migration as a Factor in *Heliothis* Management

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Abstract

Many studies have demonstrated the mobility ot our Heliothis *pest species through their capability to extend their ranges hundreds ot kilometers beyond their over-wintering ranges. Other studies have also yielded circumstantial evidence of their long-range movement within the confines ot their indigenous ranges, even though definitive studies have not yet been made of such movement between habitats. The array of techniques developed for studying movement of locusts and spruce budworms provide models upon which to base more intensive studies of* Heliothis spp *movement. A better understanding of both long- and short-range movement of the insects is required to functionally define areas of treatment for testing suppression theories that extend beyond the boundaries of our cropping system and utilize an integrated and holistic approach to population suppression.*

Résumé

*La migration, un facteur de lutte contre l'*Heliothis: *Plusieurs études ont démontré la mobilité de nos espèces nuisibles d'*Heliothis *par leur capacité à étendre leur habitat à des centaines de kilomètres de leur aire d'hivernage. D'autres recherches ont aussi fourni des preuves circonstantielles sur leurs déplacements sur de longues distances dans les limites de leur aire de répartition indigène, mais des études définitives n'ont pas encore été réalisées sur de tels mouvements entre habitats. L'éventail des techniques développées pour étudier le mouvement des locustes et de la tordeuse des bourgeons de l'épinette fournissent des modèles permettant de réaliser des études intensives sur les mouvements d'*Heliothis spp. *Une meilleure connaissance des mouvements des insectes sur de longues et courtes distances est essentielle pour délimiter de manière fonctionnelle des aires de traitement qui permettront d'évaluer les théories de suppression dans des limites dépassant nos systèmes de culture actuels et d'avoir une approche intégrée et globale dans la suppression des populations.*

Since the advent of efficient insecticides and methods of application, concepts for controlling pest insect populations have been concentrated mostly upon field-to-field management following appearance of the insect or its damage to the crop. Jackson (1979) points out that much of the insecticide-usage technology is implemented by the individual grower, who historically has utilized insecticides with little understanding of the negative effects that are triggered by such application. As a consequence, many insect-control programs were developed that placed the grower on an insecticide treadmill, making him totally reliant upon scheduled insecticide treatments to protect his crop.

With better understanding of the negative aspects of pesticide use, in relation to both the environment and the control of the target species itself, has arisen a need and demand for pest-management systems that optimize naturally occurring suppression mechanisms and utilize nonpesticide control treatments. Metcalf (1980), reviewing the pesticide treadmill syndrome, discusses the philosophical changes that are resulting in the development of integrated pest-management systems on a worldwide basis. For effective timing of control measures, such systems require accurate prediction of population buildups or outbreaks, and a thorough knowledge of the pest species population dynamics. We therefore need to determine the movement capabilities of populations both on a regional and on a local

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***U.S. Department ot Agriculture, Agricultural Research Service, Cotton Insects Research, Brownsville, Texas; Grain Insects Research, Tifton, Georgia; Western Cotton Research Laboratory, Phoenix, Arizona; and Grain Insects Research, Tifton, Georgia; respectively.**

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scale. Further, we need a better understanding of the parameters that influence movement, including the chronology of croppings systems, which determines host availability as discussed by Lopez (1976), and the development of meteorological events that offer modes of transport such as those described by Beckman (1973).

Evidence of *Heliothis* Spp Movement

The physical displacement of *Heliothis* over relatively long distances has been referred to by several investigators. Although these studies have not followed *Heliothis* spp movement from a degenerating habitat over a migratory path to a more attractive habitat, they have yielded circumstantial evidence of the capability of *Heliothis* for long-range movement.

Snow and Copeland (1971) surveyed the Cooperative Economic Insect Reports in the USA for a 19-year period, from 1951 to 1969, and observed that both in the eastern and western parts of the country, *Heliothis zea* (Boddie) had been reported as overwintering roughly up to 45°N. Through the mid-continent area, where more extreme fluctuations in temperature are normally experienced, the northern limit of winter survival appeared to correspond roughly to 40°N. These authors concluded that the range of *H. zea* winter survival corresponded roughly to those regions receiving the last spring freeze prior to April 30. However, Hardwick (1965) in his monograph on the corn earworm complex, states that *H. zea* in some years is present as far north as 52°N, indicating that in North America, *H. zea* extends its range 600 to 1200 km over about a two-generation period.

Hardwick (1965) further states that the indigenous range of *Heliothis armigera* (Hb.) probably corresponds roughly to 40° north and south latitude, thus approximating the overwintering range of *H. zea* observed in the USA. Like *H. zea, H. armigera* apparently is able to extend its range well beyond that at which it is capable of overwintering during its reproductive phase. Hardwick (1965) lists the most northerly record for the species as being Narva, Estonia, in the USSR at about 59°N. French and Hurst (1969) documented the arrival of *H. armigera* in the British Isles at about 51°N in July 1968, and through correlation with meteorological events, were able to backtrack the insects to their probable source in either northwestern Spain or north Africa, a distance of 800 to 1600 km.

Documentation of emigration or immigration within the confines of the overwintering range of the species is confounded by the presence of indigenous populations from which immigrants are difficult or impossible to distinguish. Indeed, this led Phillips (1979) to declare that in the state of Arkansas, USA, for a 6-year period from 1972 to 1978, if immigration of *H. zea* had occurred, it had done so with no net effect on the seasonal population dynamics of the species. However, several studies have indicated *Heliothis* spp dispersal or their ability to disperse within their indigenous range.

Callahan et al. (1972) placed 15 light traps at varying heights on a 318-m television tower at Pelham, Georgia, to study the vertical distribution of *H. zea.* These traps were constructed so that only insects flying above them could detect the light and thus be attracted to the traps. These investigators captured *H. zea* males and females in each of the traps, including the one at 318 m, and observed a relatively even distribution in all traps above 83 m. During peak flight periods, over 50% of all insects captured were *H. zea,* and they concluded that the moths were probably migrating.

Sparks et al. (1975) placed light traps on unmanned oil rigs in the Gulf of Mexico south of Jeanerette, Louisiana, and captured *H. zea* at all trap locations, with a decreasing concentration gradient occurring from those traps closest to shore (43 km) to those most distant (160 km). Evaluation of weather data collected on the oil rigs led Sparks and associates to conclude that these moths were being transported on southbound cool fronts.

Snow et al. (1969) labeled a naturally occurring population of *H. zea* on corn with P^{32} and observed the dispersal pattern over the 134 km^2 island of St. Croix, U.S. Virgin Islands. Labeled *H. zea* dispersed over the entire island and concentrated around areas with attractive host plants. In a later study involving the release of sterile *Heliothis virescens* (F.) and *H. zea* on St. Croix, Haile et al. (1975) operated pheromone traps for both species on the islands of Vieques and St. Thomas. Released insects of both species dispersed to these islands, which are located at a distance of 67 km (Vieques) and 61 km (St. Thomas) down- or cross-wind from St. Croix, and the investigators concluded that movement of indigenous populations between islands was highly probable.

Other studies have documented the dispersal of

Heliothis spp over relatively long distances within the continental USA. Sparks (1972) released marked laboratory-reared *H. zea* adults near Tifton, Georgia, and captured moths at a 25-km distance from the release site after one night, and at a distance of 72 km over a period of 1 to 4 days. Hendricks et al. (1973) studied the dispersal of laboratory-reared *H. virescens* adults with pheromone traps near Brownsville, Texas, and demonstrated their movement up to 112 km downwind of the prevailing wind pattern. Also, males were captured at a distance of 25 km against prevailing wind patterns; however, since no attempt was made to correlate trap captures on a temporal and spatial basis with meteorological events, one cannot rule out the possibility of these moths having dispersed on storm fronts or other meteorological phenomena that could result in temporary wind shifts from prevailing patterns.

In 1979, Raulston studied the movement of native *H. virescens* male moths, using a capture, mark, and recapture method. These males were collected from a line of 26 wind-oriented pheromone traps (Raulston et al. 1980) situated in the Lower Rio Grande Valley of Texas, extending east to west a distance of 80 km. The moths were subsequently marked by dusting them with Day-glo®[1] fluorescent powder, and released near San Fernando, Tamaulipas, Mexico, a distance of 160 km south of the Valley. Altogether, 16 000 moths were released on two occasions in May, and recapture was observed in the trap line situated in the Valley. Since subsequent observations indicated that recaptured marked moths contaminated unmarked ones, no reliable estimate can be made of the total number of moths recaptured from the release point. However, when the percentage of total marked moths observed was calculated for each trap (Fig. 1), two major areas of recapture were indicated at traps 9, 10, and 18. These three traps accounted for 40% of the observed marked moths. Assuming the moths moved primarily downwind, a wind direction between 180° and 210° would be required to transport moths from the release site to the trap-line area. Data shown in Table 1, taken from pseudo-adiabatic charts at Brownsville, Texas, indicate that favorable windflows for such transport occurred on May 10, 11, 12, 18 to 22, and 26 to 31 at altitudes below 3000 m.

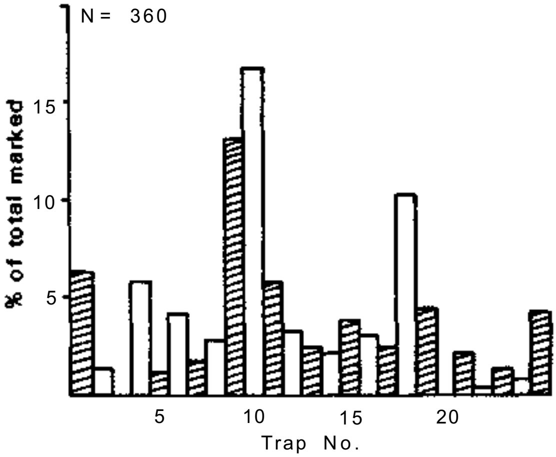

Figure 1. Recapture of fluorescent dye-marked* Heliothis virescens *in Lower Rio Grande Pheromone trap line. Males were released near San Fernando, Tamaulipas, Mexico, in May 1979.

The average temperature at 3000 m tor the month was 9.4°C, which is well above the flight threshold temperature of *Heliothis* spp observed by Carpenter et al. (1982).

To alleviate the problem of mark contamination, three releases were made in June and July utilizing black or blue felt tip markers to spot-mark individual wings on the released insects. From a total of 18 000 males released at San Fernando, only four were recaptured in the Valley trap line. Following the first release on 7 June until the second release on 14 June, no windflow at a direction greater than 170° was observed below an altitude at which the temperature was above 4.4°C. However, one marked male was recaptured, even though no favorable winds had occurred to transport released moths into the main area of the trap line. Following the second release on 14 June, favorable winds were noted on 17 June between an altitude of 900 and 2700 m, and two moths were recaptured, one on 18 June and one on 20 June. Following the third release on 22 June, favorable winds were noted on two occasions (22 and 25 July), and one moth was recaptured on 31 July. The wind shifts that occurred after May would appear to reduce the possibility of transport from the release site into the Valley. Only 16% of the days in June had favorable winds, while 51, 50, and 54% of the days in March, April, and May respectively, had favorable winds.

Between 1 August and 6 September 1979, 13 releases of a total of 44 000 males were made

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[1] Mention of a commercial product does not constitute an endorsement of that product by the USDA.

Table 1. Occurrence of winds^2 favorable for the transport of Heliothis virescens males from a release point south of San Fernando to the Lower Rio Grande Valley trap line, May 1979.

Altitude	May																					
(m)	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0																						
300																				+		
610	+												+							+	+	+
910		+								+	+	+	+					+	+	+	+	+
1230		+								+	+	+	+					+	+	+	+	+
1520		+									-	-	-					-	-	-	-	
1830	+								+		+	+						+	+	+	+	
2130	+										+	+	+					+	+	+		
2440	+	+							+		+	+					+	+	+	+		
2740	+	+		+								+					+	+	+	+		
3040	-	+		+								-			-		-	-	+			

a. + = wind direction between 180° and 210°; - = missing data.

about 30 km north of Brownsville, to study possible movement from the Valley area to the north. A line of five wind-oriented traps was extended from Chapman Ranch to Alice, Texas, for this study. (These traps were operated by Dr. John Benedict, Texas Agricultural Experiment Station, Corpus Christi, Texas). A distance of 130 km separated the release point from the trap line, and a wind direction between 150° and 170° was required to transport moths to the trap-line area. Five males were recaptured in the Chapman Ranch-Alice trap line; none in the Valley trap line south of the release point. Radiosonde data from Brownsville (Table 2) indicate 49% of the readings below 3000 m were within the range of favorable transport. The recapture of so few males may have resulted from a lack of attractive host plants in the trap-line area; however, the availability of an aerial transport mechanism was demonstrated.

Studies of the population dynamics of *H. virescens* and meteorological patterns occurring within the region have yielded further circumstantial evidence suggesting the possibility of moth transport from northeastern Mexico to southern Texas and beyond.

Pheromone- and light-trap data are shown in Figure 2 for Brownsville, Texas, and San Fernando and Tampico, Tamaulipas, Mexico. Data from Brownsville and San Fernando were obtained from pheromone traps from 1978 through 1980, while data from Tampico were obtained from light traps operated at the Las Huastecas Experimental Agricultural Station, National Institute of Agricultural Investigations, by Ing. Felipe Silguero from 1974 to 1980. The Brownsville area normally has about 120 000 ha of cotton, which is planted in late February and early March and begins fruiting in early May. The San Fernando area is primarily rangeland and dryland sorghum, while Tampico grows crops such as maize, tomatoes, soybean, chillies, safflower, and sugarcane, none of which support major populations of *H. virescens.* However, the region between San Fernando and Tampico and areas south of Tampico support large populations of two wild hosts. *Abutilon trisulcatum* (Jacq.) and *Bastardia viscosa* (L), in the spring and fall.

The major spring trap-capture peak at San Fernando occurred during the months of March through May, which also corresponds with major trap capture in the Brownsville area, well before cotton is available to produce *Heliothis* populations.

Figure 3 shows surface synoptic weather maps of the U.S. and pseudoadiabatic charts from Brownsville, Texas, for March 17 and 23 of 1980, which typify the weather patterns for the region during this period of the year. The March 17 synoptic map shows moderate low-level winds (5 to 7.5 m/sec) with the potential for surface air transport from southerly components, southwest to southeast, northward across coastal Texas and northwestward into the Mississippi River Valley, ahead of an approaching cold front. The pseudo-adiabatic chart for that date at Brownsville further illustrates

Table 2. Occurrence of winds* favorable for the transport of Heliothis virescenes mala* from a release point near Arroyo City to a trap line between Chapman Ranch and Alice, Texas, 1 Aug to 9 Sept 1979.

	Altitude (m)										
Date	0	300	610	910	1230	1520	1830	2130	2440	2740	3040
Aug 1	+		+	+	+			+	+	+	-
2	+	+	+	+	+	-	+	+	+	+	-
3	+	+	+	+	+	-	+	+	+	+	-
4		+	+		+	-	+	+	+	+	-
5									+		-
6		+				-					-
7		+	+	+	+	-	+	+			-
8	+				+	-					-
9							+	+	+	+	
10	+				+	+	+	+	+	+	-
11	+	+	+	+	+	-	+	+	+	+	+
12	+	+	+	+	+	-	+	+	+	+	-
13	+	+	+	+		+	+	+		+	-
14		+	+	+	+	-	+	+	+	+	-
15	+		+								
16	+	+	+	+			+	+	+	+	
17				+	+	4	+	+			-
18		+	+	+	+	-					-
19		+	+	+	+		+	+	+	+	-
20		+	+	+	+		+	+	+	+	-
21	+	+	+	+	+	+	+	+			-
22	+	+	+	+	+	-	+	+	+	+	-
23	+	+	+	+			+				-
24										+	-
25											-
26				+			+	+	+	+	-
27									+		
28											-
29											-
30											-
31											-
Sept 1			+			-					-
2	+	+									-
3		+	+	+							
4		+	+	+	+	-	+	+	+	+	-
5						-				+	-
6	+	+	+	+	+	-	+			+	-

a. + = wind direction between 150° and 170°; - = missing data.

that the surface wind direction of 150° progressively revolves to 240° at 2000 m elevation. The temperature at 2000 m was 16.7°C, well above the flight threshold for *Heliothis* species.

The synoptic map from March 23 shows strong low-level winds (7.5-10 m/sec) from south to north with the potential to transport moths 350 to 500 km overnight across southern Texas towards Oklahoma and Arkansas. The pseudo-adiabatic chart at Brownsville again shows a wind shift from 150° near the surface to 240° at 3000 m. Strong winds were observed between 1800 and 3000 m ranging from 15 to 22.5 m/sec.

The wind shift with elevation is a common occurrence in south Texas in the spring, and assuming this is a normal pattern along the Gulf Coast of Mexico, an aerial transport mechanism would be available along the entire Gulf Coast during the

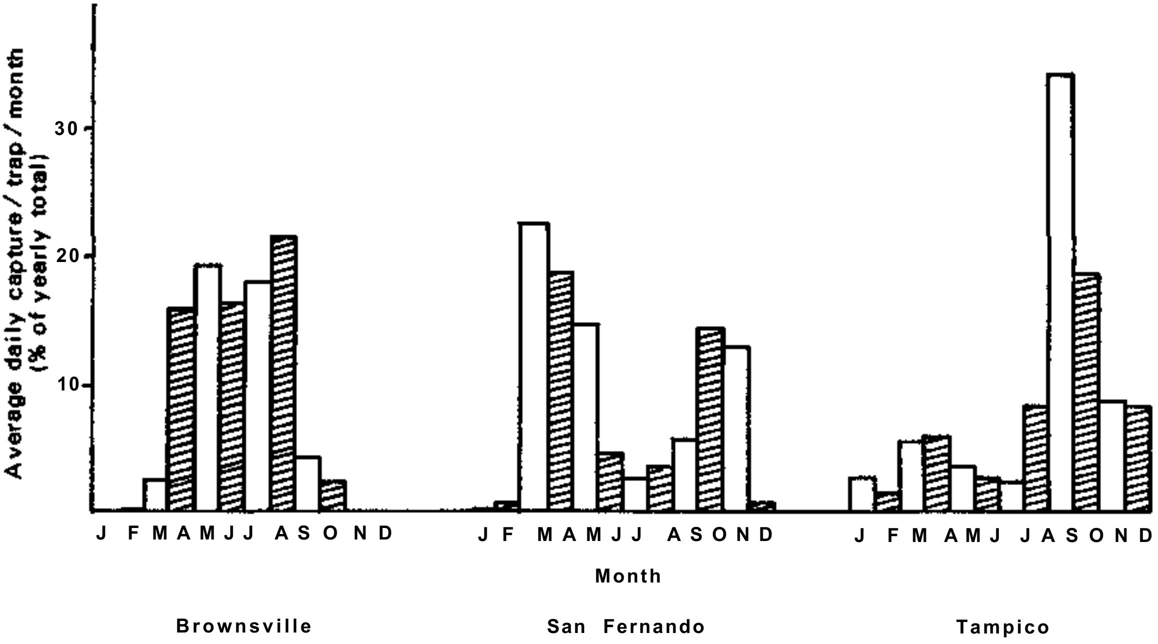

Figure 2. **Heliothis virescens** *trap capture at Brownsville, Texas, USA, and San Fernando and Tampico, Tamaulipas, Mexico. Brownsville and San Fernando data are from pheromone traps operated from 1978 through 1980; Tampico data are from light traps operated from 1974 through 1980.*

spring to aid the southern migration of a number of insect species. The wind shift with elevation discontinues in June, and the aerial transport mechanism from Mexico along the Gulf Coast would appear to break down at this time, with the exception perhaps of local meteorological events. This is exemplified in Figure 4, which shows the monthly average wind direction, speed, and temperature taken from pseudo-adiabatic charts from Brownsville, Texas, for June, July, and August 1979.

The variation in wind direction from June to August (18° to 41.8°) below 3000 m is much lower than noted in the months of March, April, and May (79° to 124°). Further, the wind direction from June to August tends to be aligned from the coast inland, which would decrease the possibility of moth transport up the coast of Mexico. As Figure 2 shows, populations are low in northern Mexico during the midsummer months, which further decreases the probability of major movements at this time of year. Interestingly, Stadelbacher and Pfrimmer (1972) observed *Heliothis zea* adults in light traps at Stoneville, Mississippi, at about the same time trap captures began to increase in the Lower Rio Grande Valley of Texas, in mid-March to late March. Over a 4-year period, from 1967 through 1970, these trap captures at Stoneville occurred on an average of 33 days prior to the first moth emergence from pupal diapause. Raulston (1979) observed a similar asynchrony in diapause emergence and trap capture for *H. virescens* in 1978 at Brownsville, Texas; however, this asynchrony did not occur in 1979 or 1980. It would seem probable that the moths captured at these various locations derive from common source areas.

In 1981, Hartstack et al. (1982) observed the relationship of *H. zea* trap capture in pheromone traps at five locations across south Texas and at Portland, Arkansas, to overwintering emergence at College Station, Texas. Table 3 shows the dates when trap peaks occurred at these locations as well as at Brownsville, Texas. (Brownsville trap data were supplied by John Norman, Texas Agricultural Extension Service, Weslaco, Texas, and diapause emergence data from Brownsville were supplied by Raulston.).

Initial trap-capture peaks in extreme south Texas from Brownsville to Corpus Christi, occurred within a 5-day period from Julian day 79 to 84 (Julian day 1 corresponding to 1 January). These trap peaks were synchronized with diapause emergence at Brownsville, which peaked on day 80.

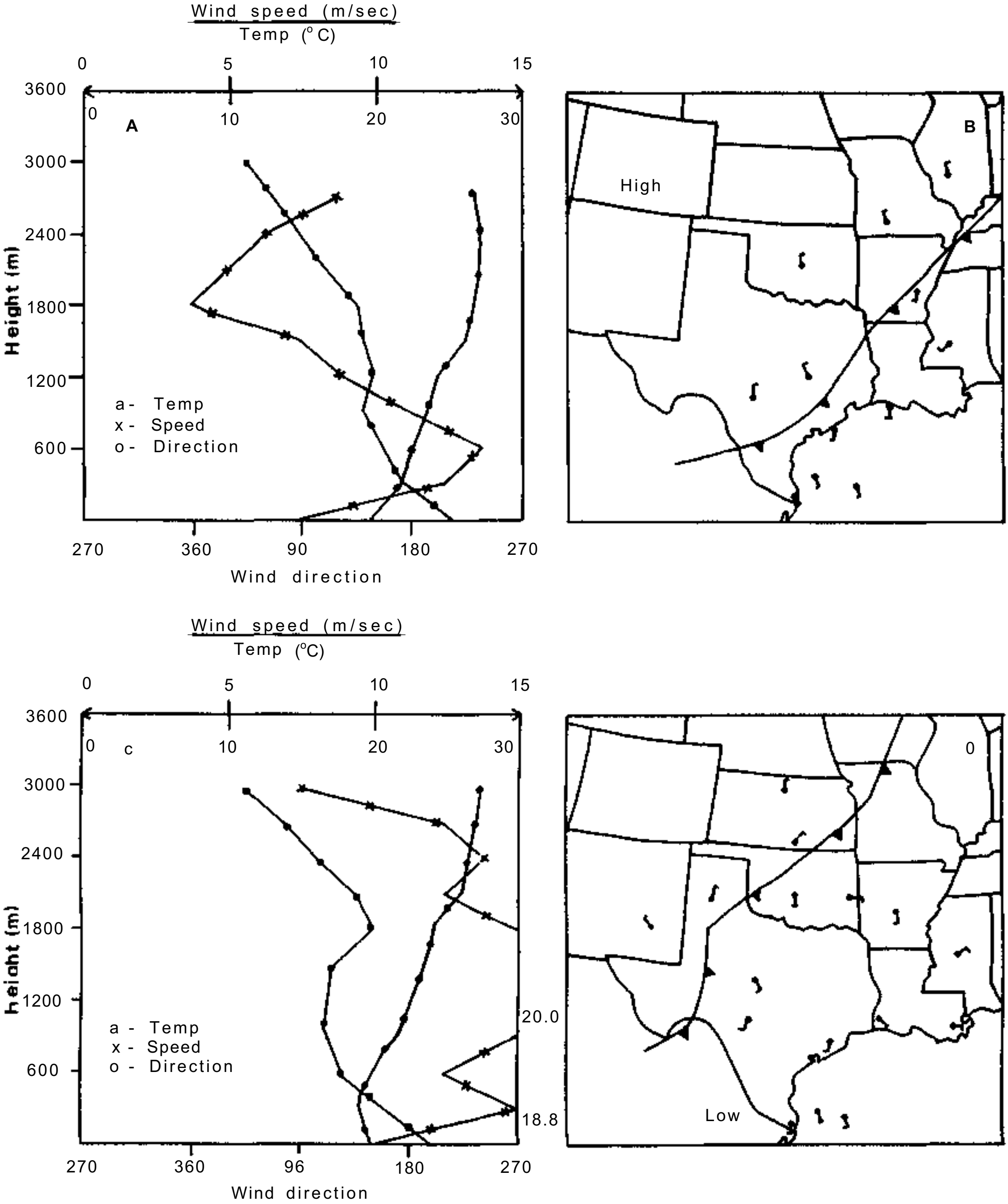

Figure 3. Pseudo-adiabatic chart readings and United States synoptic surface weather maps from Brownsville, Texas, for March 17 (A and B) and 23 (C and D) 1980, showing typical weather events for the region during the spring.

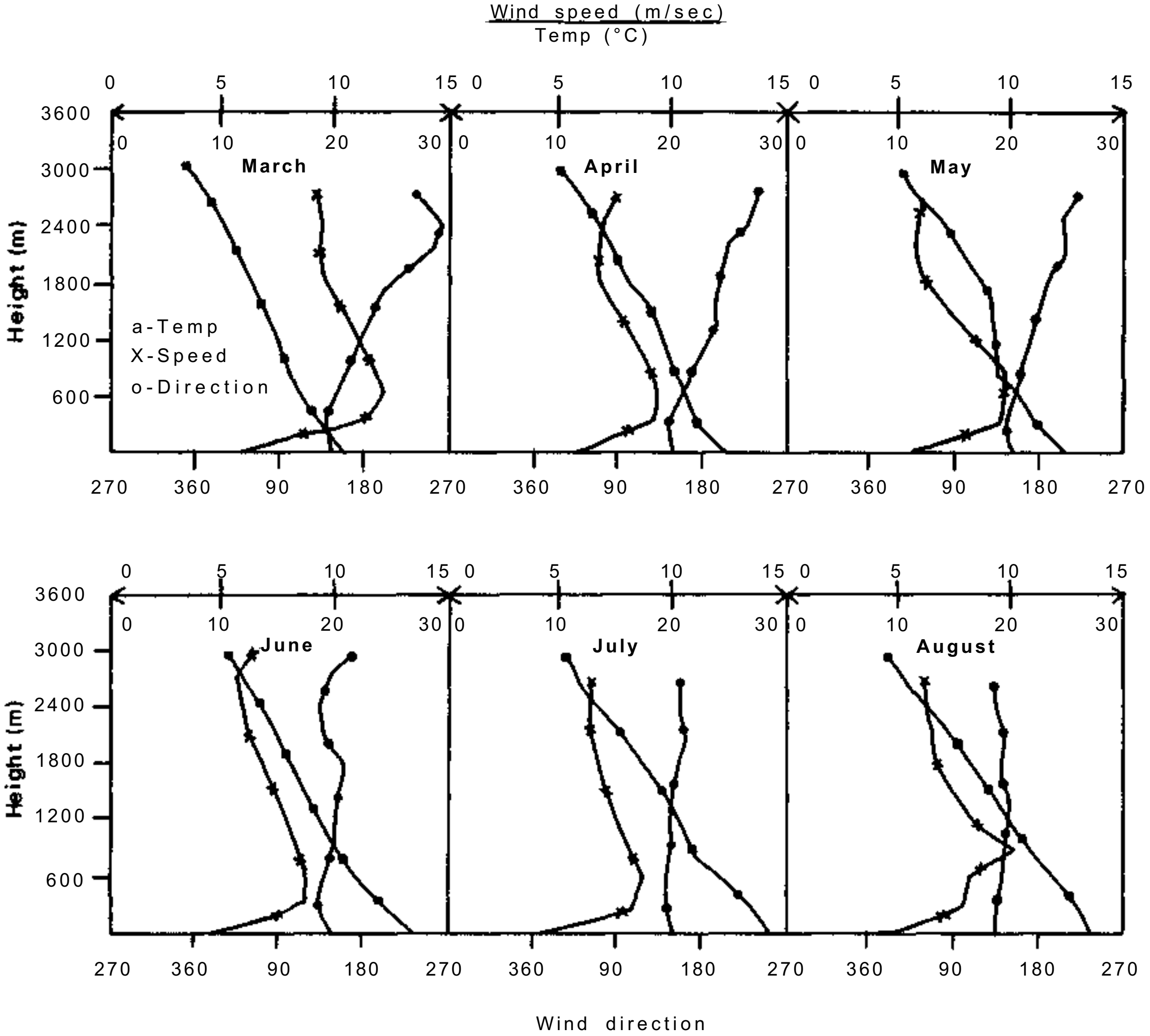

Figure 4. Average monthly pseudo-adiabatic chart readings from Brownsville, Texas, for the months of March through August 1979, showing typical wind shifts in the spring, which can provide an aerial transport mechanism for moths from the Gulf Coast of Mexico.

Trap-capture peaks occurred progressively later, moving north and east, with the last peak occurring at Portland, Arkansas, on day 99. A time difference of 20 days was observed between trap peaks from the most southern and northern areas. The peak of emergence from diapause at College Station occurred 22 days after the initial trap peak at that location and 39 days after the diapause emergence and trap peak observed at Brownsville.

The synchronization of trap and diapause peaks in extreme south Texas strongly suggests a common population, and the asynchrony of trap captures and diapause emergence at the northern locations further suggests that these initial peaks were derived from the southern locations. The wind flow patterns in south Texas at this time of year, (Figs. 3 and 4), also suggest that the Gulf Coast of Mexico may be implicated in the production of these peaks. Interestingly, 72% of the diapausing *H. zea* pupae we buried at Tampico, Tamaulipas, Mexico (22°N), emerged between 15 December 1979 and 15 January 1981, and reproductive populations of *H. zea* occur throughout the year at this latitude.

Table 3. Dates of Initial *Heliothis* zea trap-capture peaks at six locations in Texas and Portland, Arkansas, and emergence from diapause peaks at Brownsville and Collage Station, Texas, 1981.

	Location						
Julian	Texas						Arkansas
day[a]	Brownsville	Weslaco	Raymondville	Corpus Christi	College Station	Huntsville	Portland
79				X			
80	x0[b]						
83		X					
84			X				
91				X			
97					X		
98						X	
99							X
119					0		

a. Julian day 1 corresponds to 1 January.

b. X=trap peak; 0 = diapause emergence peak.

Methods and Needs for Future Research on *Heliothis* Spp Migration

Data and references presented in the preceding section illustrate the mobility of *Heliothis* spp, and through inference, their migrating ability. It is evident, however, that none of these studies has elucidated an actual migratory movement from one habitat to another, with concomitant ecological studies describing these habitats and the insect populations being supported in them. Hughes (1979) considers the implications of migration in population dynamics and discusses its relevance in relation to three major aspects, the first being those events occurring in Habitat I that elicit migratory behavior. These events may be broadly categorized as habitat deterioration brought about by maturation of host plants, increases in population density beyond the carrying capacity of the food source, and adverse environmental effects on either the quality of food or the ability of the organism to reproduce and survive within the habitat. Hughes lists as the second aspect those factors experienced en route, including intermediate feeding and/or reproduction sites and environmental effects, and as a third aspect, the conditions in Habitat II that affect its favorability for reproduction and survival.

Definitive studies of these events clearly involve a vast array of expertise and technology, such as that used in two of the most exhaustive studies of insect migration, involving a number of species in Africa and Australia and the spruce budworm (*Choristoneura fumiferana)* in Canada. These studies now form the basis for studying migration of numerous other insects. Rainey (1974) reviewed the initial work on locust migration and described the employment of photography, meteorology, and aviation as well as the biological sciences in the development of methods to track and determine the forces instrumental in swarm formation and movement. Later, Rainey (1978) listed as a major constraint to long-term locust control the period when contact with remnant populations was lost and pointed out that Joyce (1968) suggested maintaining the needed contact by using aircraft equipped with search radar and Doppler radar wind-finding equipment.

Schaefer (1976) reviewed his initial work on developing and using radar technology for studying insect flight, and provided the framework for a field of radar entomology. In a number of field expeditions in Africa, Australia, and Canada, both quantitative and qualitative observations were made on insect flight. These studies provided excellent insight into many aspects of insect flight for a number of species, including takeoff, speed, orientation, elevation, and diurnal variations in activity, and even revealed detailed structure of wind systems involved in insect transport. Further, analyses of wing-beat frequencies in the echo signature and concomitant field observations provided a method of insect identification and—under optimum conditions—sex differentiation of grasshoppers and locusts.

In one study, Schaefer (1976) was able to observe radar plumes of Noctuiid moths consisting of *H. armigera* and *Spodoptera littoralis* arising from a field of groundnut in the Sudan Gezira. He was able to observe their takeoff, which peaked about 45 min after sundown, as well as the elevation and orientation of the plume. Lingren and Wolf (1982) observed similar radar plumes arising from cotton fields near Phoenix, Arizona, which began about 65 min after sundown and rose to a height of 300 m. In other studies near Phoenix, Wolf (1979) observed insect activity over cotton fields and nearby desert areas, and in one instance was able to detect three layers of insects associated with inversion layers, a phenomenon also reported by Schaefer (1976) and Greenbank et al. (1980).

Greenbank et al. (1980) reviewed 10 years of exhaustive studies on the dispersal of the spruce budworm. This long-term investigation incorporated the experience of Schaefer, Rainey, and others, and took a holistic approach to the study of dispersal. These investigators used eight major methods in their studies: observation platforms, night-viewing telescopes, ground-based and airborne radar, airborne collecting nets, light traps, and meteorological equipment including balloon releases. With this impressive array of equipment, observations were made on emigration, moth displacement, immigration, and meteorological events determining or affecting aerial transport. The life history status and density of dispersing moths were also determined as well as the ecological status of the habitats producing the emigrating moths. Fisher and Greenbank (1979) presented a population simulation model based upon these studies, from which control strategies may be adapted. These authors concluded, however, that for the spruce budworm, predictive models of dispersal were not feasible, because of the uncontrollable meteorological events that determine direction and distances of movement.

These studies provide excellent models upon which we can base more intensive studies of *Heliothis* dispersal and migration. Indeed, such studies have already been initiated (Lingren et al. 1978, Wolf 1979, Lingren and Wolf 1982, Lingren et al. 1982), and are currently being expanded.

The following radar entomological observations, conducted by W.W. Wolf, illustrate some of the wind and insect variations that become evident only through the use of radar and meteorological technology. The radar was located northwest of Tifton, Georgia, and was operated by the U.S. Department of Agriculture. The radar was similar to the one used in Canada for studying the spruce budworm (Greenbank et al. 1980). Plumes of insects had been observed departing from various groundnut fields in late August of 1981, and one plume was detected originating from a sorghum field heavily infested with fall armyworm.

Radar observations of insects above the sorghum field on 2 September indicated that activity started at 2003 hr and reached a peak at 2012 hr (Fig. 5). The plume lasted at least 20 minutes, and at 2030 hr, significant numbers of insects were flying as high as 1000 m above ground. By 2130 hr, a layer of insects had formed at an altitude of 900 m, and additional insect layers formed later in the night.

The higher flying insects originated from fields other than the local sorghum field and were detected as they passed within radar detection range. No lumping of insect densities was observed as they passed the radar (such as a cloud of insects from a remote field). Apparently, the diffusion and mixing of insects from individual fields produced a homogeneous flow of insects at the various altitudes.

Wind velocities and directions are shown in Figure 5. There were variations in wind velocity with altitude and with time. At 2058 hr, there was a 150° shift in wind direction. By 0240 hr, a low-level jet had developed with a maximum velocity of 7.5 m/sec at 250 m.

Without these types of measurements, estimates of insect displacement must rely on assumptions about time and height of insect flight and interpolations from synoptic charts as illustrated previously. Airflows like the low-level jet shown in Figure 5 cannot be interpolated from synoptic charts, and insect displacement associated with such an event could not be accounted for by using synoptic chart analysis. Indeed, large errors in displacement estimates would occur if only surface wind measurements were used.

Interpretation of radar data is simplified when only one insect species is flying, because simple radars do not discriminate between species. When more than one species is flying, the radar data will be more meaningful if the radar provides information for classifying the targets, as discussed by Schaefer (1976). A radar that provides polarization, radar cross section, wing beating, or orientation

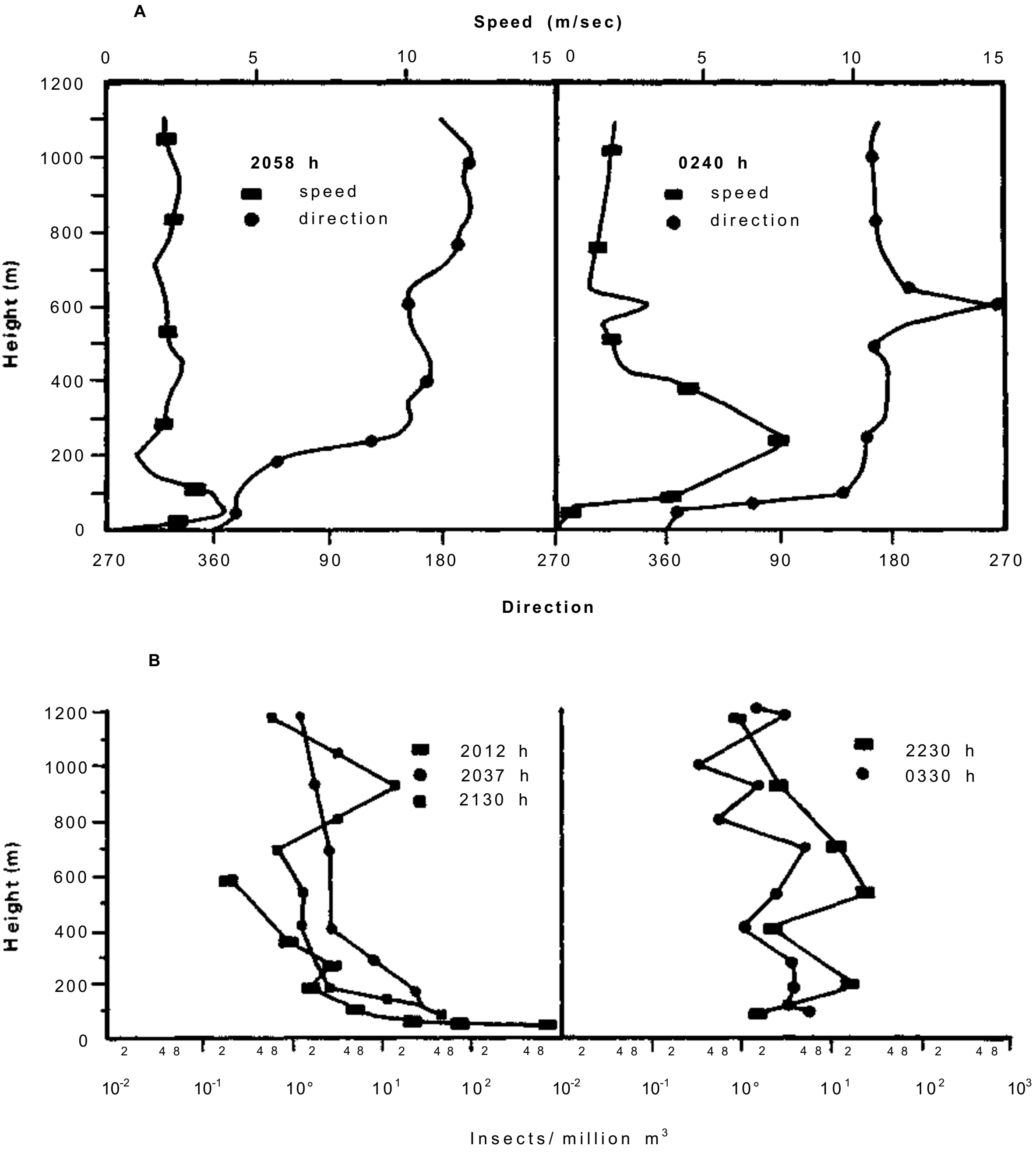

Figure 5. Radar observations (2 Sept 1981) of wind profiles (A) and insect densities (B) over a sorghum field near Tifton, Georgia, USA.

information needs to be developed for studying multispecies displacements.

As stated previously, the current impetus in agricultural entomology research to reduce our dependency on pesticides requires that we develop new theories and philosophies for control. Knipling (1978, 1982) provides a theoretical approach to management of *Heliothis* populations on an areawide basis. He discusses the relevance of attacking our *Heliothis* problems before they become established as an economic debit in our cropping systems, and advocates the use of combinations of suppression methods, such as cultural methods to destroy indigenous reproduction sites; releases of egg and larval parasites; applications of pathogens; and autocidal techniques such as the release of sterile, substerile, or hybrid sterile insects.

Such approaches to insect control beyond the confines of cropping systems per se require a thorough knowledge of all aspects of insect population dynamics. Rabb (1978) aptly states that the ecological definition of populations for management is a major difficulty and must encompass large enough geographical areas to account for movement of the target species as well as its biotic associates. He further states that suppression tactics utilizing behavior modifiers, genetic methods, and biotic agents require a wide area approach in guiding their use. In the context of mobility, population management then is a problem not only of long-range movement, but also of movement within the ecosystem, including movement within and between managed (crops) and unmanaged host reservoirs, and movement associated with specific behavior such as mating, feeding, and host finding.

The mobility of the *Heliothis* species has certainly been demonstrated, and the foundations have been laid for intensive studies of their movement. Further, the importance of studying such movement and its implications in pest management are recognized. We must now build upon these foundations to develop the information for scientifically sound pest-management systems, and, as Taylor (1979) states, "the scales of time and space needed to produce the sound and convincing ecological experimentation in flying insect pests required by agriculture are to be measured in thousands of kilometers and decades—economic entomology like insect ecology must learn to think on these scales of space and time if it is ever to increase its impact."

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References

BECKMAN, S.K. 1973. A study of wind-speed maxima near the surface over the south central United States. M.S. Thesis, Texas A&M University, College Station, Tex, USA. 73 pp.

CALLAHAN, P.S., SPARKS, A.N., SNOW, J.W., and COPELAND, W.W. 1972. Corn earworm moth: Vertical distribution in nocturnal flight. Environmental Entomology 1: 497-503.

CARPENTER, J.E., SPARKS, A.N., and HARRELL, E.A. 1982. Effect of temperature on wing beat frequency and sustained flight of certain lepidoptera insects. Journal of Georgia Entomology (in press).

FISHER, R.A., and GREENBANK, D.O. 1979. A case study of research into insect movement: Spruce budworm in New Brunswick. Pages 220-229 *in* Movement of highly mobile insects: concepts on methodology in research, eds. R.L. Rabb and G.G. Kennedy. Raleigh, NC, USA: University Graphics.

FRENCH, R.A., and HURST, G.W. 1969. Moth immigration in the British Isles in July 1968. Entomologist's Gazette 20: 37-44.

GREENBANK, D.O., SCHAEFER, G.W., and RAINEY, R.C. 1980. Spruce budworm (Lepidoptera: Tortricidae) moth flight and dispersal: new understanding from canopy observations, radar and aircraft. Memoirs of the Entomological Society of Canada 110, Ottawa, Canada. 49 pp.

HAILE, D.G., SNOW, J.W., and YOUNG, J.R. 1975. Movement of adult *Heliothis* released on St. Croix to other islands. Environmental Entomology 4: 225-226.

HARDWICK, D.F. 1965. The corn earworm complex. Memoirs of the Entomological Society of Canada 40, Ottawa, Canada. 248 pp.

HARTSTACK, A.W., LOPEZ, J.D., STERLING, W.L., KING, E.G., MULLER, R.A., and WITZ, J.A. 1982. Long range spring migration of *Heliothis zea* indicated. Environmental Entomology (in press).

HENDRICKS, D.E., GRAHAM, H.M., and RAULSTON, J.R. 1973. Dispersal of sterile tobacco budworms from release points in northeastern Mexico and southern Texas. Environmental Entomology 2:1085-1088.

HUGHES, R.D. 1979. Movement in population dynamics. Pages 14-32 *in* Movement of highly mobile insects: concepts on methodology in research, eds. R.L. Rabb and G.G. Kennedy. Raleigh, NC, USA: University Graphics.

JACKSON, R.D. 1979. Concepts, plans, and current research efforts (USDA) in insect migration research for insect population management systems. Pages 436-439 *in* Movement of highly mobile insects: concepts on methodology in research, eds. R.L. Rabb and G.G. Kennedy. Raleigh, NC, USA: University Graphics.

JOYCE, R.J.V. 1968. Possible developments in the use of aircraft and associated equipment. Chemistry and Industry 27 January 1968: 117-120.

KNIPLING, E.F. 1978. Eradication of plant pests—Pro. Bulletin of the Entomological Society of America 24: 44-52.

KNIPLING, E.F. 1982. The rationale for areawide management of *Heliolhis* populations. Bulletin of the Entomological Society of America (in press).

LINGREN, P.D., and WOLF, W.W. 1982. Nocturnal activity of the tobacco budworm and other insects. *In The* role of biometeorology in integrated pest management, eds. J.L. Hatfield and I.S. Thomanson. New York, NY, USA: Academic Press. (In press).

LINGREN, P.D., SPARKS, A.N., RAULSTON, J.R., and WOLF, W.W. 1978. Application for nocturnal studies of insects. Bulletin of the Entomological Society of America 24: 208-212.

LINGREN, P.D., RAULSTON, J.R., SPARKS, A.N., and WOLF, W.W. 1982. Insect monitoring technology for evaluation of suppression via pheromone systems. *In* Insect suppression with controlled release pheromone systems, eds. G. Zweig, A.F. Kydonieus, and M. Beroza. Boca Raton, Florida: CRC Press, (in press).

LOPEZ, J.D. 1976. The role of host phenology in the population dynamics of the bollworm, *Heliolhis zea* (Boddie), in the Brazos Valley of Texas. Ph.D. dissertation, Texas A&M University, College Station, Tex, USA. 199 pp.

METCALF, R.L. 1980. Changing role of insecticides in crop protection. Annual Review of Entomology 25: 219-256.

PHILLIPS, J.R. 1979. Migration of the bollworm, *Heliothis zea* (Boddie). Pages 409-411 *in* Movement of highly mobile insects: concepts on methodology in research, eds. R.L. Rabb and G.G. Kennedy. Raleigh, NC, USA: University Graphics.

RABB, R.L. 1978. A sharp focus on insect populations and pest management from a wide-area view. Bulletin of the Entomological Society of America 24: 55-60.

RAINEY, R.C. 1974. Flight behavior and features of the atmospheric environment. Symposia of the Royal Entomological Society of London 7: 75-112.

RAINEY, R.C. 1978. Possible impact of radar on pest management operations. Pages 81 -86 *in* Radar, insect population, ecology, and pest management. NASA Conference Publication 2070, Washington DC, USA.

RAULSTON, J.R. 1979. *Heliothis virescens* migration. Pages 412-419 *in* Movement of highly mobile insects: concepts on methodology in research, eds. R.L. Rabb and G.G. Kennedy. Raleigh, NC, USA: University Graphics.

RAULSTON, J.R., SPARKS, A.N., and LINGREN, P.D. 1980. Design and comparative efficiency of a wind-oriented trap for capturing live *Heliothis* spp. Journal of Economic Entomology 73: 586-589.

SCHAEFER, G.W. 1976. Radar observations of insect flight. Pages 157-196 *in* Insect flight, ed. R.C. Rainey. London: Blackwell.

SNOW, J.W., and COPELAND, W.W. 1971. Distribution and abundance of the corn earworm in the United States. U.S. Department of Agriculture Plant Pest Control Division, Cooperative Economic Insect Report 21: 71 -76.

SNOW, J.W., CANTELO, W.W., and BOWMAN, M.C. 1969. Distribution of the com earworm on St. Croix, U.S. Virgin Islands and its relation to suppression programs. Journal of Economic Entomology 62: 606-611.

SPARKS, A.N. 1972. *Heliothis* migration. Pages 15-17 *in* Distribution, abundance and control of *Heliothis* species in cotton and other host plants. Southern Cooperative Series Bulletin 169, Oklahoma Agricultural Experiment Station, Oklahoma State University, Stillwater, Okla, USA.

SPARKS, A.N., JACKSON, R.D., and ALLEN, C.L. 1975. Corn earworms: capture of adults in light traps on unmanned oil platforms in the Gulf of Mexico. Journal of Economic Entomology 68: 431 -432.

STADELBACHER, E.A., and PFRIMMER, T.R. 1972. Winter survival of the bollworm at Stoneville, Mississippi. Journal of Economic Entomology 65: 1030-1034.

TAYLOR, L.R. 1979. The Rothamsted insect survey - an approach to the theory and practice of synoptic pest forecasting in agriculture. Pages 148-185 *in* Movement of highly mobile insects: concepts on methodology in research, eds. R.L. Rabb and G.G. Kennedy. Raleigh, NC, USA: University Graphics.

WOLF, W.W. 1979. Entomological radar studies in the United States. Pages 263-266 in Movement of highly mobile insects: concepts on methodology in research, eds. R.L. Rabb and G.G. Kennedy. Raleigh, NC, USA: University Graphics.

The Identification and Use of Genetic Markers for Population Dynamics and Control Studies in *Heliothis*

Alan C. Bartlett and J.R. Raulston*

Abstract

The study of insect population dynamics requires some method of observation of individuals and groups. Some of the best information of this type is obtained through direct observation in the field, but this method is cost- and labor-intensive and requires well-trained and dedicated observers (particularly tor nocturnal species such as Heliothis,). *Recently, pheromone trapping has been a great help in assessment of insect numbers in natural populations, but interpretation of data from pheromone traps is still uncertain. Insect-marking techniques have long been used to acquire knowledge on insect behavior and dynamics.*

This paper discusses the use of visible and biochemical genetic markers as tools tor the study of Heliothis *spp population dynamics and reproductive behavior. Body-color and eye-color mutations have great potential tor use as markers, because they are easily recognized by workers using pheromone traps or collecting insects by hand in behavior studies. Biochemical markers, such as isozymes, are useful in long-term studies, since they are generally believed to show only minor selective effects in individuals. Procedures for the isolation and purification of mutant strains of* Heliothis spp *are easily incorporated into any laboratory rearing system if appropriate precautions are taken. The insertion of a genetic marker into the sterile hybrid* H. virescens x H. subflexa *is given as an illustration of the use of genetic markers in a* Heliothis *control program.*

Résumé

*Identification et utilisation de marqueurs génétiques dans les études sur la dynamique des populations et les mesures de lutte contre l'*Heliothis: *La recherche sur la dynamique des populations des insectes exige certaines méthodes d'observation des individus et des groupes. Certaines des meilleures informations de cette nature sont recueillies grâce à des observations directes sur le terrain, mais cette méthode est coûteuse et requiert beaucoup de travail, ainsi que des observateurs bien formés et dévoués (surtout pour des espèces nocturnes telle l'*Heliothis). *Récemment, les pièges à phéromone ont été très utiles pour évaluer le nombre d'insectes des populations naturelles, mais l'interprétation des données basées sur les pièges à phéromone est encore incertaine. Depuis longtemps des techniques de marquage d'insectes ont été utilisées pour mieux comprendre leur comportement et dynamique.*

*Cette communication porte sur l'utilisation de marqueurs génétiques visibles et biochimiques comme moyen pour étudier la dynamique des populations d'*Heliothis *spp et leur comportement reproductif. Des mutations dans la couleur du corps et de l'oeil offrent un grand potentiel d'utilisation comme marqueurs, puisqu'elles sont facilement discernées par les chercheurs utilisant des pièges à phéromone ou collectant des insectes à la main dans le cadre d'études sur le comportement. Les marqueurs biochimiques, tels les isozymes, sont utiles lors de recherches à long terme, puisqu'ils sont censés ne montrer seulement que des effets sélectifs mineurs chez les individus. Les procédures d'isolation et de purification de souches mutantes d'*Heliothis *spp s'intègrent facilement dans tout système d'élevage en laboratoire, si les précautions appropriées sont prises. L'utilisation d'un marqueur génétique chez l'hybride stérile* H. virescens x H. subflexa *sert d'exemple à l'utilisation de marqueurs génétiques dans un programme de lutte contre l'*Heliothis.

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International Crops Research Institute for the Semi-Arid Tropics. 1982. Proceedings of the International Workshop on *Heliothis* Management, 15-20 November 1981, Patancheru, A.P., India

All modern methods of *Heliothis* spp management require economically feasible ways to measure the population density and dynamics of the target pest species. In fact, integrated pest management (IPM) systems function only if the pest status (population level) can be monitored continuously (Bottrell 1979). Lingren et al. (1979) stressed the need for adequate direct observations of in-field behavior of undisturbed insect populations to determine the base parameters of population density and dynamics for pest species under a pheromone control system. That same reasoning is probably also valid for other suppression techniques. In order to successfully monitor *Heliothis* population levels, we must know what the populations would normally do at a given time (season) under given conditions. In other words, how many *Heliothis* are out there and what are they doing?

Ideally, we should have a continuous record of the whole population of the target species over the critical time period, but time and economics preclude such a complete determination. Therefore, only samples can be taken to provide the clues we require for estimation of the population dynamics of the species.

One method of studying the behavior, dispersal, migration, or other movement of populations is by the use of marked insects of release-recapture experiments (Southwood 1978). Several artificial marking techniques (for example, radioisotopes, fluorescent powders, oil-soluble dyes, etc.) have been used successfully in Lepidoptera to observe gross movements or to identify the released insects. Unfortunately, such artificial markers only last through one generation or less. Artificially applied markers do not allow the tracking of a released individual over generations, although such tracking may be necessary to evaluate such factors as generation time, intrinsic rate of increase, age structure of populations, and sex ratio changes over time. This paper discusses the use of visible and biochemical mutations to permit tracking of released individuals over time and generations after release.

The recovery and use of genetic markers in studies of insect population dynamics has been discussed for several species by Bartlett (1967, 1981 b), Stock (1979), and Huettel (1979). However, the use of genetic markers in *Heliothis* control programs or biological studies has not previously been examined. Therefore, this paper will demonstrate methods for recovery of visible and biochemical mutations in *Heliothis* species, illustrate the use of such mutations, and discuss the assumed and actual limitations of genetic markers in *Heliothis* research programs.

Mutations Available in *Heliothis* Spp

In a broad survey of the literature on Lepidoptera genetics, Robinson (1971) listed only DDT resistance as a genetic marker in any *Heliothis* species. However, since the publication of that book, several mutant characters in *Heliothis* have been described. Whitten (1973) described a mutant in *H. zea* that produces black pupae rather than the normal brown pupae of this species. The character is inherited as a simple autosomal recessive trait. The striking difference in the pupal color of individuals homozygous for this mutation could be of value in studies where larvae or pupae are recovered after the release of adults (such as in a test on diapause induction or host-plant preferences). A yellow-eyed variant of the corn earworm was described by Jones et al. (1977), which was also inherited as an autosomal recessive character. The yellow-eyed mutation also caused a light coloration of the adult body. Some effects of the mutation were noted when the strain was first isolated, but these effects were reported to have disappeared upon outcrossing and selection. The behavior of this mutation under natural conditions has not been reported, but since there seems to be no detrimental effect of the mutation on behavior in the laboratory, this eye-color mutant could be used as a population marker in release-recapture studies of *H. zea.*

A sex-linked mutant that produces yellow pupae rather than the normal brown color was reported by Proshold (1974). This mutation is of great interest since, with proper manipulation of the gene, it could be used for sexing large numbers of this species for control purposes. The distribution of sex-linked loci in Lepidoptera (Fig. 1) is discussed later in this paper in relation to insecticide resistance. The combination of a sex-linked visible marker with sex-linked resistance loci would be valuable in the development of genetic sexing techniques as well as for use in release-recapture experiments.

Sluss et al. (1978a, 1978b) compared isozyme differences between *H. virescens* and *H. zea.* In addition to demonstrating the value of isozyme studies to differentiate these two species, these authors also showed that much genetic variation exists within a species and that this variation could

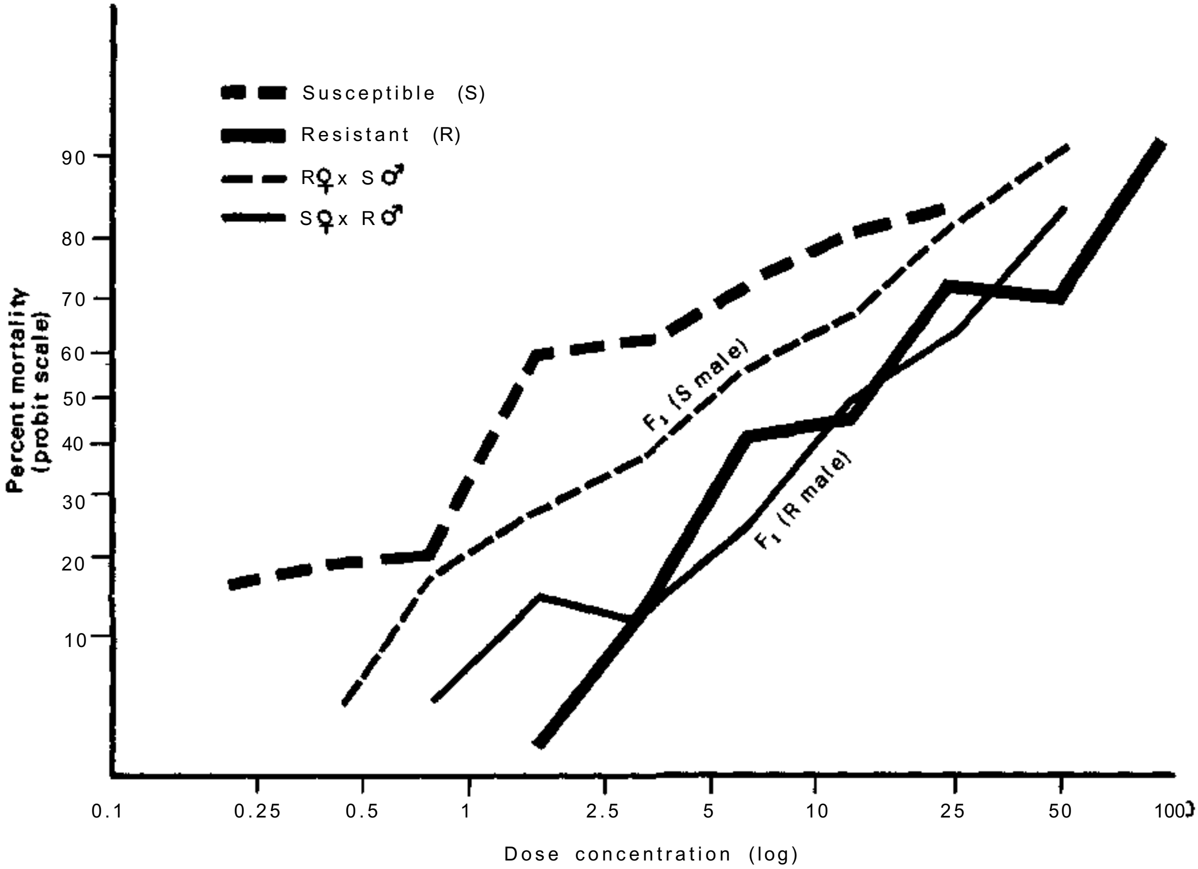

Figure 1. Response of susceptible (S) and resistant (R) strains of **Heliothis virescens** *and the reciprocal F1 crosses between them to doses of methyl parathion applied to larvae (data from Wolfenbarger et al. 1981).*

be used as genetic markers in biological experiments. For example, the hexokinase (HEX-A) enzyme system in *H. vlrescens* has four alleles in the population studied by Sluss et al. (1978b), but another population of *H. virescens* contained only three alleles at the same locus. If such gene frequency variations were examined over the geographic range of any *Heliothis* species and extended to a number of different loci (as is easily done with isozyme analyses), one may follow the migration patterns of these ubiquitous species. Sell et al. (1974a, 1974b) described and analyzed a polymorphic esterase (EST-II) system in *H.* zea and outlined the utility of such a system in studying the dispersal of this species. Since isozymes are generally regarded as transparent to selective pressures, and geographic variations appear to be present in most insect species and particularly in *Heliothis* species, long-term studies of migration should be highly productive.

Three visible mutants of *H. virescens* have been isolated and are maintained by J.R. Raulston (unpublished data). One strain has a dominant body-color mutation which has great potential as a marker as well as for control programs in this species. The other two strains carry recessive autosomal mutations which also have potential as markers in release-recapture experiments. The utilization of these markers is discussed in a later section of this paper.

The final type of genetic markers available in *Heliothis* species are those found in the insecticide-resistant strains present in many laboratories and in fields around the world. Not many of these resistant strains have been examined in enough detail to make them useful as genetic markers, but if their potential were realized, perhaps more genetic analyses would be carried out. Wolfenbarger et al. (1981) studied methyl parathion resistance in *H. virescens* to discover the genetic nature of the resistance. In crosses between susceptible and resistant strains, Wolfenbarger et al. (1981) found that when resistant males were crossed to susceptible females, the F_1 progeny were more resistant than progeny of the reciprocal cross (Fig. 1). This result is typical of at least partial *sex-linked inheritance of the gene or genes that* control the response of this strain to insecticide exposure. Figure 2 diagrams the expectations in Lepidoptera for a sex-linked resistance gene (R). The distribution of genotypes in males and females shows that males can be homozygous RR, homozygous rr, or heterozygous (Rr), but females can carry only one of the alleles, either R or r, but not both, if the trait is sex-linked. The existence of a sex-linked resistance locus in *H. virescens* has several possibilities for use in population dynamics studies and in control programs.

Lepidoptera sex linkage

	Female		Male
P_1	X^RY resistant	X	X^rX^r susceptible
F_1	X^rY susceptible		x^Rx^r resistant

Reciprocal cross

P_1	X^rY susceptible	X	X^RX^R resistant
F_1	X^RY resistant		X^RX^r resistant

Figure 2. Inheritance of sex chromosomes and types of F_1 progeny resulting from reciprocal crosses of P_1 individuals carrying a sex-linked locus for resistance to an insecticide. R=allele for resistance; r = allele for susceptibility to the insecticide. (Source: Wolfenbarger et al. 1981.)

There are probably other interesting genetic marker stocks available in laboratories around the world that have not been placed in the literature because the potential for their use is not appreciated. In addition, there are simple ways to obtain new genetic markers that have not been employed in *Heliothis* species. The remainder of this paper examines both the acquisition and utilization of such genetic markers in *Heliothis* research programs.

Isolation and Maintenance of Mutations

Many investigators have observed aberrant individuals in *Heliothis* colonies, but for lack of time or expertise, have duly noted but promptly discarded these aberrant individuals. Laboratory cultures are the best and most readily available source of mutant genes. Often a thorough examination of individuals in a laboratory culture will reveal the presence of aberrants, which should be bred systematically to reveal whether the character is inherited. All stages of the life cycle must be examined, since mutations can affect any stage of development (Bartlett 1981 b). Table 1 lists some mutant characters that have been found in economic species of Lepidoptera.

If an existing laboratory population does not show any morphological variation in a preliminary examination of a high proportion of the population, then the next step is to inbreed the population to expose any recessive mutations that may be carried by the colony. Most entomologists conscientiously avoid inbreeding of their insect colonies, since it is considered to be detrimental; however, inbreeding is necessary to expose recessive mutations. Since only a sample of the population is subjected to the process, no permanent harm is done to the colony. Once a mutation is isolated and purified, heterozygosity may be recovered in the mutant strain. An effective inbreeding scheme is given in Bartlett (1981b): (1) A number of single-pair crosses are made between individuals from a random-mating laboratory population. (2) From each single-pair cross made in the parental genertion, the F_1 progeny are mass-crossed to produce an F_2 population. If a recessive mutation were present in either of the original parents, then one-sixteenth of the F2 progeny will be expected to show the mutant phenotype. Obviously, one must exam-

Table 1. Types of mutant characters observed In different species of Lepidoptera.[a]

Character	Species	Inheritance[b]
Eye color	*Bomby x mori*	D, r, a, s
	Pectinophora gossypiella	r, a, s
	Sitotroga cerealella	r, a
	Cadra cautella	r, a
	Sterrha seriata	r, a
Larval color	*B. mori*	D, r, a
	S. seriata	r, a
	P. gossypiella	r, a
	Ostrinia nubilalis	r, a
	Celerio euphorbiae	r, a
Pupal color	*Heliothis zea*	r, a
	B. mori	D, r, a
Egg color	*B. mori*	D, r, a, s
Egg shape	*B. mori*	D, r, a, s
Wing color, pattern, or shape	*C. cautella*	r, a
	P. gossypiella	D, r, a
	H. virescens	D. r, a
	Pieris protodice	r. a
	S. seriata	D, r, a
	B. mori	D, r, a
	Papilio dardanus	D, a
Body color or pattern	*B. mori*	D, r, a, s
	P. gossypiella	D, r, a
	S. seriata	D, r, a
	P. dardanus	D, r, a
	H. virescens	D, r, a
Sex organ color	*B. mori*	D, r, a
	P. gossypiella	r, a
	S. seriata	r, a
Larval size	*B. mori*	r, a
Diapause or voltine change	*B. mori*	r, a
	P. gossypiella	D, a, s

a. This list is not intended to be exhaustive, only to suggest characters that can be altered by mutations. References are omitted to conserve space, but many can be found in Robinson (1971) or obtained from the authors.

b. D = dominant or codominant, r = recessive, a = autosomal, s = sex-linked.

ine more than 16 individuals to expect to find the mutant. If no aberrant individuals are found in 50 to 75 progeny in an F_2 family, it is reasonable to assume that the family does not contain a visible mutation and it may be discarded. (3) If any visible aberrations are found, then the family is kept for further breeding. The mutants are made into a pure culture (that is, a mutant X mutant cross), while normal-appearing siblings are mass-crossed to produce F_3 progeny. Mutants will again appear in the F_3 and can be added to the pure culture started in the F_2 generation. (4) This inbreeding process is continued until the pure colony has sufficient numbers to sustain the population. (5) At this point, if any detrimental effects of inbreeding are apparent in the mutant colony, an outbreeding scheme can be initiated to increase heterozygosity in the genetic background of the pure culture.

The number of parental crosses to be made will depend partly upon the resources available to the investigator. A few calculations will estimate the expectations for recovery of a mutant culture from a random-mating population. The genome of *Heliothis* species contains 31 (2n=62) pairs of chromosomes (Chen and Graves 1970); thus a single-pair cross will sample 124 chromosomes. If each chromosome contains, on the average, 1000 loci (Hartl 1977), then each single-pair cross is sampling about 124 000 loci. If the spontaneous mutation rate is, as estimated in other organisms, about 1×10^{-6} per locus (Ayala 1976), then one single-pair mating would be expected to yield about 0.1 newly arisen mutation. Ten matings, therefore, should produce about one new mutation. Since some of these mutations will not be visible (that is, they will be biochemical or affecting internal structures), we may assume that the yield of new visible mutations will be less than 0.1 per mating. Even if we assume that only 10% of the new mutations are visible, we could expect one visible mutant from 100 single-pair crosses. Of course, mutations could have occurred in earlier generations of laboratory rearing and should also be present in the population, thus increasing the probability of a visible mutant.

Simple Mendelian mutations show only three types of inheritance: recessive, dominant, or codominant. If a mutant allele shows its phenotype only when two identical alleles are present in an individual, then the trait is said to be recessive; if only one allele is needed for full expression of the mutant trait, then the trait is said to be inherited as a dominant; if an individual shows one appearance when heterozygous and a different appearance when homozygous, the trait is inherited as a codominant (or intermediately dominant) trait. Most newly arisen visible mutations are recessive.

Dominant and codominant visible mutants are the easiest classes of mutant to detect, but the least frequent in occurrence. They are also the most valuable mutations to use in release-recapture experiments since not only will the released individuals be marked, but any progeny of matings with the released individuals will also be marked. Codominant mutations are extremely valuable in this type of experiment, since one could theoretically release marked individuals of one sex for two generations and still be able to tell the released individuals from the F_1 progeny of matings between the original marked insects and native insects. In the third generation after the original release, the investigator would be able to identify three types of individuals: (1) heterozygous mutants resulting from crosses between natives and either released homozygotes or F_1 heterozygotes, (2) homozygous mutants resulting from crosses between the released homozygotes and the F_1 heterozygotes or among R heterozygotes, and (3) native x native crosses. Thus, with a codominant mutation, there is a possibility of studying mating interactions between native and released individuals across three generations in the field without the heavy demands of time and money imposed by direct observation of mating pairs.

Once a mutant culture is established in the laboratory, it is necessary to keep it homozygous for the mutant gene and vigorous. To many biologists, these are opposing concepts. This view results from the almost universal recognition of the detrimental effects of inbreeding on animal vigor and reproduction. However, changes in the size of inbreeding coefficients depend wholly on the size of the population being bred in the laboratory, as shown by the following formula (Falconer 1960) for change in the inbreeding coefficient over generations:

$$\Delta F = 1/8Nm + 1/8N_t$$

where F = the inbreeding coefficient, Nm = the number of males in the breeding population, and N_f = the number of females in the breeding population.

If equal numbers of males and females were used to produce progeny, the change in inbreeding coefficients per generation for $N_m = N_t = 10, 100$, or 1000 would be 0.025, 0.0025, or 0.00025. Thus it appears that inbreeding increases very slowly as population size exceeds 100 pairs of breeding individuals. Very few laboratory populations are maintained at numbers less than 100 pairs, especially if a population is to be used for release. The problem with inbreeding arises in the first few generations after isolation of the mutation, when numbers of mutant individuals are low. In a study of the effects of inbreeding on reproduction and viability in *Hylemya antiqua* during the isolation of homozygous translocation stocks, Robinson (1977) found wide differences in response of various lines to the effects of inbreeding. In five of the inbred lines there was a significant reduction in egg hatchability, but in three other lines no such reduction was observed. No effect of inbreeding on mating propensity or sex ratio was observed in any of the lines over three generations of intensive inbreeding (Robinson 1977). Similar results have been observed in *Aedes aegypti* (Craig and Hickey 1967) and *Drosophila melanogaster* (Lints 1961). Typically, fitness does decline in inbred lines for a few generations; some lines are lost, but then surviving lines are easily maintained, and it appears that inbreeding depression should not be a serious obstacle to the production of mutant stocks of insects (Robinson 1977).

If inbreeding depression does occur in *Heliothis* species and a good mutant stock is hampered by poor reproduction or viability, it is possible to outbreed the strain to an unrelated population and then to re-isolate the mutant culture. This procedure will take two generations to recover homozygous mutants. If the breeding populations are kept large enough, then the change in inbreeding coefficient can be kept low, as shown by the previous formula for ΔF. The strain used for outbreeding should not be the same strain used to produce the mutant in the first place, since the mutant strain will already contain loci in common with that strain. To maximize heterozygosity in the re-isolated mutant strain, one should use either a newly colonized wild strain or a strain colonized in another laboratory.

The maintenance of mutant strains of *Heliothis* is no more difficult than the maintenance of any colonized strain (nor is it any easier!). Certain precautions common to all rearing procedures should be emphasized. First, population levels should be kept as high as possible to avoid inbreeding problems. Second, genetic purity of the strain must be maintained so that when releases of the mutant culture are made the experimenter is sure that captured wild (native) individuals are not part of the released population. (If some wild-type individuals are present in the release strain, then that proportion must be accurately measured). Mutant strains of insects respond to quality control in rearing just as other laboratory stocks do. The quality of a laboratory-reared strain of insects depends a great deal on the purpose for which it is intended. In this discussion, because the prime purpose of the mutant strain is to interact as normally as possible with the native insects, the experimenter must keep the colonized strain as nearly like the field strain as possible. The effects of laboratory rearing on the behavior and usefulness of insect species have been discussed recently (Boiler 1979; Huettel 1979; Bartlett 1981 a). These publications should be consulted for detailed advice on the genetic effects of laboratory rearing.

Use of Visible Genetic Markers

An effective marking technique for insect research should meet the following minimum criteria:

- ease of application of the marker;
- minimal manipulation of insects to apply the marker;
- ease of recognition of the marker by laboratory or field personnel;
- certainty of persistence of the marker through the life stages of the organism;
- relative freedom from deleterious biological effects due to the marker.

Visible genetic markers meet these criteria very well; however, previous work using visible genetic markers has been subjected to the criticism that, because natural selection operates on these markers, they do not meet the last criterion (Huettel 1979). In most studies of population dynamics, the genetic markers should not be expected to persist more than two or three generations. If the markers used in release-recapture experiments are chosen carefully and adequate preliminary investigations made to determine the extent of deficiencies, then this factor should not seriously inhibit the use of visible genetic markers in *Heliothis* research.

The successful use of visible genetic markers in the boll weevil, cabbage looper, and pink bollworm has recently been discussed by Bartlett (1981 b). The markers in each case were melanic body-color mutations. These mutations are often inherited as dominant or codominant characters, and, judging by the success of melanic forms in Lepidoptera native to industrial areas (Ford 1964), often have little detrimental effect on the carrier.

To illustrate the use of a visible melanic genetic marker in a *Heliothis* control program, we have chosen to examine the marker, black body, in *Heliothis virescens* (Raulston, unpublished). This mutation causes two significant, and easily observed, changes in the body color of the insect. In the black-body mutant, wing color is changed to a dark green, wifh no evidence of the normal striping pattern. The abdomen and thorax of this mutant are a dusky black rather than the normal light grey or creamy white color. This mutation is inherited as a dominant character with recessive lethal effects; its inheritance pattern is shown in Figure 3a. An individual carrying two of the alleles controlling black body color will die, but an individual carrying only one allele for black body color has the typical mutant phenotype. The use of a similar body-color mutation in the cabbage looper *(Trichoplusia ni)* for

3a

P_1 B/+ Black X +/+ Wild type

F_1 1/2 B/+ Black 1/2 +/+ Wild type

1

P_1 B/+ Black X B/+ Black

F_1 1/4 B/B Die 2/4 B/+ Black 1/4 +/+ Wild type

2

3b

P_1 Black *male* X Hybrid female

F_1
females: 1/2 black, 1/2 wild type
males: 1/2 black, 1/2 wild type (sterile)

F F_2 and later

Progeny distribution as in
cross (1) or (2) above
(depending on male encountered)

Figure 3. (a) Crosses showing the distribution of progeny from a mating of an individual carrying the black body color mutation of* H. virescens. *The same distribution is found regardless of sex carrying the trait, (b) Distribution of progeny when a hybrid female (F_1 or backcross progeny of* H. virescens x H. subflexa *cross) is crossed to a black-body male.

an autocidal control program was described by Bartlett and Butler (1975). Thus this body-color mutation shows promise as a control tool simply because of the nature of the inheritance of the gene.

However, because of the existence of sterility in *H. virescens* and *H. subllexa* hybrids (Laster 1972), this mutant offers even further promise. In Figure 3b, a series of crosses are diagrammed to illustrate the incorporation of this mutant into the hybrid. Only females of the hybrid strain are fertile; thus black-body *H. virescens* males must be used to insert the mutant gene into the hybrid strain. Black-body females are selected from the Ft progeny of the cross between hybrid females and black-body males and crossed again to males of the black-body strain. The strain will never be pure-breeding, because of the recessive lethal nature of the black-body locus. However, since production of the hybrid strain involves continuous outcrossing of the hybrid females to normal males, no added work is involved in the maintenance of the black-body hybrid strain. In the hybrid black-body strain, about 66% of the F_1 progeny will have the black-body marker. When this strain is released in an autocidal control program, it has several advantages over an unmarked or mechanically marked release strain. First, over two-thirds of the released individuals carry the black body color and can be recognized in recapture studies. If selection is practiced on the strain before release (that is, if the wild-type individuals are removed), then all of the released individuals would be marked. As the released females mate and reproduce in the field, 50% of their progeny will carry the black marker, and the success of the release program can be evaluated in the first generation and subsequent generations simply by counting the number of black individuals captured versus the number of native individuals captured. At present, the evaluation of the success of this sterile hybrid release program depends upon the capture and subsequent testing of sterility of live males from the release zone. Such sterility testing is a costly and time-consuming process compared to the simple counting of mutant individuals in a pheromone trap.

In addition to simplifying evaluation of the hybrid release program, the recessive lethal locus gives an added dimension of protection against the breakdown of hybrid sterility. If some of the crosses between hybrid females and native males produced fertile male progeny, then 50% of those males would carry the black-body gene. These males crossing with subsequently released females would then produce 25% lethality in the progeny due to the presence of two black-body genes in the progeny. Furthermore, these black-body males could be collected and tested for sterility periodically. The magnitude of this work would be reduced from testing all males (in the case of an unmarked release program) to testing only those males that the experimenter knew were progeny of released hybrid females.

Previously we mentioned that two recessive body-color mutations (striped body and veined wing) of *H. virescens are* available (Raulston, unpublished). Although recessive mutations cannot be conveniently followed over generations in the field, they are still excellent tools for population assessment at given points in time. The investigator should observe certain precautions: (1) A preliminary estimate of population densities should be made to determine if sufficient numbers of the marker will be available to produce enough insects for recapture. (2) Releases should be made during the inactive period of the species (for *Heliothis* spp this means daylight releases). (3) Releases should be made over a short period of time (1 or 2 days only) to provide an estimate of survival rates. (4) Releases must be scattered over the complete range of the recapture area so that complete mixing of released and native insects can take place, or alternatively, if movement of the released insects is of interest, then one point of release should be chosen, and intensive trapping or collection should be made at points radiating out from the release point in a precise array. In either case, records from various parts of the recapture area must be examined individually for differences in numbers of recaptured insects which may be dependent on the movement of the released individuals or variation in density of the native population over the habitat (Southwood 1978).

The use of genetic markers must be subjected to the same care and interpretation as any other marking method. The advantages of these markers are in the ease of use and permanence of the marker, not only over the life of the individual, but over generations of the species.

Use of Insecticide Resistance Genes

Certain strains of *H. virescens* seem to possess a sex-linked methyl parathion resistance allele (Wolfenbarger et al. 1981). If strains containing such an allele could be purified (this has not yet been attempted in *Heliothis* species), then it would be possible to use the strain not only as a marker stock, but in the development of specific control programs as well. Young (1979) used patterns of insecticide resistance of the fall armyworm to three insecticides to determine the possible origins of this insect in the eastern United States during 1977. A similar study could be done in a more elegant manner if one knew the inheritance pattern of the insecticide resistance. A strain homozygous for a sex-linked resistance gene would also permit interesting combinations of release and treatment to change sex-ratios or otherwise manipulate the target population.

A sex-linked resistance marker would also be helpful in the development of various autocidal control schemes. If females from a strain homozygous for the resistance gene were crossed to males carrying the susceptible allele at that locus, all F_1 males would be resistant to the chemical, but all females would be susceptible (Fig. 2). The discriminating dose applied to the F_1 progeny would kill the females and preserve the males for further use (for example in a sterile-male release program). This type of automatic (or genetic) sexing has been used successfully in mosquitoes, but has not yet been used in *Heliothis* species.

Use of Isozyme Markers

A number of review articles have been published that explain the methods of electrophoresis used to identify isozyme markers and the use of those markers in population dynamics studies of insects (Pashley and Bush 1979; Steiner and Joslyn 1979; Stock 1979; Huettel 1979). The presence of isozyme variants in *Heliothis* species has been mentioned previously. A desirable feature of isozyme genetics lies in the ease with which an experimenter can obtain genetic variation. Individual insects can be examined for as many as 30 isozyme loci, and up to 70% of these loci may show polymorphisms. Many investigators prefer these "invisible" markers in release-recapture experiments because they do not affect fitness appreciably or alter normal behavior, since most variant alleles are already present in the population. In fact, one of the limitations of this method is that there is so much variation present in most populations that it is hard to find loci that will discriminate between populations without a great deal of experimentation. However, in ubiquitous *Heliothis* species there is a good chance that populations will differ in rare alleles at various loci, which can serve as population markers.

Conclusions

The use of artificial markers for studying insect population dynamics and reproductive behavior is well accepted. However, many artificial markers, such as dyes, radioactive materials, and mutilation are difficult to apply, affect the behavior of the marked insects, and/or last for only a short time during the insect's life cycle. The use of either visible or biochemical genetic markers could help investigators to avoid many or all of these problems.

Good visible mutants have been reported in some *Heliothis* spp, but none of these mutations are presently in use as markers in behavioral or release programs, probably because very little research has been done on the biological characteristics of these mutants. Further research must be done to help demonstrate the usefulness of genetic markers in behavioral studies and control programs as well as to isolate valuable mutations in species such as *H. armigera,* where no mutations are now available.

References

AYALA, F.J. 1976. Molecular genetics and evolution. Pages 1 -20 in Molecular evolution, ed, F.J. Ayala. Sunderland, Maryland: Sinauer Associates.

BARTLETT, A.C. 1967. Genetic markers in the boll weevil. Journal of Heredity 58: 159-163.

BARTLETT, A.C., and BUTLER, G.D., Jr. 1975. Genetic control of the cabbage looper by a recessive lethal mutation. Journal of Economic Entomology 68: 331 -335.

BARTLETT, A.C. 1981a. Genetic processes of domestication. *in* Advances and challenges in insect rearing, eds. E.G. King and N.C. Leppla. U.S. Department of Agriculture Handbook. (In press.)

BARTLETT, A.C. 1981b. Genetic markers, discovery and use in insect population dynamics studies and control programs. *In* International Symposium on the Sterile Insect Technique and the Use of Radiation in Genetic Insect Control, Vienna, Austria. IAEA-SM-255. (In press.)

BOLLER, E.F. 1979. Behavioral aspects of quality in insectary production. Pages 153-160 *in* Genetics in relation to insect management, eds. M.A. Hoy and J.J. McKelvey. New York, USA: The Rockefeller Foundation.

BOTTRELL, D.R. 1979. Integrated pest management. Washington, DC, USA: U.S. Government Printing Office. 120 pp.

CHEN, G.T., and GRAVES, J.B. 1970. Spermatogenesis of the tobacco budworm. Annals of the Entomological Society of America 63: 1095-1104.

CRAIG, G.B., and HICKEY, W.A. 1967. Genetics of *Aedes aegypti.* Pages 67-131 *in* Genetics of insect vectors of disease, eds. S.W. Wright and R. Pal. New York, USA: Elsevier Press. 794 pp.

FALCONER, D.S. 1960. Introduction to quantitative genetics. New York, USA: The Ronald Press. 365 pp.

FORD, E.B. 1964. Ecological genetics. London, UK: Methuen. 335 pp.

HARTL, D.L. 1977. Our uncertain heritage: genetics and human diversity. Philadelphia, USA: Lippincott. 494 pp.

HUETTEL, M.D. 1979. Genetic approaches to basic problems in insect behavior and ecology. Pages 161 -169 *in* Genetics in relation to insect management, eds. M.A. Hoy and J.J, McKelvey. New York, USA: The Rockefeller Foundation.

JONES, R.L., WIDSTROM, N.W., and PERKINS, D. 1977. Yellow-eye variant of the corn earworm. Journal of Heredity 68: 264-265.

LASTER, M.L. 1972. Interspecific hybridization of *Heliothis virescens* and *H. subflexa.* Environmental Entomology 1: 682-687.

LINGREN, P.D., RAULSTON, J.R., SPARKS, A.N., and PROSHOLD, F.I. 1979. Tobacco budworm: nocturnal behavior of laboratory-reared irradiated and native adults in the field. USDA ARR-W-5, February, U.S. Department of Agriculture, Berkeley, Calif, USA. 17 pp.

LINTS, F.A. 1961. Diversity by inbreeding in *Drosophila melanogaster.* Genetica 32: 177-199.

PASHLEY, D.P., and BUSH, G.L. 1979. The use of allozymes in studying insect movement with special reference to the codling moth, *Laspeyresia pomonella* (L.) (Olethreutidae). Pages 333-341 *in* Movement of highly mobile insects: concepts and methodology in research, eds. R.L Rabb and G.G Kennedy. Raleigh, NC, USA: University Graphics.

PROSHOLD, F.I. 1974. A yellow pupal body, sex-linked mutant in the tobacco budworm, *Heliothis virescens* (Lepidoptera: Noctuidae). Canadian Entomology 106: 1195-1200.

ROBINSON, A.S. 1977. Genetic control of *Hylemya antiqua.* II. Can inbreeding depression be a serious obstacle to the development of homozygous rearrangement lines? Entomologia Experimental et Applicata 21: 207-216.

ROBINSON, R. 1971. Lepidoptera genetics. New York, USA: Pergamon Press. 687 pp.

SELL, D.K., WHITT, G.S., and LEE, L.K. 1974a. Inheritance of est-II phenotypes in the corn earworm. Journal of Heredity 65: 243-244.

SELL, D.K., WHITT, G.S., METCALF, R.L., and LEE, L.K. 1974b. Enzyme polymorphism in the corn earworm, *Heliothis zea* (Lepidoptera: Noctuidae). Hemolymph esterase polymorphism. Canadian Entomologist 106: 701-790.

SLUSS, T.P., SLUSS, E.S., GRAHAM, H.M., and DUBOIS, M. 1978a. Allozyme differences between *Heliothis virescens* and *H. zea.* Annals of the Entomological Society of America 71: 191 -195.

SLUSS, T.P., ROCKWOOD-SLUSS, E.S., PATANA, R., and GRAHAM, H.M. 1978b. Dietary influenced allozyme differences between laboratory populations *of Heliothis virescens.* Annals of the Entomological Society of America 71: 367-371.

SOUTHWOOD, T.R.E. 1978. Ecological methods. London, UK: Chapman and Hall. 524 pp.

STEINER, W.W.M., and JOSLYN, D.J. 1979. Electrophoretic techniques for the genetic study of mosquitoes. Mosquito News 39: 35-54.

STOCK, M.W. 1979. Genetic markers in applied research on forest Lepidoptera. Pages 328-332 *in* Movement of highly mobile insects: concepts and methodology in research, eds. R.L. Rabb and G.G. Kennedy. Raleigh, NC, USA: University Graphics.

WHITTEN, C.J. 1973. Inheritance of a genetic marker in the tobacco budworm. Annals of the Entomological Society of America 66: 1219-1220.

WOLFENBARGER, DA., RAULSTON, JR., BARTLETT, A.C., DONALDSON, G.E., and LOPEZ, P.P. 1981. Tobacco budworm: selection for resistance to methyl parathion from a field-collected strain. Journal of Economic Entomology 74. (In press.)

YOUNG, J.R. 1979. Assessing the movement of the fall armyworm *(Spodoptera frugiperda)* using insecticide resistance and wind patterns. Pages 344-351 *in* Movement of highly mobile insects: concepts and methodology in research, eds. R.L. Rabb and G.G. Kennedy. Raleigh, NC, USA: University Graphics.

Distribution of *Heliothis armigera* Eggs on Cotton in the Sudan Gezira: Spatial and Temporal Changes and their Possible Relation to Weather

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Abstract

To determine the extent to which the distribution of ovipositing Heliothis armigera *might be "clumpy" rather than random, the numbers of eggs during September-October, the first half of the cotton-growing season throughout the Sudan Gezira, were subjected to analyses of variance. It was found that at any time there was more variability between than within areas, highly significantly so for units of* 600 to *700* km^2*. Within all areas, the numbers of eggs varied very significantly with time, and manyfold increases in numbers of eggs occurred Simultaneously over thousands of square kilometers. In every 3-day period there were two or more significantly different levels of infestation, each extending over areas ranging from a few hundred to several thousand square kilometers; the boundaries of such areas changed continually, and no consistent differences or patterns were found. At all times there were areas with egg numbers below those considered economically serious; this finding has been utilized in new control strategy and tactics that have been effectively implemented both experimentally and commercially. Spraying against larvae appeared also to reduce oviposition for at least* 3 *days, but could account for only some of the differences between areas.*

These findings suggest redistribution of mobile populations of moths over large distances, and the dominant, contemporary, synoptic, and mesoscale weather patterns were considered as possible agencies operating on appropriate scales. The most vigorous systems are the outflows from rainstorms, and a statistically significant relationship was found between *the distribution of rain and of* H. armigera *eggs. In each of the seven seasons 1970-1976, in the 3 days immediately following rainfall that was widespread in the Gezira,* H. armigera *laying at increased density reaching economically significant levels was reported, but over the areas outside and adjoining the rain, and not within the rain area itself. In addition, the seasonal southward movement of the intertropical discontinuity across northern Sudan tends to occur in an irregular series of to-and-fro surges of 400 km' or more in a period of 2 to 5 days; in three* seasons, *the peak laying coincided with one* of these *southward surges and may have been associated with it, but in a manner not yet understood. These two associations are suggested as being of value for forecasting localized areas potentially at greatest immediate risk* of *heavy attack by* H. armigera.

Résumé

*Répartition des oeufs d'*Heliothis armigera *sur le cotonnier dans la région de Gezira au Soudan — modifications spatio-temporelles et relation éventuelle avec la température: Afin de déterminer dans quelle mesure la répartition des oeufs d'*Heliothis armigera *est groupée plutôt que dispersée, le nombre d'oeufs, de septembre à octobre, soit la première moitié de la saison de croissance du cotonnier dans la région de Gezira au Soudan, a fait l'objet d'analyses de variance. On a trouvé qu'en tout temps il y a eu une plus grande variabilité entre les zones qu'à l'intérieur d'elles et de manière fort significative pour des unités de 600 à 700* km^2*. Dans toutes les zones, le nombre d'oeufs a varié très significativement en* fonction du temps et il y a eu une grande prolifération d'oeufs simultanément sur des milliers de kilomètres carrés. *A chaque période de trois jours, il y avait deux ou plusieurs niveaux d'infestation significativement différents, chacun s'étendant sur des superficies allant de quelques centaines à plusieurs milliers de kilomètres carrés; les limites changeaient*

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continuellement, et l'on n'a pas trouve de difference ou systeme consistants. On a toujours trouve des surfaces ayant un nombre d'oeuts sous des seuils consideres comme economiquement graves; cette decouverte a servi dans de nouvelles strategies et techniques de lutte qui ont ete utilisees de maniere efficace tant au niveau experimental que commercial. Une pulverisation contre les larves semblait aussi reduire l'oviposition pour au moins trois jours; mais ne comptait que pour quelques-unes des differences entre les zones.

Ces observations semblent montrer une redistribution des populations mobiles de papillons sur de grandes distances et les regimes meteorologiques dominants, actuals synoptiques et a moyenne echelle seraient des agents eventuels operant sur des echelles appropriees. Les systemes les plus vigoureux sont les pluies violentes etil y a eu une relation statistiquement significative entre la distribution des pluies et les oeufs d'H. armigera. *A chacune des* sept saisons, 1970-1976, dans les trois jours suivant les pluies qui couvraient largement *la region de Gezira,* H. armigera *pondait a une densite accrue atteignant des niveaux economiquement significatifs, mais dans des aires non couvertes par la pluie ou attenantes aux aires pluvieuses, et non dans ces dernieres. De plus, le mouvement saisonnier vers le sud de la discontinuite intertropicale traversant le nord du Soudan tend a se manifester en series irregulieres de mouvements ponctuels de va-et-vient de 400 km^2 ou plus dans une periode de 2 a 5 jours; au cours de trois saisons, le maximum de ponte a coincide avec l'un de ces mouvements puissants vers le sud et pourrait lui etre associe, mais de maniere encore non comprise. Ces deux associations pourraient servir a identifier les zones potentiellement le plus en danger immediat d'etre tortement attaquees par* H. armigera.

In the Sudan Gezira *Heliothis armigera* (Hubner) has been considered a major pest of cotton only since 1965 (Hassan 1970; Joyce 1976b). Its oviposition is generally closely related to the flowering period of its host plants (Pearson 1958), but in the Gezira, although the irrigated cotton remains apparently suitable as a host plant for *H. armigera* until December, eggs are laid on *Gossypium barbadense* in numbers of economic importance only from early September to early November; i.e., from a few weeks after sowing and before the formation of fruiting buds, until after flowering has started in mid-October and the first bolls are forming (Joyce 1976b). Local practice was to use persistent insecticides in the 1970s—about four applications directed against bollworm larvae and two later sprays against other pests, particularly whitefly.

In 1970 a multidisciplinary research project was begun in the Gezira, at the request of the Sudan Ministry of Agriculture, to develop and improve crop-protection methods. Initially, emphasis was laid on detecting the adult stages of insect pests, in particular *H. armigera,* to discover their distribution and potential as spray targets (Joyce 1976b). At the end of 2 years' large-scale field trials it was concluded that timely application of nonpersistent insecticides, applied when *H. armigera* laying was approaching its peak so that the chemical contaminated the plants at the time of maximum hatching, was effective (Russell-Smith, in Haggis 1973).

The biogeographical studies described in the present paper formed part of that project and were undertaken to determine whether any large-scale patterns could be discerned in the distribution of *H. armigera* eggs; in this, full use has been made of the intensive survey data and other findings of the project. Egg counts were used as evidence of recent activity by the female moths, since the eggs hatch in 2 days in the Gezira (Balla 1970), and because the numbers of *H. armigera* attracted to light-traps proved to be very small, limiting the value of this approach (Bowden and Gibbs 1973).

It was first noted in 1970 that throughout the Gezira as a whole, the distribution of *H. armigera* eggs appeared to be "clumpy rather than random; i.e., that when there were high counts in one 'Block', often there were eggs in numbers in adjacent 'Blocks' at about the same time" (Haggis 1970).[1] This inference was tested statistically, using data from later seasons, as described in the first part of this paper (and see Haggis 1981). Variations in the spatial and temporal distribution of *H. armigera* may be related to a number of causes, both biological and physical; better knowledge of them might enable areas under immediate threat to be identified more speedily. The cessation of important egg-

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[1] M.J. Haggis, 1970, Relationship between American bollworm in the Gezira and the Inter-Tropical Front. Report to the Plant Protection Division, Sudan Ministry of Agriculture, November 1970, (unpublished typescript).

laying by *H. armigera* usually closely coincides with the end of the monsoon season and the departure southwards of the intertropical convergence zone, and winds were already known to concentrate or disperse insects of many species (e.g. Rainey 1963, 1976; Johnson 1969); therefore, one aspect of the present studies, described in the second part of this paper, was directed to assessing whether the distribution of ovipositing moths was more closely related to the major windfields and whether these could be used for forecasting, as for the desert locust and African armyworm (Betts 1976). Other associated contemporary studies in the project investigated the distribution of airborne insects in relation to winds (Bowden and Gibbs 1973; Rainey 1976; Schaefer 1976), and the importance of other host plants (Joyce 1976b; Topper 1978).

Description of the Site

The Sudan Gezira is uniquely homogeneous in its topography, climate, farming methods, crops, and pest survey and control practices. It occupies a roughly triangular area of some 25 000 km^2 between the Blue and White Niles and is a featureless clay plain over much of which the gradients are too gentle to be visibly perceptible. The irrigation system described in detail by Allan and Smith (1948), now covers 8400 km^2. Cotton is the most important cash crop, with some 200 000 ha planted annually. The agronomy and farming practices are closely controlled by the Sudan Gezira Board (SGB); for example, sowing is scheduled to take place within a period of 2 weeks over the entire Gezira, around the end of July. Up to 1975 the cotton grown was mainly G. *barbadense,* variety Barakat, with also some earlier flowering *G. hirsutum,* variety Acala, chiefly in the north; both strains are highly resistant to blackarm disease, which at one time was a major problem there. A number of other agronomic changes also have been introduced in recent years: e.g. during the late 1960s to early 1970s, the area of *lubia (Dolichos lablab* L.) sown in September, was progressively replaced with groundnut *(Arachis hypogaea* L.), which is sown in July and begins flowering in late August, and further changes in the rotation greatly reduced the annual acreage of fallow after the mid-1970s.

For administrative and operational purposes, the Gezira is subdivided into more than 100 units called Blocks, which vary in size and comprise between 50 and 400 fields. The size of most fields is 1350 x 280 m (90 feddans or 37.8 ha).

Distribution of *Heliothis armigera* Eggs

Data and Methods

The SGB survey data on *H. armigera* egg counts for each season, 1970 to 1976, and all parts of the irrigated area were extracted from the files of the Chief Entomologist, and the mean numbers of eggs per block were plotted, for most years on daily map series. At this time, insect survey counts were usually expressed as numbers per 3-m row; this was adopted as the basic unit for these analyses, and as spraying was recommended at two or more *H. armigera* eggs or larvae per 3-m (Balla, in Haggis, 1973), this has been used as a convenient reference level. At the standard spacing of 50 x 80 cm and three cotton plants per station, the 3-m row represents 18 plants and a sample of 2.4 m^2. Within each block, usually six such samples were taken in each of six to ten fields at 3- to 6-day intervals. The detailed counts made in individual fields including, since 1973, the intensive survey counts made every 3 days to meet the requirements of the new spray program of the project (Joyce 1975; Russell-Smith 1975), made possible more detailed study by using maps of a scale large enough to permit precise location of each field. These counts were similarly plotted on daily maps. Both map series were designed to show rises and falls as well as actual levels of infestation.

To examine the changing distribution of *H. armigera* eggs through the season, the egg counts of 1971 and 1975 (transformed to logarithms) were subjected to analyses of variance, using 3-day periods (omitting Fridays), as described elsewhere (Haggis 1981). A grid was superimposed on the detailed maps to give respectively units of 600 to 700 km^2 and 800 to 900 km^2, in each of which some 5 to 50 fields were sampled in each 3-day period; for both years the maps of block mean egg counts were divided into seven areas 1000 to 2000 km^2 in extent.

Results

The mean numbers of *H. armigera* eggs in 1971 in each of the eight small grid sections (600-700 km^2) are presented in Figure 1, which shows that there

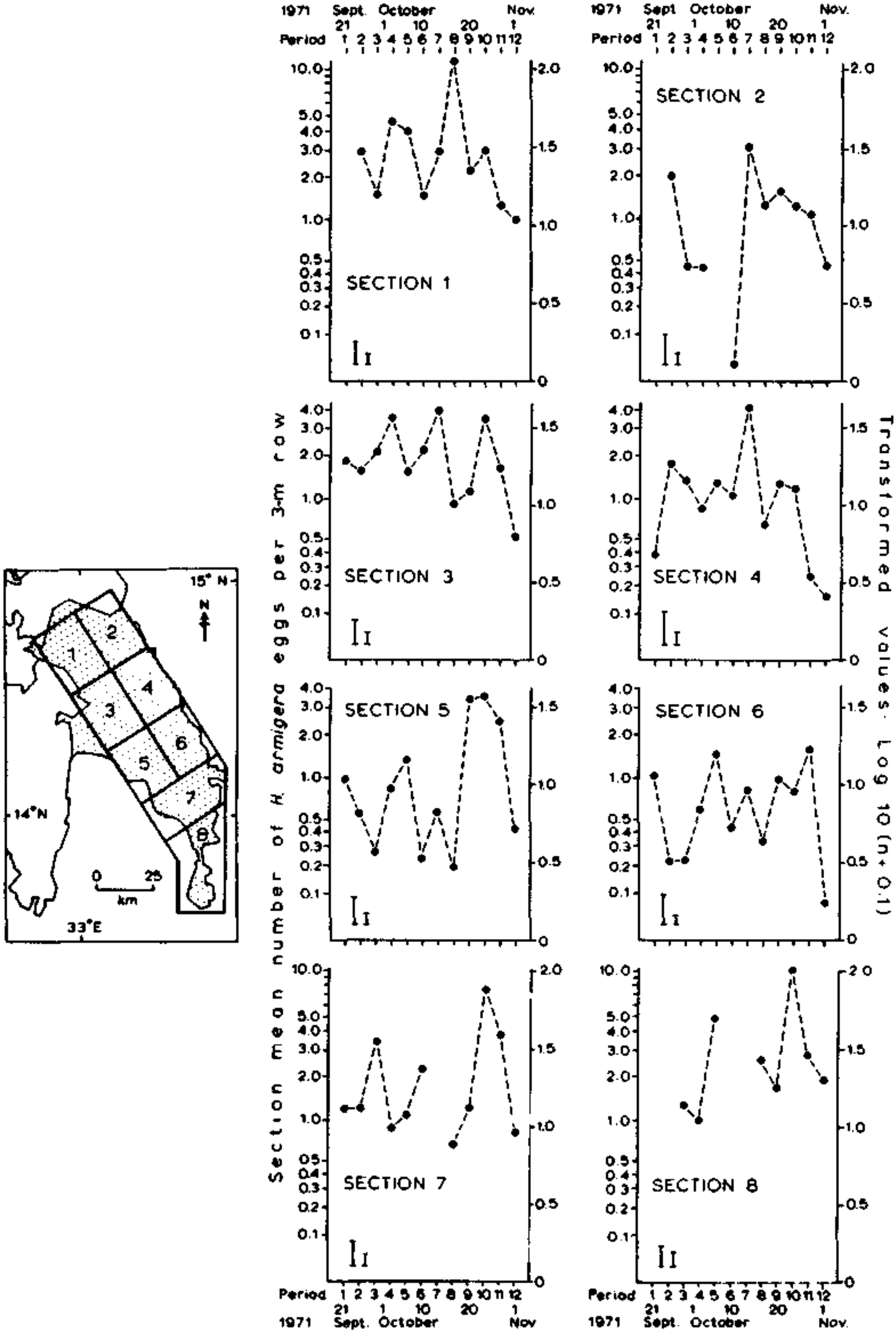

Figure 1. Mean numbers of H. armigera *eggs per 3-m row from 21 September to 1 November 1971, in small sections, showing the largest and smallest standard errors. The map shows the boundaries of the sections over the area (shaded) for which detailed counts were available.*

were conspicuous differences between sections and with time, during the season. The highest and most widespread peak in period 10 (23-25 October) included means of 11.2 eggs per 3 m in Section 8 and 7.6 in Section 7, which together represented the highest egg counts of the season anywhere in the Gezira, although four sections showed little or no increase in numbers at this time. In sections 2, 4, and 6, the density was usually less than two eggs per 3-m row, while in Section 1 it was rarely below this level.

The analyses of these detailed egg counts showed that differences between sections were highly significantly greater (at the 0.1% level) than within them in all periods except the first (5%) and ninth (not significant), and that for each section differences were highly significantly greater (at the 0.1% or 1.0% levels) between periods than within them.

The changing levels of egg numbers in the larger area units for the same period and part of the Gezira are shown in Figure 2; the individual areas are named geographically—North, North-Central, etc. Despite marked differences between north and south, each area showed at times similarities to the area(s) adjacent to it. However, between no two periods was the trend the same in all areas. Tests using least significant differences showed that in all periods except 4 and 6, there were significant differences between two or more of the seven areas, and in all but one period, between areas that were adjacent or adjoining.

Comparison of the curves for the NC, SEC, and SE Areas and those of their constituent sections showed that similarities between them varied with time, and changes in level of infestation in an area could be dominated by the number of eggs in one part, rather than in the whole of it, but that within individual areas of 1000 to 2000 km^2, no one section (600-700 km^2) predominated throughout the season.

Similar analyses of the 1975 block mean egg counts in the same seven areas showed that in this year egg numbers were generally highest in the N Area, where the mean reached a record of 29 eggs per 3-m row during 11 to 13 October; the main laying of the season was at this time in all areas except SEC, where there was a minor peak. Differences between areas were highly significant, at the 0.1 % or 1.0% levels, in 8 of the 12 periods; however, between periods, differences at the 0.1% level were found only in SEC and SE Areas, which were almost entirely covered by the intensive sampling system of the project, and differences at the 1.0% level only in NC, into which the project extended. Analyses of the detailed egg counts of the project area (divided into five sections of 800-900 km^2) for the first half of the season showed that they varied very significantly more (at the 0.1% or 1.0% levels) between sections than within them in four of the six periods, and with time in all five sections. In five of the six periods, two to four sections had mean egg numbers below the level considered as threatening economic loss.

Thus these analyses confirmed the findings from 1971, that over large areas from several hundred to some thousands of square kilometers, the levels of *H. armigera* oviposition on cotton usually varied significantly less within areas than between them; that there were no consistent differences or patterns; that at any time substantial areas had egg numbers below those considered economically serious; and that the boundaries of such areas changed continually.

In a study based on intensive counts over two blocks, it was found that egg numbers were reduced in the period immediately following spraying (Russell-Smith 1975; Joyce 1976b). Although the earlier control measures had been directed against larvae, the present studies found a similar effect in the SGB block mean egg counts of 1971 : of 64 cases in that season where blocks were known to have been counted within 3 days both before and after the date of spraying, only three cases showed any increase in egg numbers immediately after spraying; in 16 cases decreases were by a factor of 10 or more, including 5 by a factor of > 20. Two of the increases were fourfold to > 5.0 eggs per 3 m; one of these, in NC Area, occurred during the mid-October peak; the other, in SE, was during the massive peak there later in the month (Fig. 2), suggesting that in these cases the numbers of moths available to invade the cotton from localities not currently under spraying far exceeded the numbers that may have been killed.

When Sections 1 to 8 of the 1971 analysis were examined to see how far the significant differences between them might be attributable to effects of spraying, it was found that, while this might at least in part account for some of the significant differences between sections, less than half of them could be attributed to this cause. Indeed, some of the differences might have been even more marked in the absence of spraying.

A fuller description of these analyses can be found elsewhere (Haggis 1981).

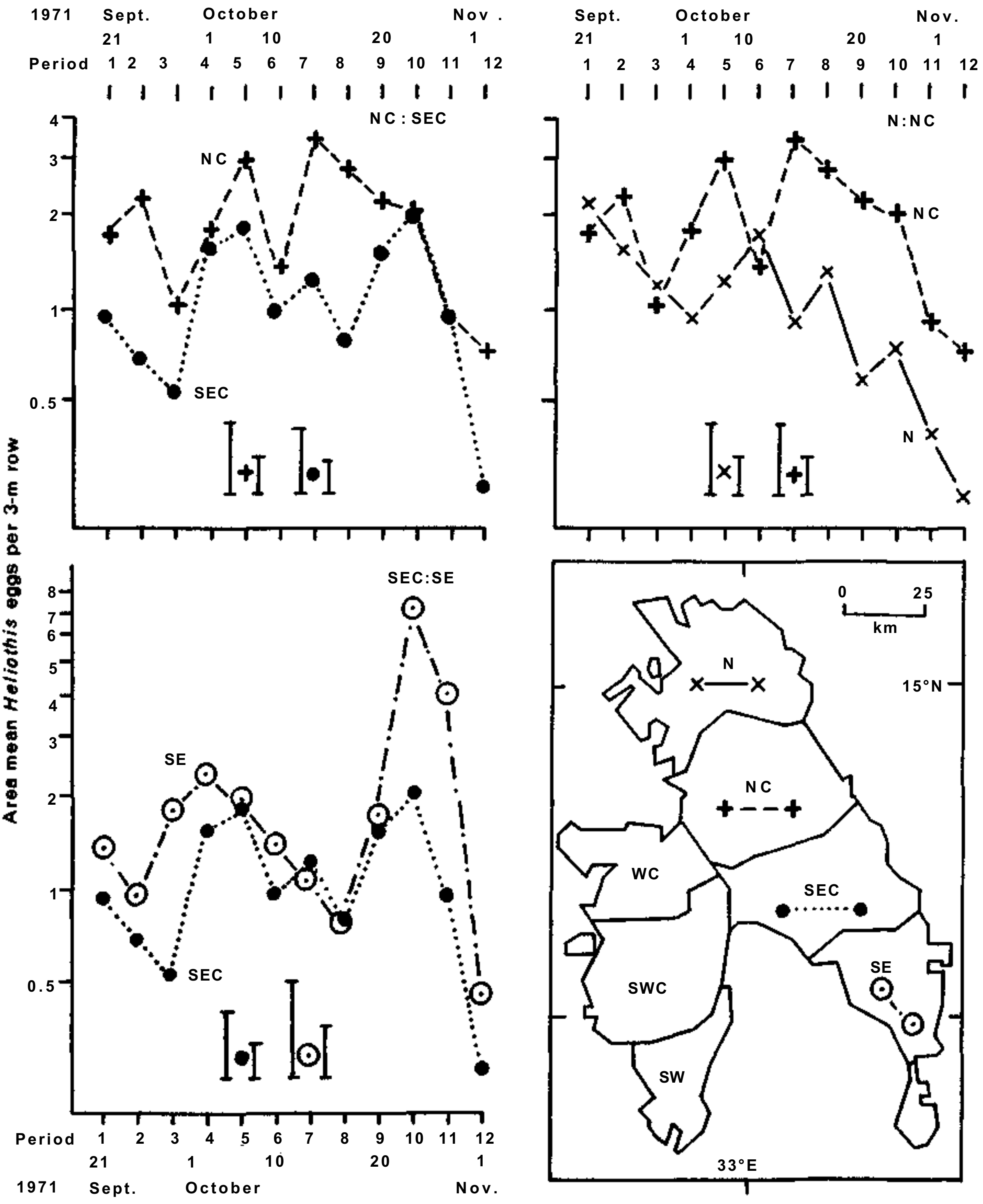

Figure 2. Mean number of H. armigera *eggs per 3-m row from 21 September to 1 November 1971 over large areas of the Old Gezira, showing similarities and differences between adjoining areas. Largest and smallest standard errors for each area shown on relevant graphs and key to areas and symbols on the map.*

Discussion

These analyses are believed to have been the first to consider statistically the distribution of *H. armigera* egg-laying over the 8400 km^2 area of the Gezira as a whole. In 1971 it was found (Joyce 1976b) that over an experimental area of two adjacent blocks (200 km^2) containing 4000 ha of cotton, the numbers of eggs rose and fell synchronously. The present analyses extend this finding to show that over periods of 3 days there was significantly more variability in oviposition between than within areas of 600 to 700 km^2 (i.e., about six times the area of individual blocks), and that frequently such areas of simultaneous rise or fall were of some thousands of square kilometers, but that their boundaries changed continually. Within each period, areas of 1300 km^2 or greater (two or more sections) had egg numbers below the level considered economically threatening. The implications of this finding for control strategy and tactics have already been discussed (Joyce 1975, 1976a). Its particular significance has been to demonstrate that spray aircraft serving in areas with negligible infestation may safely be redeployed temporarily to reinforce operations elsewhere. Since 1973 these tactics, together with the effect of the insecticide on adult moths, have been utilized in the commercial program carried out alongside the research project; the consequent improvement in control has consistently been reflected in the high cotton yields within the project area (Joyce 1978,1980).

On the scales of these analyses and apart from spray effects, no consistent differences or patterns of change were found in the distribution of *H. armigera* eggs. This would conform with the degree of uniformity in the terrain and in the cropping of the irrigated area. Therefore other agents that might influence the distribution of oviposition were considered. Earlier studies had found relationships between the incidence of other pests and rainfall (e.g. Joyce 1961), but this approach initially proved inconclusive for *H. armigera* as counted on irrigated cotton, though some such relationship due to host-plant availability might be expected in the adjacent grasslands across the Blue Nile, where vast numbers of larvae were observed (R.J.V. Joyce and N. Russell-Smith, personal communication). While no association with other host plants could be determined in the early years (Russell-Smith, in Joyce 1976b), in more recent studies made in a single block under the new, more intensive crop rotation (Topper 1978), groundnut was found to be an important breeding area and source of *H. armigera* populations and also to provide local roosting sites by day for moths laying on the neighboring cotton by night. The increase in levels of *H. armigera* infestation requiring corresponding increases in control measures since the introduction of groundnut into the Gezira rotation have been recognized (El Tigani and El Tagib 1978); the role of groundnut in changes in *H. armigera* distribution of the scale and type reported in the present paper merits further study in the light of the relevant agronomic data.

The fact that there can be a simultaneous and sudden onset of widespread and heavy oviposition despite extensive spraying within the same areas—as in SE Area in late October 1971, when there was almost a tenfold increase in egg numbers over 1200 km^2 (Fig. 2)—suggests that those eggs must have been deposited by newly arrived moths from an unsprayed area, for locally emerging ones would have been subjected to insecticide, often before they had time to lay eggs at 3 to 4 days old (Balla 1970). Such oviposition peaks, and similar widespread simultaneous sudden rises in *H. armigera* egg numbers in the new Rahad Scheme to the southeast of the Gezira, recorded in 2 years before groundnut was introduced into the cropping there (R.J.V. Joyce, personal communication), appear likely to be due to mass immigration by moths, possibly over at least tens of kilometers. The highly significant changes in distribution, e.g., between Periods 1 and 2 (21 -27 Sept) in Sections 4 and 6, and between Periods 7 and 8 (12-18 Oct) in Sections 1 and 3 (Fig. 1), when in both cases the Gezira mean egg numbers remained constant or comparable (see Fig. 5), also strongly suggest redistribution of ovipositing moths over similar distances. In other insects mass immigration is associated with particular meteorological conditions operating on comparable scales (Rainey 1963, 1976; Johnson 1969).

Distribution of *H. armigera* Eggs in Relation to Weather

The main weather feature of the Gezira area during September to early November is the retreating intertropical convergence zone (ITCZ) as the southerly monsoon gradually gives way to the northerly trade winds, with the storm cells embedded in the ITCZ system intermittently and briefly superimposing much stronger, but relatively local, windfields on the area. Observations with modified marine radar in the southern Gezira showed that within storm outflow fronts insects could be 60 times more dense than in the air ahead of the front; they appeared on the radar display as a line-echo or arc, up to 20 km ahead of the precipitation and initially accelerating away from it, and coming to a halt only when the storm had decayed (Schaefer 1976). Radar, ground observations, and light-trapping showed that these lines consisted of insects of many species, including moths. Line-echoes from insects, albeit less well marked than those at storm outflows, were observed by the radar in the ITCZ also, at the main wind shift (Schaefer 1976), and the highest numbers of insects of several species were caught in suction traps in the hours when this system passed overhead (Bowden and Gibbs 1973; Russell-Smith in Joyce 1976b).

Description of the Weather

The synoptic-scale weather system dominating the area during September to early November is the intertropical convergence zone (ITCZ), which during the northern summer lies a few hundred kilometers north of Khartoum, separating dry, warmer, northern-hemisphere air from moist, cooler air of southern-hemisphere origin (Osman and Hastonrath 1969). The boundary between the two, now called the intertropical discontinuity (ITD) is frequently very marked at low level (e.g. Rainey 1976; Balogun 1981). Its position can be readily inferred from the surface wind directions and dew points of the regular synoptic observations and is routinely plotted on the surface analyses of the Khartoum Meteorological Department. The southward shift of the ITD, following the sun, begins about mid-September and proceeds in irregular stages with relatively small diurnal fluctuations superimposed.

The rains that accompany its seasonal movements occur from May to October, with amounts decreasing from a mean annual total of 400 mm at Wad Medani in the southeast to 160 mm at Khartoum in the north (Ireland 1948). Local incidence of storms is very irregular: they are more frequent in the central and southern Gezira, as convective clouds, with associated low-level wind convergence, develop where the underlying moist air is sufficiently deep, usually some 300 km to the south of the position of the ITD at the surface (Pedgley 1969). The outflows associated with such meso-scale rainstorms have been identified as the strongest windfields in the Gezira area (Bhalotra 1958, 1959).

Data and Methods

This study was limited to indirect observations on the effects of windfields on the distribution of ovipositing *H. armigera* moths by the absence of a close network of weather stations and of immediate knowledge of the moth's behavioral and physiological responses to physical stimuli, such as changes in humidity. Temperature changes were considered probably too small to be a major influence on moth behavior, since the mean daily range is of only 11 to 14°C in this season and at this latitude (Ireland 1948).

In addition to the insect survey data already described, the distribution of rainfall is recorded in an exceptionally dense network of raingauges operated by the SGB throughout the Gezira, with some 300 gauges within a general area of 10 000 km^2. These could provide circumstantial evidence on possible winds associated with storms, if the rain areas are regarded, on the radar evidence, as centers from which squalls, carrying lines of insects, could have been moving out. Attention was concentrated on occasions when rain was widespread in the Gezira, defined for present purposes as recorded in at least 18 adjacent blocks, i.e., over some 1500 km^2. For each case study the rainfall distribution was mapped in detail. To assess the immediate possible effect of a storm on moth distribution, only those egg counts were used that were made during the 3 days following the rainfall concerned. Although the eggs of some insects may be washed off plants by rain, this effect has not been observed for *H. armigera* in the Gezira (I. Outram, personal communication).

The position of the ITD across eastern Sudan, as plotted on the routine 3-hourly synoptic charts, was made available by the Khartoum Meteorological Department (from 1971 to 1976 transmitted for current use by the project), and plotted on daily maps. As the usual orientation of the ITD over this part of Sudan is approximately northeast-southwest, its movements were measured relative to a line passing through Khartoum and Wad Medani, roughly northwest-southeast, and conveniently representing the long axis of the Gezira. For each of these seasons and 1970 this movement of the ITD was presented graphically, relative to the Khartoum-Wad Medani line; the mean daily numbers of *H. armigera* eggs throughout the Gezira, computed from the block means, were plotted against the same time axes.

Results

Plots of the daily extent of rainfall and the daily numbers of blocks recording economically serious infestations of *H. armigera* eggs showed that the numbers of blocks with many eggs frequently increased immediately after rain in the Gezira. The daily maps of these data showed that, in each year, in the 3 days after widespread rain (as defined), egg numbers were indeed found extensively at increased density, but that the highest counts were generally outside or on the edge of the rain, with only small numbers of eggs recorded within the rain area itself.

For example, on 17 Sept 1973, rain fell in 30 contiguous blocks of the Old Gezira and in 12 blocks of the Managil Extension (Fig. 3). Insect surveys were already in progress in most areas. During 18 to 20 September, *H. armigera* egg numbers increased in many blocks, in 10 blocks to more than double the numbers counted during the previous 3 days. All the high counts were outside the main rain areas; the daily maps showed that within the rain areas, in four blocks egg numbers fell to half their earlier value, and three blocks that recorded markedly increased numbers nevertheless had mean egg counts below the reference level of two eggs per 3 m. In the central Managil, some egg numbers may have been suppressed by spraying, which was completed immediately before the counts were made. In many of the blocks unshaded on Figure 3, no counts were made because spraying was in progress 16 to 19 October.

There were altogether 17 occasions over the seven seasons 1970 to 1976 when rain was widespread (as defined) and the insect counts were adequate for statistical treatment. Analyses of variance showed a significant (5%) interaction between the numbers of eggs inside and those on the edge of and outside the rain areas immediately before and after the rain: while egg numbers increased outside and on the edge of the rain, over the next 3 days oviposition within the rain area continued at the same level as before the storm. However, this effect did not persist, and in the following 3-day period egg numbers within and on the edge of the rain areas increased sharply to exceed those outside (Fig. 4). Visual inspection of the less complete plots for a further four occasions suggested a similar egg distribution pattern for three of them.

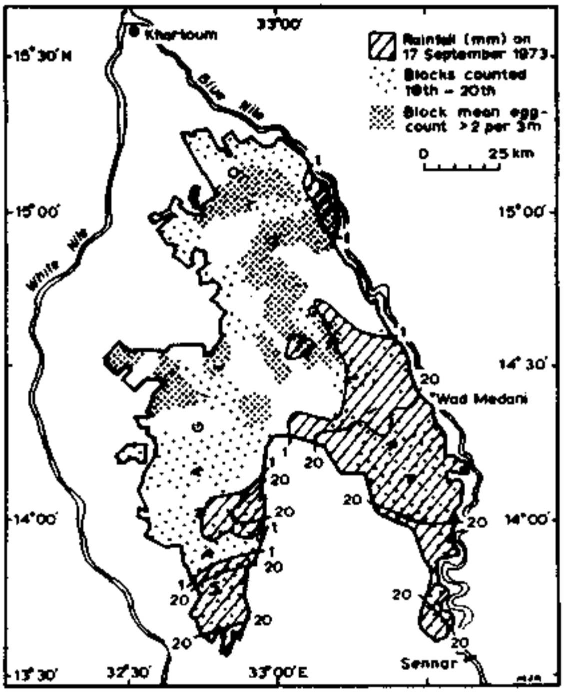

Figure 3. Distribution of rainfall on 17 September 1973 and mean numbers of H. armigera *eggs in blocks counted from 18 to 20 September.*

An example of the irregularity of the displacements of the ITD is provided in Figure 5, in which the upper line represents the movements of the ITD relative to the Khartoum-Wad Medani line, and the map has been skewed accordingly. The lower curve represents the daily mean numbers of *H. armigera* eggs throughout the Gezira, and attention is drawn to the very close agreement repeatedly shown between the mean numbers on successive days, for which the figures relate to sampling in completely different sets of blocks.

The coincidence over 4 to 5 days of increased *H. armigera* laying (the season's peak) and a strong southward surge of the ITD from far north of the Gezira beyond Atbara to south of Sennar (400-500 km) was first noted in 1970. There were similar coincidences in each of the four subsequent seasons, although in three cases they occurred near the start of the season, when an increase in egg

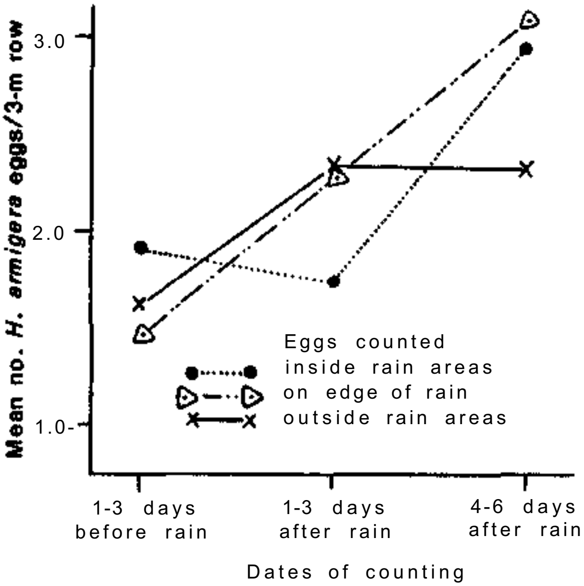

Figure 4. Numbers of H. armigera *eggs before and after widespread rainfall in the Gezira: means of 17 occasions, 1970-1976.*

numbers could have been expected. However in 1971 and 1973 the heaviest laying of the season again coincided with the most extensive southward movement of the ITD. In 1971 this was near the end of the season: while the ITD moved 600 km from around Atbara at 0000 GMT on 22 October to south of Roseires by 0600 GMT on 25 October (Fig. 5), altogether 40 blocks reported economically significant numbers of eggs; four blocks with means of > 10 per 3 m and nine with means of > 5 eggs per 3 m were counted in 2 days, and the heavy oviposition was concentrated in the southeastern Gezira. The significance of this peak and the distribution of the eggs has already been discussed (Fig. 2 and Haggis 1981).

It was also noted in 1970 that when blocks reported high numbers of *H. armigera* eggs-above 5 per 3-m row—most often the ITD was close over these blocks, and that high mean egg counts also occurred when the ITD lay to the north of the blocks concerned, but not when it was to the south. In 1971 (using the 1000 to 2000 km^2 areas of the earlier analyses), out of 80 area/periods, there were 17 when the area mean egg count exceeded two per 3-m row. For nine of these, on one or more of the nights when the eggs would have been laid, the ITD had been over the area at 1800 GMT, and for seven others, the ITD was moving rapidly southwards into or across the Gezira. The exception was SE Area in Period 11 (26-28 Oct): the ITD had traversed the Gezira immediately prior to this period, when it remained to the south beyond Sennar, and egg numbers, which were generally declining, remained high in the southeast (Figs. 2 and 5).

Discussion

Direct evidence of the influence of windfields on flying insects in the Gezira has come from trapping and radar studies (Bowden and Gibbs 1973; Rainey 1976; Schaefer 1976). The present studies of more indirect, circumstantial evidence have likewise found significant association between the distribution of ovipositing *H. armigera* moths and the contemporary weather. The rainstorms considered here certainly will have caused brief disturbances in the windfield—mainly in the first half of the night, when the moths are most active—and the radar observations have suggested a plausible mechanism that could at least in part explain the significant spatial pattern found, even though the exact cause of egg laying temporarily increasing only outside and on the edge of areas of rainfall is not yet understood. Whatever the causes, the finding could still be of value for forecasting localized areas of potential major attack, such as in Figure 3, if immediate knowledge were available of the daily rainfall distribution, e.g., as observed by weather radar. This would enable the main survey effort to be concentrated outside the rain areas and in the areas where laying is likely to be heaviest, thereby identifying more quickly the zones of serious egg infestation most immediately requiring control.

The apparent association between *H. armigera* laying and movements of the ITD is difficult to assess, for there is no obvious mechanism for concentrating insects ahead of the system when it is moving southwards. It may still be valid to anticipate a general increase in oviposition at such a time; indeed, one was tentatively forecast by the author and the late N. Russell-Smith on 6 Oct 1973, at the beginning of the main ITD movement and before the initial rise in egg numbers, heralding the peak laying of that season, was reported. A similar forecast in early October 1976 was less successful, for although the ITD moved south 800 km from Wadi Haifa into the Gezira, *H. armigera* egg numbers remained very low, both through that period and for the rest of the season.

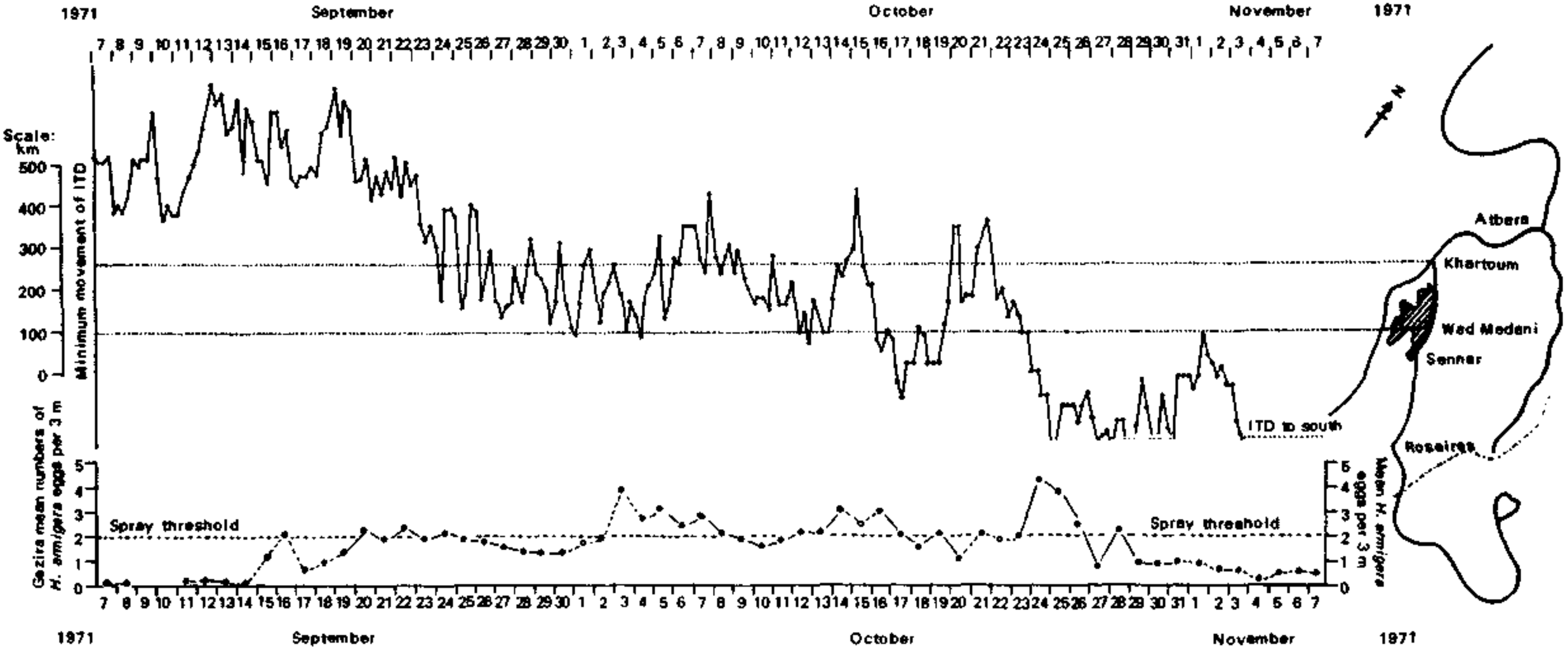

Figure 5. *Six-hourly positions of the inter-tropical discontinuity (ITD) relative to the Khartoum-Wad Medani line, and mean numbers of H. armigera eggs counted daily throughout the Gezira, 7 Sept-7 Nov 1971. Extent of Gezira scheme shaded on upper graph.*

General Conclusions

The distribution of *H. armigera* oviposition in the Sudan Gezira has been found to vary significantly less within than between areas that extended over hundreds to thousands of square kilometers, but whose boundaries changed continually. At all times there were areas where egg numbers were below the economic threshold. These findings have proved of value for control strategy and tactics. The spatial and temporal associations found between *H. armigera* oviposition and rainfall and perhaps also the ITD are considered sufficiently strong to be of immediate value for forecasting where and when potentially serious attacks may occur, even though the mechanisms for these associations are not yet understood and require further research.

Acknowledgments

Thanks are particularly due to Professor R.J.V. Joyce, the Research Director of the project in the early 1970s, and to his successor and other members of the team, for their help and stimulating discussions over the years, and to Miss S.M.Green, Statistician at COPR, for invaluable guidance on the treatment and presentation of the data. The data and other facilities provided by the Sudan Gezira Board, by the Sudan Meteorological Department, and by CIBA-GEIGY, who also sponsored the fieldwork, are gratefully acknowledged.

References

ALLAN, W.N., and SMITH, R.J. 1948. Irrigation in the Sudan. Pages 593-632 *in* Agriculture in the Sudan, ed. J.D. Tothill. London, UK: Oxford University Press. 974 pp.

BALLA, A.N. 1970. American bollworm in the Gezira and Managil. Pages 281-292 *in* Cotton growth in the Gezira environment: a symposium to mark the 50th anniversary of the Gezira Research Station, eds. M.A. Siddiq and L.C. Hughes. Wad Medani, Sudan: Agricultural Research Corporation. 318 pp.

BALOGUN, E.E. 1981. Seasonal and spatial variations in thunderstorm activity over Nigeria. Weather (London) 36: 192-197.

BETTS, E. 1976. Forecasting infestations of tropical migrant pests: desert locust and the African armyworm. Pages 113-118/ in Insect flight, ed. R.C. Rainey. Symposia of the Royal Entomological Society of London 7, Oxford, UK: Blackwell.

BHALOTRA, Y.P.R. 1958. Dust storms at Khartoum. Sudan Meteorological Service Memoir 1, Sudan Survey Department, Khartoum, Sudan. 74 pp.

BHALOTRA, Y.P.R. 1959. Adverse weather conditions at Khartoum, El Obeid and Wadi Haifa. Sudan Meteorological Service Memoir 2, Sudan Survey Department, Khartoum, Sudan. 112 pp.

BOWDEN, J., and GIBBS, D.G. 1973. Light-trap and suction-trap catches of insects in the northern Gezira, Sudan in the season of southward movement of the Inter-Tropical Front. Bulletin of Entomological Research 62: 571 -596.

EL TIGANI, M., and EL TAGIB, M. 1978. Development of crop protection in the Sudan, with special reference to application of ULV and water-based insecticides. Pages 149-163 *in* Proceedings, Fourth Scientific Conference on Chemicalisation of Plant Production in the Tropics and Subtropics, Volume 3. Institut fur tropische Landwirtschaft, Karl-Marx Universitat, Leipzig, German Democratic Republic.

HAGGIS, M.J. 1973. Insect flight and its relevance to the strategy of control of insect pests of cotton in the Sudan Gezira. Pest Articles and News Summary 19:419-421.

HAGGIS, M.J. 1981. Spatial and temporal changes in the distribution of eggs of *Heliothis armiger* (Hubner) (Lepidoptera: Noctuidae) on cotton in the Sudan Gezira. Bulletin of Entomological Research. 71: 181-193.

HASSAN, H.M. 1970. Progress in chemical control of pests of cotton in the Gezira. Pages 232-246 *in* Cotton growth in the Gezira environment: A symposium to mark the 50th anniversary of the Gezira Research Station (eds. MA. Siddiq and L.C. Hughes), Wad Medani, Sudan: Agricultural Research Corporation. 318 pp.

IRELAND, A.W. 1948. The climate of the Sudan. Pages 62-83 *in* Agriculture in the Sudan, ed. J.D. Tothill. London, UK: Oxford University Press. 974 pp.

JOHNSON, C.G. 1969. Migration and dispersal of insects by flight. London, UK: Methuen. 763 pp.

JOYCE, R.J.V. 1961. Some factors affecting numbers of *Empoasca lybica* (De Berg.) (Homoptera: Cicadellidae) infesting cotton in the Sudan Gezira. Bulletin of Entomological Research 52: 191 -232.

JOYCE, R.J.V. 1975. The implications to control strategy of the observed flight activity of pest species in the Sudan Gezira. *In* Proceedings, Seminar on the Strategy for Cotton Pest Control in the Sudan Gezira. CIBA-GEIGY, Wad Medani, Sudan.

JOYCE, R.J.V. 1976a. Sequential aerial spraying of cotton at ULV rates in the Sudan Gezira as a contribution to synchronised chemical application over the area occupied by the pest population. Pages 47-54 *in* Proceedings, Fifth International Agricultural Aviation Congress. International Agricultural Aviation Centre, UK. 403 pp.

JOYCE, R.J.V. 1976b. Insect flight in relation to problems of pest control. Pages 135-155 *in* Insect flight (ed. R.C. Rainey). Symposia of the Royal Entomological Society of London 7. Oxford, UK: Blackwell.

JOYCE, R.J.V. 1978. Yield response of *Gossypium barbadense* in the Sudan Gezira to aerial spraying at ULV rates with Nuvacron 40® Pages 229-242 *in* Proceedings, Third Seminar on the Strategy for Cotton Pest Control in the Sudan. CIBA-GEIGY, Basel, Switzerland. 357 pp.

JOYCE, R.J.V. 1980. Aircraft equipment and biological objectives. Pages 13-22 *in* Trends in airborne equipment for agriculture and other areas. Aero-Agro 1978. Proceedings of a Seminar Organized by the United Nations Economic Commission for Europe. 18-22 Sept 1978, Warsaw, Poland. Oxford, UK: Pergamon Press. 358 pp.

OSMAN, O.E.,and HASTENRATH, S.L. 1969. On the synoptic climatology of summer rainfall over central Sudan. Archiv fur Meteorologie, Geophysik und Bioklimatologie, Serie B 17: 297-324.

PEARSON, E.O. 1958. The insect pests of cotton in tropical Africa. London, UK: Empire Cotton Growing Corp. and Commonwealth Institute of Entomology. 355 pp.

PEDGLEY, D.E. 1969. Diurnal variation of the incidence of monsoon rainfall over the Sudan: Part I and II. Meteorological Magazine (London) 98: 97-107,129-134.

RAINEY, R.C. 1963. Meteorology and migration of desert locusts: applications of synoptic meteorology in locust control. World Meteorological Organization Technical Notes 54. Geneva, Switzerland: WMO.

RAINEY, R.C. 1976. Flight behavior and features of the atmospheric environment. Pages 75-112 *in* Insect flight (ed. R.C. Rainey). Symposia of the Royal Entomological Society of London 7. Oxford, UK: Blackwell. 287 pp.

RUSSELL-SMITH, N.A. 1975. The distribution and sampling of *Heliothis armigera* (Hb.) eggs on cotton in the Sudan Gezira. *In* Proceedings, Seminar on the Strategy for Cotton Pest Control in the Sudan Gezira. CIBA-GEIGY, Wad Medani, Sudan.

SCHAEFER, G.W. 1976. Radar observations of insect flight. Pages 157-197 *in* Insect flight (ed. R.C. Rainey). Symposia of the Royal Entomological Society of London 7. Oxford. UK: Blackwell. 287 pp.

TOPPER, C. 1978. The incidence of *Heliothis armigera* larvae and adults on groundnuts and sorghum and the prediction of oviposition on cotton. Pages 17-33 *in* Proceedings, Third Seminar on the Strategy for Cotton Pest Control in the Sudan. CIBA-GEIGY, Basel, Switzerland.

Discussion — Session 2

Dr. Hartstack confirmed that there was good correlation between trap catches of moths and oviposition in crops in the area of more than 1000 ha of land under his study in the USA. This had not yet been extended to an area that was anywhere near the size of the Sudan Gezira. Oviposition and the subsequent populations of larvae are known to be influenced by many factors, including rainfall, irrigation and other cultural practices, and parasites and predators. The individual effects of each element have yet to be quantified, but generalizations can be useful for modeling. It is not essential that all the factors affecting *Heliothis* populations be fully quantified before a model can become useful.

When asked what proportion of *Heliothis* moths in any population migrate, Dr. Raulston could give no precise data; however, he said that Drs. Hughes and Fisher are currently studying the movement of *Heliothis* moths from the ground to different levels in the atmosphere. They are also recording the activity of moths in different crops by observation and trapping. The migration of moths to the southern USA is also being studied.

Dr. Bartlett did not think that the disruption of long-range migrations of moths would reduce the vigor of a species by reducing genetic mixing. Most local populations already contain a great deal of genetic variation, as shown by electrophoretic analysis. Random mating within the population would maintain that heterozygosity in the Hardy - Weinberg equilibrium. Isozyme analysis is a convenient means of measuring genetic variability and should be used to distinguish geographic populations in order to determine how important and extensive migration really is. There is no evidence that strains carrying genetic markers are electropnoretically distinguished from the wild strains of Heliothis.

It is not clear whether rainfall directly stimulates oviposition by *Heliothis* or whether it does so indirectly, by stimulating crop growth, which then attracts oviposition. Dr. Haggis commented that there appear to be differential ovipositional responses to rainfall in irrigated and unirrigated fields. Work in the USA has shown an increased nectar flow in cotton after rainfall, which could influence moth feeding and subsequent oviposition. But heavy rainfall could also wash the eggs off plants.

The moth populations of the Sudan Gezira are not isolated, for they are known to be affected by migration from outside the area. Within the Gezira, *Heliothis* feeds on a range of crops, including cotton, groundnut, and sorghum. There is substantial movement of populations between these crops. There appear to have been no other intensive studies of oviposition by populations *of Heliothis* on an area as large as the Gezira anywhere else in the world, but attempts are being made to monitor migrations of moths over large areas of USA.

Session 3

Natural and Biological Control Elements

Chairman: B.R. Wiseman

Cochairman: N.N. Ramakrishnan

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Prospects for Utilization of Parasites and Predators for Management of *Heliothis* Spp

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Abstract

Naturally occurring predators and parasites (natural enemies) are important in regulating populations of Heliothis*. Explicit instructions in insect control guides, developed through qualitative and quantitative evaluations of natural enemies, are needed so that natural enemy numbers can be used more directly in decision-making. Many species of natural enemies of* Heliothis *have been identified in every country where a search has been conducted. Frequently,* Heliothis spp *egg and larval parasitism levels are high, but a critical analysis must be conducted to* assess *the actual contribution of each species to* Heliothis *population regulation. Opportunities exist for importing and establishing exotic natural enemies in vacant niches (e.g., unattacked life stages, certain habitats or host plants), for displacing natural enemies that do not contribute to population regulation by more effective ones, and for establishing natural enemies that have pesticide tolerance. Where natural enemy numbers are inadequate for maintaining* Heliothis *populations at subeconomic levels, augmentation may be feasible. Performance of lower numbers of parasites may be improved by application of behavioral chemicals to mimic high host populations. Nevertheless, inexpensive rearing procedures, such* as *in vitro rearing, that result in a vigorous parasite or predator with essential behavioral characteristics intact over time, will have to be developed before augmentation by rearing and periodic release is economically feasible for most parasites and predators.*

Résumé

Perspective d'utilisation de parasites et prédateurs dans la lutte contre Heliothis *spp: Les prédateurs et parasites naturels (ennemis naturels) sont importants dans la limitation des populations d'*Heliothis*. Des instructions explicites dans les guides de lutte contre les insectes, basées sur des évaluations qualitatives et quantitatives des ennemis naturels, sont nécessaires, afin que le nombre d'ennemis naturels puisse servir plus directement à une prise de décision. Dans tous les pays où des recherches ont été faites, il a été possible d'identifier plusieurs espèces d'ennemis naturels d'*Heliothis*. Souvent, les niveaux de parasitisme des oeufs et des larves d'*Heliothis *spp sont élevés, mais il faut effectuer une analyse critique pour évaluer la contribution réelle de chaque espèce à la limitation des populations d'*Heliothis*. Il serait possible d'importer et d'établir des ennemis naturels exotiques dans des niches vacantes (ex: stades de vie non attaqués, certains habitats ou plantes-hôtes), ainsi que de remplacer des ennemis naturels qui ne contribuent pas à la limitation des populations par d'autres plus efficaces et d'introduire des ennemis naturels ayant une tolérance aux pesticides. Une augmentation est réalisable là où le nombre d'ennemis naturels est insuffisant pour maintenir les populations d'*Heliothis *à un niveau sous-économique. La performance de petits nombres de parasites peut s'améliorer en utilisant des produits chimiques de comportement permettant de simuler une densité élevée des populations hôtes. Néanmoins, il faudra d'abord mettre au point des techniques d'élevage peu coûteuses, tel l'élevage in vitro, fournissant des parasites ou prédateurs vigoureux doués de caractéristiques de comportement essentielles et durables, avant que l'augmentation par l'élevage et les lâchers périodiques soient économiquement viables pour la majorité des parasites et prédateurs.*

Heliothis spp feed on a wide range of wild and cultivated plants. Both wild and cultivated host plants are important because they contribute to maintenance and increase of *Heliothis* populations; however, cultivated host crops (cotton, maize, soybeans, sorghum, groundnut, pigeonpea,

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chickpea, tobacco, and tomatoes and other vegetables) are of primary concern, because of their economic value. In the USA alone, annual losses of over one billion dollars are attributed to *Heliothis,* and numerous other countries (e.g., India and Australia) experience similar high losses (see other papers in these Proceedings).

Heliothis larvae compete with man for food and fiber, usually directly, by attacking the fruiting forms. Typically, the most severely damaged crops are the cultivated annuals, which tend to compose an unstable agroecosystem. To further compound the problem, high-yielding cultivars are often selected without regard to *Heliothis* resistance, thus often requiring higher levels of pesticides, which are usually detrimental to natural enemy populations.

Nevertheless, naturally occurring predators and parasites are important in regulating numbers of *Heliothis* (Quaintance and Brues 1905; Fletcher and Thomas 1943; Ewing and Ivy 1943; Whitcomb and Bell 1964; Van den Bosch and Hagen 1966; Ridgway et al. 1967; Lingren et al. 1968; Van den Bosch et al. 1969). In the absence of insecticides, these natural enemies often maintain *Heliothis* populations at subeconomic levels in most crops. Where this fails to happen because of inadequate numbers of natural enemies, augmentation of beneficials may be feasible. Introduction and establishment of more effective natural enemies also has potential. We summarize here the status of the use of predators and parasites for *Heliothis* control, attempt to synthesize this information, and suggest priority research for the future.

Distribution and Abundance of *Heliothis* Spp

The genus *Heliothis* Ochsenheimer may contain the most economically important group of insects in the world (Kogan et al. 1978). The corn earworm complex was examined by Hardwick (1965), who defined the following five species groups within his new genus *Helicoverpa: punctigera, gelotopoeon, hawaiiensis, armigera,* and *zea.* Although 17 species were placed in *Helicoverpa* Hdwk. (Hardwick 1965), all species are discussed herein under the genus *Heliothis.* Hardwick's (1970) generic revision of the North American Heliothidinae, in which 158 species in 14 genera were listed, included one *Helicoverpa* and 13 *Heliothis* spp. This list was extensive because it included the genus *Schinia* Hbn. with 134 species. Todd (1978) also listed 14 *Heliothis* species for North America (excluding Hawaii), treating *Helicoverpa* as a synonym of *Heliothis;* 13 species were common to Hardwick's (1970) list. Seventy-eight species and subspecies of world *Heliothis* (excluding *Schinia) were* listed by Todd (1978), for which he cross-indexed 154 species-group names.

Western Hemisphere

Heliothis zea and *H. virescens* are distributed widely over North, Central, and South America, where they are economically important (Kogan et al. 1978). In the USA, these two species are most abundant in the southeast, with importance decreasing north and west of this region (Stinner et al. 1980). The *H. zea* to *H. virescens* ratio fluctuates greatly according to year, location, host crop, and crop phenology. Other North American *Heliothis* (Hardwick 1970; Todd 1978) are less abundant and limited in distribution. *Heliothis subflexa* (Guenee) is not economically important, and is known to feed only on ground cherry, *Physalis* spp; it is well known for its hybridization with *H. virescens* under laboratory conditions (Laster 1972). The distribution of *H. subflexa* ranges from Mississippi to Texas (Mississippi: Smith et al. 1976a; Louisiana and Arkansas: Brazzel et al. 1953; Texas: M I. Laster, Entomologist, Delta Branch Experiment Station, Mississippi Agricultural and Forestry Experiment Station, Stoneville, Mississippi, personal communication), Mexico (M I. Laster, personal communication), South America (Colombia: Hallman 1980), and on the island of St. Croix (M.L. Laster, personal communication).

In South America, *H. zea* is distributed more widely than *H. virescens* (Kogan et al. 1978). The *gelotopoeon* group (four species) is endemic to South America. *Heliothis gelotopoeon* (Dyar) is economically important in Argentina (Hardwick 1965) and coexists with *H. atacamae* (Hdwk.) in central Chile. The latter species inhabits arid regions of southern Peru and northern and central Chile.

Eastern Hemisphere

The most important agricultural pest in the eastern hemisphere is *H. armigera* Hb. (Hardwick 1965). This species occurs widely in Europe, much of

Africa, India, Asia, New Zealand, Australia, and on several Pacific Islands. In Africa, *H. armigera* occurs with *H. assulta* Guenee, *H. fletcheri (Hdwk.)* and *H. toddi* (Hdwk.). Only the endemic *H. helenae* (Hdwk.) occurs on St. Helena Island, but H. *assulta, H. pacifica* (Hdwk.), *H. minuta* (Hdwk.), *H. confusa* (Hdwk.), *H. hawaiiensis* Quaint. and Brues, and *H. pallida* (Hdwk.) occur on the Pacific Islands, in addition to *H. armigera.*

In Australia, *H. armigera* is limited mainly to the coastal and subcoastal areas of eastern Australia and the North Territory (Common 1953). However, the indigenous *H. punctigera* Wallengren is widely distributed, and occurs in every state. These two species cause economic damage to many fruit, vegetable, and ornamental crops. *Heliothis* spp were reported in 1928 (Lea) to be a chief pest of lucerne in South Australia. Two *Heliothis* species that are not of pest status in Australia are *assulta* and *rubrescens* (Walker) (Common 1953).

Heliothis spp are of considerable economic importance on many Egyptian crops (Ibrahim 1980). *H. armigera* is most abundant throughout Egypt, but *peltigera* (Denis and Schiff.) also occurs widely, while *H. nubigera* Herrick-Schaffer is more limited in distribution. In India, *H. armigera* has a wide distribution and causes serious losses in many crops (Rao 1974), while *H. assulta* and *H. peltigera* have limited host ranges and distribution. In Japan, *H. viriplaca adaucta* Btlr. coexists with *H. armigera* where their geographic ranges overlap (Stinner et al. 1980).

Natural Enemies of *Heliothis* Spp

Parasites and predators that occur with *Heliothis* spp in the USA and in other parts of the world are discussed below.

Parasites in the USA

The value of natural control agents, particularly parasites in regulating pest species is becoming more apparent as research is conducted. The principal parasites that contribute to mortality of *Heliothis* eggs and larvae are shown in Table 1. The importance of egg and larval parasites of *H. zea* was recognized by Quaintance and Brues in 1905.

Table 1. Principal parasites of *Heliothis* app.

Parasite	Reference
USA	
Hymenoptera: Braconidae	
Apanteles marginiventris (Cresson)	Ridgway and Lingren 1972
Cardiochiles nigriceps (Vierick)	Snow et al. 1966: Lewis and Brazzel 1968
Microplitis croceipes (Cresson)	Snow et al. 1966: Lewis and Brazzel 1968
Hymenoptera: Ichneumonidae	
Campoletis sonorensis (Cameron)	Lingren et al. 1970
Hymenoptera: Trichogrammatidae	
Trichogramma pretiosum Riley	Graham 1970: Oatman and Platner 1971
Trichogramma exiguum Pinto & Platner	King et al., unpublished data
Diptera: Tachinidae	
Archytas marmoratus (Townsend)	Shepard and Sterling 1972
Eucelatoria bryani Sabrosky	Bottrell et al. 1968
Australia	
Hymenoptera: Braconidae	
Microplitis demolitor Wilkinson	Hafez 1951
Hymenoptera: Ichneumonidae	
Heteropelma scaposum (Morley)	M. Shepard, personal communication

Continued

Table 1. *Continued*

Parasite	Reference
India	
Hymenoptera: Braconidae	
Bracon brevicornis Wesm.	Achan et al. 1968
Hymenoptera: Ichneumonidae	
Campoletis chlorideae Uchida	Rao 1974
Eriborus sp	Rao 1974
Hymenoptera: Trichogrammatidae	
Trichogramma spp	Rao 1974
Diptera: Tachinidae	
Carcelia illota (Curran)	Rao 1974
Goniophthalmus halli Mesnil	Rao 1974
Palexorista laxa (Curran)	Rao 1974
Europe	
Hymenoptera: Braconidae	
Apanteles kazak Telenga	Carl 1978
Hymenoptera: Ichneumonidae	
Hyposoter didymator (Thunb.)	Carl 1978
Israel	
Hymenoptera: Ichneumonidae	
Hyposoter didymator (Thunb.)	Rossler et al. 1975
Egypt	
Hymenoptera: Braconidae	
Apanteles spp	Ibrahim 1980
Microplitis rufiventris Kok	Ibrahim 1980
Brecon brevicornis Wesm.	Ibrahim 1980
Barylypa humeralis Brauns.	Ibrahim 1980
USSR	
Hymenoptera: Braconidae	
Bracon brevicornis Wesm.	Habib 1973
Apanteles kazak Telenga	Habib 1973
Hymenoptera: Trichogrammatidae	
Trichogramma evanescens W.	Habib 1973
South Africa	
Hymenoptera: Braconidae	
Apanteles spp	Habib 1973
Bracon brevicornis Wesm.	CIBC 1978
Cardiochiles nigricollis (Cam.)	Habib 1973
Hymenoptera: Ichneumonidae	
Charops spp.	Habib 1973
Diptera: Tachinidae	
Palexorista laxa (Curran)	Habib 1973
Goniophthalmus halli Mesnil	Habib 1973

They found that the egg parasite, *Trichogramma pretiosum* Riley, and the larval parasite *Microplitis croceipes* (Cresson) (= *nigripennis* Ashmead) (Krombein et al. 1979) were the most frequently encountered hymenopterans attacking *H. zea* in Texas. They reported that *M. croceipes,* which was common in the fields late in the season, was responsible for lowering the *H. zea* larval populations at that time of year. Although tachinids occurred, they were ineffective against large *Heliothis* populations.

Surveys made in 1969 and 1970 of the parasites of *Heliothis* spp in cotton in Texas by Shepard and Sterling (1972) showed that larval parasites accounted for approximately 7% regulation of *Heliothis* spp. They found that *Cardiochiles nigriceps* Vierick and *Archytas marmoratus* (Townsend) were most abundant, with *Apanteles marginiventris* (Cresson), *M. croceipes,* and *Eucelatoria bryani* Sabrosky (= *armiger* [Coquillet]) (Sabrosky 1981) appearing less frequently; the egg parasite *T. exiguum* Pinto and Platner (= *fasciatum* [Perkins]) (Pinto et al. 1978) emerged from only 1 % of *Heliothis* eggs collected. Van den Bosch and Hagen (1966) and Graham (1970) pointed out the importance of *T. pretiosum* Riley (= *semifumatum* [Perkins]) (Pinto et al. 1978) in *Heliothis* egg mortality in Texas and California.

Butler (1958a) reported that the only braconids attacking *Heliothis* spp in Arizona were *M. croceipes* and *Chelonus insularis* Cresson (= *texanus* Cresson) (Krombein et al. 1979), while *E. bryani* (Butler 1958b) was the primary tachinid. In Oklahoma, the only important parasite of *H. zea* in cotton was *M. croceipes,* while others common in *H. zea* and *H. virescens* included C. *insularis, E. bryani, Lespesia archippivora* (Riley), and *A. marmoratus* (Bottrell et al. 1968; Young and Price 1975).

In surveys by Snow et al. (1966) of *Heliothis* spp larval populations on *Geranium carolinianum* L. in South Carolina, Mississippi, and Georgia, and in cultivated and wild host plants by Lewis and Brazzel (1968) and Smith et al. (1976a) in Mississippi, *Cardiochiles nigriceps* and *M. croceipes* were most common. However, C. *nigriceps* did not develop in *H. zea.* Roach's (1975) survey in northeastern South Carolina revealed that only C. *nigriceps* and *Campoletis* spp occurred in sufficient numbers to affect *Heliothis* populations. Likewise in North Carolina, C. *nigriceps* and *Campoletis sonorensis Cameron were* most commonly reared from *Heliothis* spp in summer (Danks et al. 1979). Early in the season, C. *sonorensis* may parasitize up to 80% of the *H. virescens* larvae in tobacco in North Carolina (A.H. Baumhover, Agricultural Research Service, U.S. Department of Agriculture, Oxford, North Carolina, personal communication).

In Virginia, C. *sonorensis* (= *Sagaritis provancheri* [Dalla Torre]) (Carlson 1972) parasitized more than 50% of early-stage *H. virescens* larvae (Wene 1943). Other parasites that are distributed where *Heliothis* spp occur in the USA include *Netelia, Winthemia, Hyposoter,* and *Meteorus* species (Neunzig 1963; Shepard and Sterling 1972; Van den Bosch and Hagen 1966; Bottrell et al. 1968; Snow et al. 1966; A.H. Baumhover, personal communication).

Parasites Worldwide

Extensive lists of parasites of *H, armigera* of the world were given by Ibrahim (1980) and by Habib (1973); Ibrahim listed 103 species in 10 families of Hymenoptera and Diptera. A list of natural enemies of *Heliothis (armigera* and *assulta)* in Taiwan was given by Yen (1973). In Egypt, *Heliothis* spp were parasitized predominantly by *Apanteles* spp, *Microplitis rufiventris* Kok„ *Chelonus inanitus* (L.), and to a lesser extent by *Bracon brevicornis* Wesm. and *Barylypa humeralis* Brauns (Ibrahim 1980, 1981).

Observations in India indicated that the parasites that had an effect on *H. armigera* populations were *Campoletis chlorideae* Uchida, the most important *Heliothis* parasite in India, *Eriborus* sp, *Carcelia illota* (Curran) *(=Eucarelia), Palexorista laxa* (Curran) *(=Drino imberbis* [Wied.]) (CIBC 1978), *Exorista fallax* Mg., *Goniophthalmus halli* Mesnil and *Trichogramma* spp, although 60 species of parasites were recorded (Rao 1974). *Campoletis chlorideae* was imported to the USA from India, but studies showed that this species adversely affected C. *sonorensis* populations in the field. When the two species mated, progeny had an abnormal sex ratio. For this reason, it is not advisable to import C. *chlorideae* to countries where C. *sonorensis* already exists.

Carl (1978) reported that *Hyposoter didymator* (Thunb.) and *Apanteles kazak* Telenga were the only important parasites of *H. armigera* found in Greece and Bulgaria. These two species were to be shipped to New Zealand for testing of possible interference with *Apanteles ruficrus* Hal.

The most abundant parasites of *H. armigera* in

Australia are the braconid *Microplitis demolitor* Wilkinson and the ichneumonid *Heteropelma scaposum* (Morley) (M. Shepard, Clemson University, Clemson, South Carolina, personal communication). In one soybean field near Coominya, Queensland, more than 35% of the *Heliothis* spp larvae were parasitized by *M. demolitor* (Shepard, Lawn and Schneider, in press). This species is currently being investigated in the USA for use in management programs for *Heliothis.*

Predators Worldwide

Common predators on *Heliothis* in the USA are listed in Table 2. Many of these same predator groups work against *Heliothis* spp in other parts of the world. *Coccinella, Scymnus, Orius,* and *Chrysopa* species were among those predators listed for Egypt (Ibrahim 1980). The most abundant predators in cotton in Israel were *Chrysopa* sp and *Orius* spp (Rossler et al. 1975). India has five reduviids that attack *Heliothis* (Rao 1974), and one, *Sycanus indagator* (Stal), was imported to the USA for study. Predation by *S. indagator* has been studied by Greene and Shepard (1973) as well as others. Another reduviid, *Pristhesancus papuensis* Stal, was imported from Australia and studied in the laboratory (Shepard, McWhorter, and King, in press). Room (1979) made an extensive list of natural enemies (predators and parasites) found in Namoi Valley cotton in New South Wales, Australia. Other studies in Australia (Bishop and Blood 1981) revealed that certain spider species exhibited direct numerical relationships with changes in *Heliothis* populations. The spiders' role in the natural enemy complex was considered important in regulating *Heliothis.*

Table 2. Important predators of Heliothis spp and stage attacked.

Predator		Principal stage attacked	Reference
Hemiptera			
Anthocoridae	*Orius insidiosus* (Say)	Eggs	Lincoln et al. 1967
Berytidae	*Jalysus spinosus* (Say)	Eggs	Elsey 1972
Lygaeidae	*Geocoris punctipes* (Say)	Eggs, first-stage larvae	Lopez et al. 1976; Lincoln et al. 1967
Nabidae	*Nabis* spp	Eggs, first-, second-stage larvae	Lincoln et al. 1967; Donohoe and Pitre 1977
Pentatornidae	*Podisus maculiventris* (Say)	Third-stage larvae	Lopez et al. 1976
Neuroptera			
Chrysopidae	*Chrysopa carnea* Stephens	Eggs, first-stage larvae	Lopez et al. 1976
Coleoptera			
Carabidae	*Calosoma* spp	Large larvae, pupae	Lincoln et al. 1967, van den Bosch & Hagen 1966
	Calleida decora (F.)	Eggs, small larvae	M. Shepard, pers. comm.
Coccinellidae	*Scymnus* sp	Eggs	Lincoln et al. 1967
	Hippodamia convergens (Guerin-Meneville)	Eggs, first-stage larvae	Lincoln et al. 1967
	Coleomegilla maculate (DeGeer)	Eggs, first-, second-stage larvae	Lincoln et al. 1967
Araneida			
Oxyopidae	*Oxyopes salticus* Hentz	Second-stage larvae	Whitcomb and Eason 1967

Increasing the Effectiveness of Naturally Occurring Predators and Parasites

Conservation of beneficial arthropods is a fundamental principle of the integrated pest management (IPM) concept. Conservation is activity to protect and maintain the pests' natural enemies, i.e., reduction of activities that are deleterious to them. Perhaps the most important means of dealing with pest problems while conserving natural enemies is to use selective control strategies, some of these are host-plant resistance, selective insecticides or judicious use of some broad-spectrum insecticides, and cultural practices. Successful IPM programs include these and other ecologically sound methods. Because of the high value of cotton and the importance of *Heliothis* worldwide, much of the research on natural enemies has been conducted on this crop; consequently, much of the following discussion relates to cotton.

Faunal Diversity

Even in annually disrupted agroecosystems such as cotton and maize, large numbers of predators and parasites may be found. For example, in the USA, Whitcomb and Bell (1964) recorded over 600 predators in Arkansas cotton fields, and Van den Bosch and Hagen (1966) estimated about 350 different predators and parasites in California. One of us (Smith) has estimated that 400 to 500 arthropod species are associated more than superficially with cotton fields in Mississippi. The diversity of parasites was indicated earlier, and these tabulations did not include parasites only occasionally recorded attacking *Heliothis.*

Natural Enemy Efficacy

One of the first major studies on predators of *Heliothis* was by Quaintance and Brues (1905). They made key observations on several predaceous enemies of *H. zea* in cotton and reported 51% parasitization of the larvae and 43 to 100% parasitization of eggs in corn. Later, Fletcher and Thomas (1943) observed that during a 7-year period, predators in the field destroyed 15 to 33% of *H. zea* eggs and 13 to 60% of the first-stage larvae. *Orius insidiosus* (Say) was cited as one of the more important predators.

In other field studies, Bell and Whitcomb (1964) and Whitcomb and Bell (1964) placed *Heliothiszea* eggs on cotton plants and observed up to 45% egg predation. Van den Bosch et al. (1969) determined that naturally occurring predators, particularly *Geocoris pallens* Stal, killed up to 66% *H. zea* eggs and first-stage larvae in field cages.

Ewing and Ivy (1943) confined various predator species with *H. zea* eggs in the laboratory and recorded the number consumed. Three predators, *Chrysopa rufilabris* Burmeister, *Hippodamia convergens* Guerin-Meneville, and Coleomegilla fusci*labris* (Mulsant), consumed over 25 eggs per predator per day. In other laboratory studies (Lingren et al. 1968; Lopez et al. 1976) several predator species were efficient in consuming *Heliothis* eggs and larvae; the more voracious consumed an average of 130 to 180 eggs and 104 to 136 larvae each. *Hippodamia convergens* larvae consumed large numbers of eggs, and adult females and *Chrysopa* spp larvae consumed large numbers of first-stage *Heliothis* larvae. When adult *Geocoris punctipes* (Say) and second-stage *Chrysopa carnea* Stephens larvae were confined to cotton terminals infested with *H. virescens* eggs for 2 days, 78 to 88% of the eggs were eaten.

Releases of predators in field cages containing immature *Heliothis* life stages demonstrate their efficacy. Lingren et al. (1968) reported up to 99% reduction in *H. virescens* egg and larval populations after release of *Chrysopa* spp larvae alone, *Geocoris* spp adults alone, or a combination of both species. Van den Bosch et al. (1969) reported 41 to 88% reduction of *H. zea* after release of varying numbers of Geocoris spp, C. carnea, and Nabis *americolerus* Carayon.

Based on the previous data, Ridgway and Lingren (1972) surmised that 50 to 90% of eggs and larvae of *Heliothis are* normally destroyed by naturally occurring predators and parasites. They agreed with Knipling (unpublished)' that it was reasonable to assume 75% natural control of *Heliothis* by insect predators and parasites for purposes of designing control programs.

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[1] E.F. Knipling, 1967. A theoretical appraisal of the natural control agents in insect population dynamics and control with particular reference to *Heliothis* spp, unpublished report distributed to members of Entomology Research Division, U.S. Department of Agriculture, December 13, 1967.4 pp.

Use of Insecticides

Newsom and Smith (1949) were among the first to recognize that insecticides could upset the interaction normally existing in untreated fields between aphids, spider mites, *H. zea,* and their natural enemies. Ridgway et al. (1967) demonstrated the impact of a presumably selective insecticide, aldicarb, on predator populations, and the role of these predators in suppressing *Heliolhis* spp populations. Others have also shown the detrimental effect of insecticides on natural enemy populations.

In fact, decline in predator populations in cotton fields has often been attributed to insecticide applications (Dinkins et al. 1970). However, Smith and Stadelbacher (1978) reported that predator populations in cotton within the Delta area of Mississippi normally decline in mid-season to late season, regardless of insecticide applications. They concluded that peak predator populations closely coincided with peak squaring of cotton (Figure 1) and surmised that plant phenology and attendant changes in the nutritional value of the cotton plant may explain the seasonal decline of natural enemies.

Newsom (1975) concluded that no insecticides known then were selective enough to discriminate between pest and beneficial species to any useful degree. However, "ecological" selectivity can be effective. Early-planted trap plots or small plots of a preferred plant can attract and concentrate overwintered pest populations in small areas where they can be treated with conventional insecticides, thereby preserving the natural enemies in the remainder of the field.

Cultural Control

Early workers used cultural practices as the mainstay of their insect control efforts. Newsom (1975) pointed out that the rediscovery of the importance of cultural control tactics—e.g., early planting, destruction of crop residues, and use of trap crops-has provided highly effective components of pest management systems for soybeans and cotton. The use of strip-cropping to increase beneficial arthropod populations was described by Laster (1974). He pointed out that beef finishing on high-energy silage has been introduced recently in the Mississippi Delta, and this enterprise has potential for being compatible with cotton production and for making good reservoir crops available for beneficial insects. Robinson et al. (1972) found that cot-

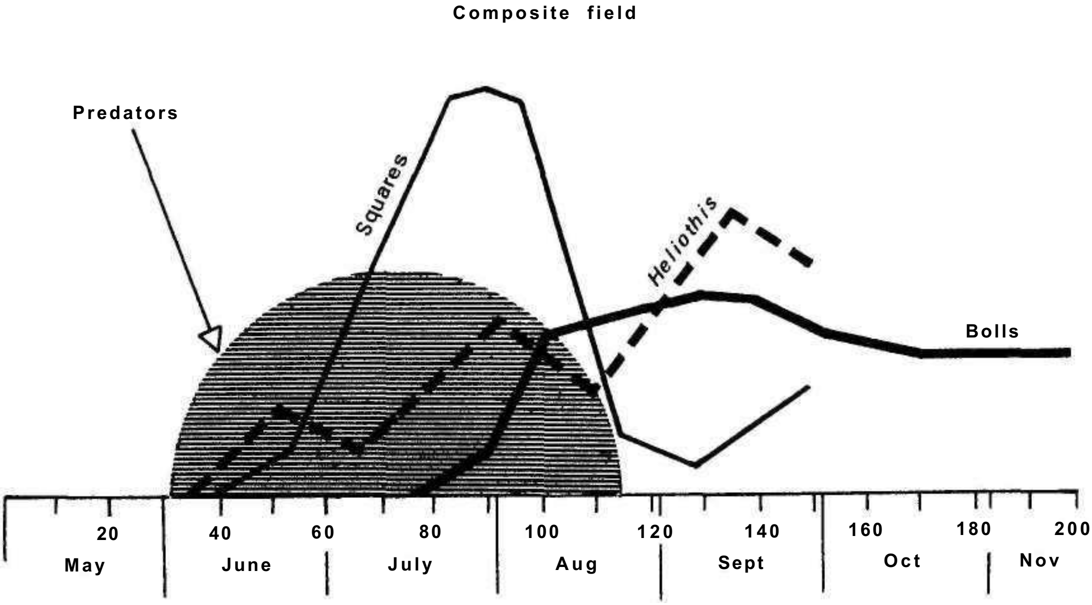

Figure 1. Rise and decline of predator populations within cotton fields in the Delta of Mississippi and correlation with **Heliothis** *spp populations and plant phenology.*

ton strip-planted with sorghum suffered less floral bud damage from bollworms than cotton strip-planted with corn, soybean, alfalfa, or groundnut.

The importance of uncultivated marginal areas in the survival, buildup, and subsequent abundance of predators and parasites in cotton cannot be overemphasized (Stadelbacher, unpublished data). Monoculture in modern agriculture, particularly of annual crops, often discriminates against natural enemies and favors development of "explosive" pest populations. Whitcomb (1974) stated that habitat manipulation both inside and outside the cultivated field will be emphasized in the future. He pointed out that the date of plowing, the species of plants on a highway right-of-way or canal bank, a drought, or even the destruction of the aphid population on goldenrod by a fungus disease may affect predator populations over a large area or lead to decisions on the number of insecticide applications that must be used on nearby cultivated crops. According to Fye (1972), management of naturally occurring populations of insect predators may depend on knowledge of the succession of winter weeds and crops that provide natural hosts for food for the predator species.

In a 2-year study on the abundance of predators in the various habitats in the Delta of Mississippi between early March and mid-June, predator populations in all the marginal areas except woods margins were observed to be much higher than in the more homogeneous areas, such as woods and old cotton and soybean fields. The numbers of beneficials found in the old cotton and soybean fields were proportional to the density of the stand of winter and spring annuals, with soybean fields haying the higher plant and predator populations (E.A. Stadelbacher and J.W. Smith, Bioenvironmental Insect Control Laboratory, unpublished data). The early-season activity of most predators in the Delta of Mississippi is very similar to that reported by Whitcomb and Bell (1964) for Arkansas. At that time, very few predators move directly from overwintering sites to cotton; most emerge in March and early April and pass one or two generations on weeds and legumes in the uncultivated marginal areas.

The maturation of early-season host plants and dispersal of natural enemies normally is well synchronized with the germination and early development of cotton. Numerous ingenious methods have been tested to entice, force, release, feed, hold, and manipulate natural enemy populations to increase their abundance in cotton fields. However, elimination of thrips and aphid populations on seedling cotton through the widespread use of seeds treated with systemic insecticides and subsequent postplanting application of insecticides is bound to be detrimental to the early-season establishment of these beneficials and their subsequent buildup in cotton.

Economic Thresholds, Decision Making, and Pest-Management Models

Economic Thresholds and Decision Making

Control strategies for a pest-management system are based on estimates of pest population densities. The accuracy of these pest population estimates depends on the reliability of the sampling methods. Thus, the dependability of economic thresholds (population levels at which supplemental control measures are justified) that are used in decision-making is subject to the quality of the population estimates. Overestimation may result in unnecessary insecticide application or use of some other control measure that is not cost effective (Gonzalez 1970). The need for economic threshold data based on reliable pest population estimates is critical. With this information, growers and farm advisors can be convinced more easily that higher pest densities can be tolerated without a reduction in yield (Gonzalez 1970).

Arthropod population levels have been determined using two types of sampling procedures. First, an estimate of the absolute population per unit area (Smith et al. 1976b) is used to study population dynamics of pest and beneficial species in their natural habitats. This information is useful in determining thresholds and correlating the natural enemy population with pest population dynamics.

The potential effect of natural enemies on *Heliothis* spp populations is often recognized in insect control guides, but explicit instructions for using their numbers in decision-making are generally lacking, and where present, are used with reservations. Numbers of naturally occurring predators can be used in decision-making, as shown by Hartstack et al. (1976). They describe an index whereby a predator: prey ratio is established, and the probability of biological control occurring is predicted

(Figure 2). As egg density on the vertical axis increases, the necessity of intervention becomes more urgent, depending on the predator population given on the horizontal axis. In the "Treat" region of the figure, the probability of biological control occurring is low because of low predator numbers. In the region between the dotted lines, the effectiveness of biological control is uncertain; therefore, other factors (weather, plant phenology, etc.) may be important in making a treatment decision. Finally, in the lower region a high predator: prey ratio exists, with a consequent high probability that biological control will occur.

Accurate economic thresholds must be established for each crop and cotton-growing area, and further decision-making techniques must contain the flexibility to account for season, plant maturity, weather, and treatment history as well as natural enemy populations. Research in each of these areas is important for effective *Heliothis* management.

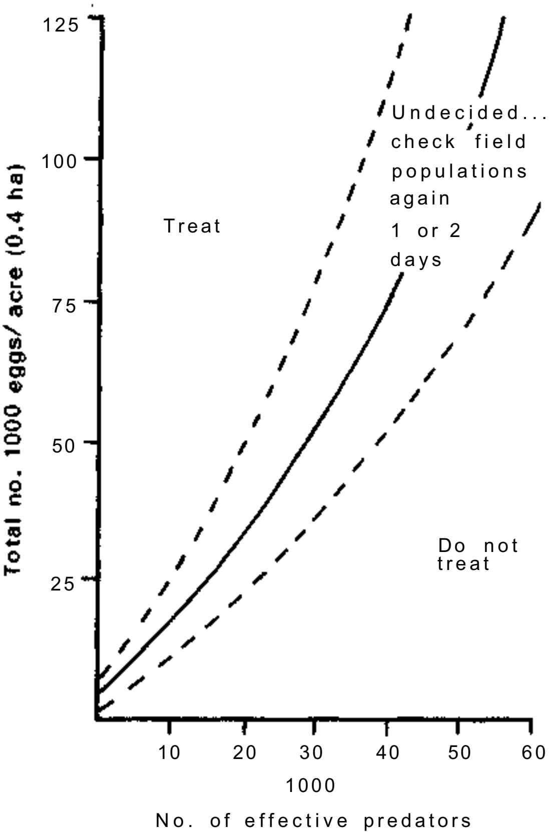

Figure 2. Decision-making index (utilizing predator: prey ratio) based on the probability of biological control occurring (Source: Hartstack et al. 1976).

Pest-Management Models

An emerging technology used in planning and executing pest-management strategies consists of computer-oriented, weather-based simulations of agricultural production systems. The development and use of these models require the coordinated efforts of multidisciplinary teams.

The main controlling factors for the functions in each life stage in each generation of an insect should be understood for development of realistic models. Some of these dependent functions are: rates of development and egg production, mating behavior, egg fertilization, longevity, mortality, migration, diapause, host selection, and feeding behavior. Much emphasis will be placed on the interactions of these factors in pest-management systems models in the immediate future. For example, one cotton model, which is a modification of SIMCOTT II (McKinion et al. 1974), incorporates a *Heliothis* spp submodel and predation and parasitism subsubmodels (Hartstack et al, 1976). Other *Heliothis* models that might fit equally well in the future are being developed in the USA (Arizona, California, Mississippi, and North Carolina).

Natural mortality such as predation has been considered in several *Heliothis* spp models. An example of one approach used at Mississippi State University was developed specifically for interfacing with COTCROP and BWEEV. Since *H. zea* and *H. virescens* develop and oviposit at different rates, and also react differently to insecticides, they are separated in this model. The model further separates *H. virescens* by cohorts (insects that enter a life stage on the same day). The variance in development time within a cohort is accounted for by movement of the members of a cohort to the next life stage distributed over several days. The stage is a function of the age of the cohort and the degree day (temperature) accumulation for that day. Fecundity is a function of temperature and moth ages. The number of eggs destroyed daily by predators is calculated and the proportion of the larvae within each cohort that are destroyed by the predators varies with the age of the cohort.

Another approach to handling predation in *Heliothis* spp models is that of Knipling and McGuire (1968). These simple models were adapted by

Hartstack et al. (1976) in their *Heliothis* model MOTHZV-2:

$$M = 1\text{-}EXP\ [(-0.693)\ (Pn)/(N)\ (S)]$$

where
M = probability of egg or larval mortality;
Pn = number of effective predators;
N = number of Pn to cause 50% mortality; and
S = relative search area.

Other factors that influence predation can be assessed in a similar manner. The exponential functions are only a suggestion from A.W. Hartstack, (College Station, Texas, personal communication), and he stated that other types of functions may fit the data better. Both of the above approaches are in use at present, each with certain advantages. These models and submodels would fit into a system model that could be used in areawide *programs to guide farmers in their decisions* on application of insect pest management techniques.

Biological Control by Augmenting Natural Enemy Populations

Production, Release, and Evaluation

The possibility of augmenting natural enemies to obtain control of arthropod pests has been considered. Results of early efforts have been summarized by Clausen (1956) and DeBach and Hagen (1964). More recently, a book edited by Ridgway and Vinson (1977) reviewed biological control by augmentation of natural enemies, worldwide, including theoretical aspects as well as production and utilization. Other general reviews include Rabb et al. (1976) and Stinner (1977). Specifically, Knipling (1979) developed theoretical models for appraising the potential value of augmentative releases of predators and parasites and Ridgway et al. (1981) reviewed the use of *Trichogramma* spp in augmentative releases to control lepidopterous pests. King and Morrison (in press) reviewed production of predators and parasites, including quality control and in vitro rearing.

The technical feasibility of suppressing *Heliothis* spp by augmenting parasite and predator populations has been demonstrated (Tables 3, 4, and 5), but results are often inconsistent, and economic feasibility is generally lacking. The difficulty of mass producing natural enemies at a cost competitive with other control strategies is a major factor limiting use of the augmentation strategy. Thus, emphasis has been placed on *Trichogramma* spp and *Chrysopa* spp because these two natural enemies can be mass produced (see Morrison et al. 1978, Shcheptil'nikova et al. 1974, and Jiminez 1980 for *Trichogramma* spp; Ridgway and Vinson 1977 for *Chrysopa carnea).* The following is a brief review of progress made within the last 15 years on the use of selected natural enemies for biological control of *Heliothis* spp by augmentation.

Trichogramma Spp

Tests demonstrating increase in parasitization after release of *Trichogramma* spp are given in Table 3. Some of the tests in cotton indicated a *reduction in larval population as a consequence of* parasitization. However, only in tests with tomatoes was yield correlated with increased parasitization.

In the USA, the following major advances have been made in the taxonomy and production and utilization of *Trichogramma:*

1. The taxonomy of North American species has recently been placed on a solid foundation with the designation of neotypes for *T. pretiosum* and *T. minutum* and the designation of lectotypes for several species often confused in the past literature (Pinto et al. 1978).

2. Host eggs are "glued" to a permanent substrate with a fine mist of water for exposure to the parasites, thereby making the parasitized eggs available in free form for distribution (Morrison et al. 1978).

3. The quality of *T. pretiosum* reared on *Sitotroga cerealella* (Olivier) eggs is assured by use of a broad genetic base and rearing hosts on wheat containing at least 13% protein (King and Morrison, in press).

4. A mechanical unit has been designed and constructed for aerial broadcast application of parasitized host eggs under refrigerated conditions (Bouse et al. 1981).

5. The role that host-seeking substances play in aiding parasites and predators to find their hosts has been elucidated.

Table 3. Biological control of *Heliothis* spp by augmentative release of *Trichogramma.*

Heliothis spp	Release rate (000/ha)[a]	No. of eggs (000/ha)	Parasitization (%)		Control evidence	Reference
			Release (treated)	Nonreleased or prereleased		
				Cotton		
H. zea/H. virescens	494.0		58	11		Lingren and Kim 1970
	46.0-955.9	7.4-27.7	33-81	5		Stinner et al. 1974
	191.4 297.1	7.4-27.7	61	7	66% reduction in *Heliothis* larvae	Stinner et al. 1974
	123.5-247.0		24-73	0-7		Ridgway et al. 1977
	176.0	0.2- 7.8	0-43	3-27		Jones et al. 1977
	176.0	6.0-39.3	3-73	0- 9		Jones et al. 1977
	112.0-178.0	14.6-17.1	55-84	7-81	21% reduction in *Heliothis* larvae	Jones et al. 1979[b].
	110.0		15-90	15-90	Reduction in *Heliothis* larvae	Abies et al. 1979[b]
				Tomato		
H. zea	40.5		81	75	45% reduction in fruit damage	Oatman and Platner 1971
	49.6		64	42	71% reduction in fruit damage	Oalman and Platner 1971
	74.1-98.8		53-85	0-41	84% reduction in fruit damage	Oatman and Platner 1971
H. armigera	125.0		35	6		Patel 1975
	250.0		71	26	65% reduction in fruit damage	Patel 1975
	250.0		76	2	69% reduction in fruit damage	Patel 1975

a. Releases typically made at 2- to 4-day intervals for several applications, except for Patel 1975. where releases were made at 7- to 10-day intervals.

b. Releases conducted using latest taxonomic, rearing, and release technology.

Table 4. Biological control of *H. zea* and *H. vire*scens In cotton by augmentative release of C. *carnes.*[a]

No. of *C. carnea* released (000/ha)	No. *H. zea* and *H. virescens* larvae/ha		Larval reduction (%)	Cage or field test
	Release (treated)	Nonrelease (control)		
1037.0	1.5	42.0	96	Cage
988.0	0.7	144.7	99	Cage
988.0	35.6	144.7	75	Cage
61.8	4.0	15.1	74	Cage
247.0	4.0	15.1	74	Cage
741.0	4.0	15.1	90	Cage
360.6	1.7	44.5	96	Cage
494.0	4.2	23.5	82	Field
227.2	2.0	18.5	89	Field
24.7	10.4	15.6	33	Field
74.1	7.2	15.6	54	Field
247.0	2.7	15.6	83	Field

a. Source: Ridgway et al. (1977).

Table 5. Parasitism on Heliothis spp in cages afterr release of larval parasites.

Parasite	No. of parasites/ha	No. of *Heliothis* larvae/ ha	Parasitism (%)	Reference
Campoletis sonorensis	1993	11 115	52	Noble and Graham 1966
C. sonorensis	3984	21 242	82	Noble and Graham 1966
C. sonorensis	2062		85-95	Lingren 1977
Microplitis croceipes	2964		58	Jackson et al.1970
Eucelatoria sp	6175	4570	57	Jackson et al.1970
Palexorista laxa	6175	3273	51	Jackson et al.1970

Tests combining this technology are footnoted in Table 3. In addition, a pilot study is being conducted in southeast Arkansas, USA (1980-1983), to consolidate this technology into a scheme for the use of *Trichogramma* as an effective and acceptable pest-management alternative. Other reports on use of *Trichogramma* for control of *Heliothis* spp by augmentative release are Beglyarov and Smetnick (1977) and Bournier and Peyrelongue (1973). Wang (1979) provides directions for the use-of *Trichogramma* to control *Heliothis* in cotton in China. Release of *Trichogramma* at the rate of 227 thousand/ha (five releases for the second generation of *Heliothis)* and 303 thousand/ha (three releases for the third generation) resulted in increased parasitism, reduced *Heliothis* larvae per 100 plants, and reduced damage to floral buds and bolls.

Predators

No predators are currently being used to any degree for controlling *Heliothis* spp by augmentation. However, Ridgway and his coworkers have demonstrated the technical feasibility of suppressing *Heliothis* spp larval populations in cotton by periodic release of *C. camea* eggs or larvae (Table

4). In fact, release of 2- to 3-day-old larvae consistently produced significant reductions of *Heliothis* spp on cotton. Reductions in *Heliothis* spp larval populations were obtained by releasing as few as 24.7 thousand *C. carnea* larvae/ha, and high levels of reduction were obtained in the field by releasing 247 to 494 thousand/ha (Ridgway et al. 1977).

Releases of several hemipteran predators indicate that it might be feasible to augment their populations if economical procedures for mass producing them could be developed. Field-cage studies by Lingren et al. (1968), Van den Bosch et al. (1969), and Lopez et al. (1976) with *G. punctipes, N. americoferus,* and *Podisus maculiventris* Say, respectively, in cotton demonstrate the ability of these predators to suppress *Heliothis* spp populations. Another hemipteran predator, *Jalysus spinosus* (Say), has been used experimentally in tobacco to suppress populations of *H. virescens* and *Manduca sexta.* In one experiment, the seasonal density of *J. spinosus* was increased by early-season releases, but only *Manduca* spp were suppressed (Elsey 1975).

Gillaspy (1979) reviewed the possibility of managing lepidopterous pest populations by use of *Polistes* wasps. He described shelters that could be easily erected and dismantled for use around target fields as nesting areas for the wasps. His studies, as well as a number of others that he cited, indicated that these wasps are opportunistic and will attack prey (lepidopterous larvae) that are most readily available, including *Heliothis* spp. Others have also reported research on the use of *Polistes* spp as possible control agents for *Heliothis* spp. For example, Lawson et al. (1961) reported on control in tobacco fields, and the Institute of Agricultural and Forestry Sciences of Shang-Chiu (1976) reported that *Polistes* spp could be used for insect pest control in cotton fields. This latter report stated that *Polistes* spp, when introduced in colonies of about 1500 wasps per ha, are effective in controlling *H. armigera* and another lepidopterous species. The report also stated that a control rate of about 70 to 80% larval reduction could be attained 5 to 7 days after nest transfer.

Larval Parasites

As stated earlier in this paper, larval parasites are an important factor in the environmental resistance against increases in *Heliothis* spp populations. Potential for using larval parasites in augmentative releases has been indicated in some small-scale tests (Table 5), and Knipling (1979) demonstrated in theoretical studies the feasibility of suppressing *Heliothis* spp populations areawide by augmentative releases.

Lingren (1969) reported that *A. marginiventris* had considerable potential for use in augmentation programs. Also, release of *C. sonorensis* at the rate of 680 per day for 10 consecutive days in a 0.2 ha cage infested with *H. virescens* resulted in 85% parasitization for 9 consecutive weeks (Lingren 1977). Jackson et al. (1970) reported 58% parasitization of third-stage *H. virescens* larvae in cages when 2964 (equivalent) *M. croceipes* (Cresson) female wasps were released per ha. Jackson et al. (1970) reported from their studies with tachinids that if *Eucelatoria bryani* and *Palexorista laxa* (a parasite imported from India) were released at the rate of 6175 female flies per ha on cotton containing 12 350 *Heliothis* spp larvae per ha, about 50% parasitization should occur in 2 days.

The tachinids above can only be considered as population suppressants, since they prefer late-stage larvae; consequently they cause little direct reduction in damage (Brewer and King 1980). However, the solitary hymenopterous parasites prefer second- to third-stage larvae and directly reduce crop damage by reducing larval food consumption after parasitization.

Larval parasites are typically strong fliers and disperse, thus making it difficult to assess their efficiency in cage studies. In one field study, Lewis et al. (1972) reported that 80% parasitism of H. *virescens* larvae in cotton could be attained with 988 to 1482 *C. nigriceps* females per ha. Their calculations were based on a 2-year study during which visual estimates of total actively searching females of *C. nigriceps* per ha were made and correlated with percentage of *H. virescens* larvae parasitized by *C. nigriceps.* Similar studies need to be conducted on other larval parasite species.

Nutrition, In Vitro Rearing, and Quality Control

Artificial diets have been developed for *C. carnea,* though improvement is still needed (King and Morrison, in press), and diets have been developed for in vitro rearing of several parasites, including *Trichogramma* (King 1981). Consistent and economical production of quality natural enemies for use in augmentation programs may well depend on continued advancement in our knowledge about nutritional requirements of predators and the development of in vitro rearing techniques for parasites.

Opportunities exist for improving the quality of mass-produced natural enemies by reduction of genetic deterioration and by improved nutrition. However, techniques must first be developed for monitoring the essential characteristics. At present, genetic deterioration in *C. camea* and *Trichogramma* spp is partially circumvented by periodically replacing the laboratory colony with field-collected material. Vigor is maintained in *Trichogramma* colonies in the People's Republic of China by requiring them to fly in search of host eggs (King and Morrison, in press). Parasite quality may be dependent on nutrition of the host, and as stated earlier, wheat containing below 13% protein content is unacceptable for rearing the unnatural host, S. *cerealella,* for production of *Trichogramma.* Genetic deterioration or reduced quality may be indicated by changes in natural enemy adaptability, sexual activity, host selection, and/or motility.

Management of Parasites and Predators

Dispersal from the target area after release often reduces the effectiveness of the augmentation approach. Provision of supplemental resources such as food to maintain the released or indigenous natural enemy, and use of kairomones to attract, arrest, retain, or stimulate the natural enemy to search more intensively for the host or prey could provide mechanisms for managing parasites and predators (Hagen and Hale 1974; Nordlund et al. 1981).

Ables and Ridgway (in press) reviewed the use of supplementary foods, particularly simulation of aphid honeydew to attract and concentrate adult chrysopid populations. Hagen et al. (1971) reported that a dairy product composed of the yeast *Saccharomyces fragilis* and its whey substrate sprayed on cotton increased the effectiveness of C. *carnea* against *H. zea* eggs and larvae. Coccinellid populations have also been reported to be increased in response to application of supplementary foods such as sucrose or molasses on com plants (Carlson and Chiang 1973).

The "state of the art" in identification, elucidation of the role of, and utilization of chemicals (kairomones) that aid parasites and predators in finding their hosts has recently been reviewed (Nordlund, et al. 1981). Here, the chemistry of substances found in moth scales that elicit activity by *Trichogramma* spp, and in larval frass, cuticle, and/or salivary glands, that elicit response by hymenopterous and tachinid larval parasites, is discussed. As part of a pilot study, diatomaceous earth particles are being impregnated with crude extracts of *H. zea* moth scales and applied along with sterile *H. zea* eggs to retain and increase the effectiveness of aerially applied *T. pretiosum.* Substantial information exists in support of the possibility that kairomones can eventually be used to manipulate the field behavior of *Heliothis spp* parasites and predators.

Discussion

Heliothis spp are among the most economically important insects of cultivated crops worldwide, even though they are attacked by a wide range of natural enemies. Vacant niches (e.g., unattacked life stages of *Heliothis* spp or host plants that are unattractive to indigenous natural enemies) do occur, and opportunities exist for establishing more effective natural enemies. Considering the economic importance of species such as *H. zea* and H. *armigera,* establishment of even a partially effective natural enemy against a particular life stage could result in saving millions of dollars as well as reducing environmental pollution from insecticides. Some effort should be made toward exploration, importation, and establishment of natural enemies that have been shown to regulate *Heliothis* spp populations.

Indirectly, most economic thresholds for Helio*this* spp on crops include suppression by natural enemies, and insect control guides often refer to the need tor preserving predators and parasites of *Heliothis.* However, explicit instructions for monitoring and using natural enemy numbers in actual decision-making are generally lacking. Thus, the efficacy of key predators and parasites should be determined through the use of correlative and experimental methods (day and night observations); means must be developed for rapidly monitoring these populations so that their numbers can be used in decision-making; and dynamic economic thresholds for *Heliothis* should be developed that include natural enemy numbers (qualitatively and quantitatively weighted).

Research must be continued on the development of selective insecticides for *Heliothis* spp as well as other associated pest insects. Insecticidal intervention will continue to be necessary on many crops, regardless of advances in host-plant resistance and biological control. Thus, sound economic thresholds are required so that chemicals can be used only as needed, and application techniques should allow for maximum predator and parasite survival.

The ability to consistently control *Heliothis* spp by augmentative release of predators and/or parasites, at a cost competitive with the use of insecticides, is dependent on (1) elucidation of factors affecting host searching and (2) development of mass-production procedures using artificial diets. Even in the case of *Trichogramma,* in vitro rearing techniques utilizing defined artificial diets could enable production of a high-quality, standardized product. In fact, the present cost of rearing *Trichogramma* is U.S. $0.03 to $0.05 per 1000, and of C. *carnea* is U.S. $1.50 to $2.50 per 1000 (R.K. Morrison, Cotton Insect Research Unit, ARS, U.S. Department of Agriculture, College Station, Texas, personal communication). Additionally, efforts should be intensified to isolate and identify chemicals emanating from the host, host products, and plant that can be used to manage natural enemies of the pest, particularly in augmentative releases.

International cooperation could encourage the flow of information on biological control *of Heliothis* as well as the exchange of natural enemies. Specific natural enemies occur only at particular times of the season, and this, coupled with travel restrictions, often prohibits the importation of important natural enemies. Also, international cooperation could enable rapid screening of candidates for identification and augmentation of those that can be most easily mass reared and managed after release.

References

ABLES, J.R., JONES, S.L., MORRISON, R.K., HOUSE, V.S., BULL, D.L., BOUSE, I.F., and CARLTON, J.B. 1979. New developments in the use of *Trichogramma* to control lepidopteran pests of cotton. Pages 125-127 *in* Proceedings, Beltwide Cotton Production Research Conference, National Cotton Council, 1979, Memphis, Tenn, USA.

ABLES, J.R., and RIDGWAY, R.L. 1982. Augmentation of entomophagous arthropods to control pest insecis and mites. Pages 103-127 *in* Proceedings, Symposium in Agricultural Research. V. Biological control in crop production, Beltsville, USA.

ACHAN, P.D., MATHUR, K.C., DHARMADHIKARI, P.R., and MANJUNATH, T.M. 1968. Parasites of *Heliothis* spp. in India. Pages 129-149 *in* Commonwealth Institute of Biological Control technical bulletin 10, Ascot, Berks, UK.

BEGLYAROV, G.A., and SMETNIK, A.I. 1977. Seasonal colonization of entomophages. *In* Biological control by augmentation of natural enemies, eds. R.L. Ridgway and S.B. Vinson. New York, USA: Plenum. 480 pp.

BELL, K.O., and WHITCOMB, W.H. 1964. Field studies on egg predators of the bollworm, *Heliothis zea* (Boddie). Florida Entomologist 47: 171-180.

BISHOP, A.L, and BLOOD, P.R.B. 1981. Interactions between natural populations of spiders and pests in cotton and their importance to cotton production in southeastern Queensland. General Applied Entomology 13:98-104.

BOTTRELL, D.G., YOUNG, J.H., PRICE, R.G., and ADAMS, R.H. 1968. Parasites reared from *Heliothis* spp. in Oklahoma in 1965 and 1966. Annals of the Entomological Society of America 61:1053-1055.

BOURNIER, J.P., and PEYRELONGUE, J.Y. 1973. Introduction, elevage et lachers de *Trichogramma brasiliensis* Ashm. (Hym. Chalcididae) en vue de lutter contre *Heliothis armigera* Hbn. (Lep. Noctuidae) a Madagascar. Coton et Fibres Tropicale 28:231 -237.

BOUSE, L.F., CARLTON, J.B., and MORRISON, R.K. 1981. Aerial application of insect egg parasites. Transactions of the American Society of Agricultural Engineers 1981: 1093-1098.

BRAZZEL, J.R., NEWSOM, L.D., ROUSSEL, J.S., LINCOLN, C, WILLIAMS, F.J., and BARNES, G. 1953. Bollworm and tobacco budworm as cotton pests in Louisiana and Arkansas. Louisiana Agricultural Experiment Station technical bulletin 482, Baton Rouge. La, USA. 47pp.

BREWER, F.D., and KING, E.G. 1980. Consumption and utilization of a soyflour-wheat germ diet by larvae of the tobacco budworm parasitized by the tachinid *Eucelatoria* sp. Entomophaga 25(1):95-101.

BUTLER, G.D., Jr. 1958a. Braconid wasps reared from lepidopterous larvae in Arizona. Pan-Pacific Entomologist 34-222-223.

BUTLER, G.D., Jr. 1958b. Tachinid flies reared from lepidopterous larvae in Arizona, 1957. Journal of Economic Entomology 51:561 -562.

CIBC (Commonwealth Institute of Biological Control). 1978. Possibilities of biological control of *Heliothis armigera* and *H. zea.* CIBC status paper 13, Ascot, Berks, UK.

CARL, K.P. 1978. *Heliothis armigera;* parasite survey and introduction of *Apanteles kazak* to New Zealand.

Commonweath Institute of Biological Control Report, European Station, Delemont, Switzerland. 8 pp.

CARLSON, R.W. 1972. Suppression of the name *Campoletis perdistincta* (Hymenoptera: Ichneumonidae) and the identity of species to which the name has been applied. Entomological News 93:75-82.

CARLSON, R.E., and CHIANG, H.C. 1973. Reduction of an *Ostrinia nubilalis* population by predatory insects attracted by sucrose sprays. Entomophaga 18:205-211.

CLAUSEN, C.P. 1956. Biological control of insect pests in the continental United States. U.S. Department of Agriculture technical bulletin 1139, Washington DC, USA. 151 PP

COMMON, I.F.B. 1953. The Australian species of *Heliothis* and their pest status. Australian Journal of Zoology 1:319-344.

DANKS, H.V., RABB, R.L., and SOUTHERN, P.S. 1979. Biology of insect parasites of *Heliothis* larvae in North Carolina. Journal of the Georgia Entomological Society 14:36-64.

DeBACH, P., and HAGEN, K.S. 1964. Manipulation of entomophagous species. Pages 429-458 *in* Biological control of insects, pests and weeds, ed. P. DeBach. London, UK: Chapman and Hall.

DINKINS, R.L., BRAZZEL, J.R., and WILSON, C.A. 1970. Seasonal incidence of major predaceous arthropods in Mississippi cotton fields. Journal of Economic Entomology 63:814-817.

DONOHOE, M.C., and PITRE, H.N. 1977. *Reduviolus roseipennis* behavior and effectiveness in reducing numbers of *Heliothis zea* on cotton. Environmental Entomology 6:872-876.

ELSEY.K.D.1972. Predation of eggs of Heliothis spp. on tobacco. Environmental Entomology 1:433-438.

ELSEY, K.D. 1975. *Jalysus spinosus:* Increased numbers produced on tobacco by early season releases. Tobacco Science 19:13-15.

EWING, K.P., and IVY, E.E. 1943. Some factors influencing bollworm populations and damage. Journal of Economic Entomology 36:602-606.

FLETCHER, R.K., and THOMAS, F.L. 1943. Natural control of eggs and first instar larvae of *Heliothis armigera.* Journal of Economic Entomlogy 36:557-560.

FYE, R.E. 1972. The interchange of insect parasites and predators between crops. Pest Articles and News Summaries 18:143-146.

GILLASPY, J.E. 1979. Management of *Polistes* wasps for caterpillar predation. Southwest Entomologist 4:334-352.

GONZALEZ, D. 1970. Sampling as a basis for pest management strategies, *in* Proceedings, Tall Timbers Conference on Ecological Animal Control by Habitat Management, 26-28 Feb 1970, Tallahassee, Fla, USA.

GRAHAM, H.M. 1970. Parasitism of eggs of bollworms, tobacco budworms and loopers by *Trichogramma semifumatum* in the Lower Rio Grande Valley, Texas. Journal of Economic Entomology 63:686-688.

GREENE, G.T., and SHEPARD, M. 1973. Biological studies of a predator, *Sycanus indagator.* II. Field survival and predation potential. Florida Agricultural Experiment Station Journal Series No. 5002. 38 pp.

HABIB, R. 1973. Memorandum on possibilities of biological control of *Heliothis armigera.* Commonwealth Institute of Biological Control, Rawalpindi, Pakistan. 18 pp.

HAFEZ, M. 1951. Notes on the introduction and biology of *Microplitis demolitor* Wilk. Bulletin of the Society of Fouad Ier Entomology 35:107-120.

HAGEN, K.S., and HALE, R. 1974. Increasing natural enemies through use of supplementary feeding and non-target prey Pages 170-181 in Proceedings, Summer Institute on Biological Control of Plant Insects and Diseases, eds. F.G. Maxwell and F.A. Harris. Jackson, Miss, USA: University Press of Mississippi. 647 pp.

HAGEN, K.S., SAVELL, E.F., Jr., and TASSAN, R.L. 1971. The use of food sprays to increase the effectiveness of entomophagous insects. Proceedings, Tall Timbers Conference on Ecological Animal Control by Habitat Management 2:59-81.

HALLMAN, G. 1980. Revista Columbiana de entomologia publicacion oficial de la sociedad Columbiana de entomologia. September 1980. 4 (3 and 4): 60-69.

HARDWICK, D.F. 1965. The corn earworm complex. Memoirs of the Entomological Society of Canada 40, Ottawa, Canada. 247 pp.

HARDWICK, D.F. 1970. A generic revision of the North American Heliothidinae (Lepidoptera: Noctuidae). Memoirs of the Entomological Society of Canada 73, Ottawa, Canada. 59 pp.

HARTSTACK, A.W., Jr., WITZ, J.A., HOLLINGSWORTH, J.P., RIDGWAY, R.L., and LOPEZ, J.D. 1976. MOTHZV-2: a computer simulation of *Heliothiszea* and *Heliothis virescens* population dynamics. U.S. Department of Agriculture User's Manual ARS-S-127, Washington DC, USA. 55 pp.

IBRAHIM, A.E. 1980. Biotic factors affecting different species in the genera *Heliothis* and *Spodoptera* in Egypt. Institute of Plant Protection Report 2, Cairo, Egypt. 56 pp.

IBRAHIM, A.E. 1981. Biotic factors affecting different species in the genera *Heliothis* and *Spodoptera* in Egypt. Institute of Plant Protection, Report 4, Cairo, Egypt. 58 pp.

Institute of Agricultural and Forestry Sciences of Shang-Chiu. 1976. A preliminary study on the bionomics of hunting wasps and their utilization in cotton insect control. Acta Entomologica Sinica 19:303-308.

JACKSON, C.G., BRYAN, D.E., BUTLER, G.D., Jr., and PATONA, R. 1970. Development, fecundity, and longevity of *Leschenaultia adusta,* a tachinid parasite of the salt marsh caterpillar. Journal of Economic Entomology 63:1396-1397.

JIMINEZ, E. 1980. Review of some interesting developments, (3.2) plant protection, Mexico. International Organization of Biological Control Newsletter 15:5.

JONES. S.L., MORRISON, R.K., ABLES, J.R., and BULL, D.L. 1977. A new and improved technique for the field release of *Trichogramma pretiosum.* Southwestern Entomologist 2:210-215.

JONES, S.L., MORRISON, R.K., ABLES, J.R., BOUSE, L.F., CARLTON. J.B., and BULL, D.L. 1979. New techniques for the aerial releases of *Trichogramma pretiosum.* Southwestern Entomologist 4:14-19.

KING, E.G., Jr. 1981. Production, release, and evaluation of predators and parasites of arthropod pests attacking food and fiber crops in the USA. Pages 154-168 *in* Proceedings, First Japan/USA Symposium on IPM29-30 Sept 1981, Tsukuba, Japan.

KING, E.G., and MORRISON, R.K. (In Press). Some systems for production of entomophagous arthropods. *In* Advances and challenges in insect rearing, eds. E.G. King and N.C. Leppla. U.S. Department of Agriculture technical bulletin, Washington, DC, USA.

KNIPLING, E.F. 1979. The basic principles of insect population suppression and management. U.S. Department of Agriculture Agricultural Handbook Washington, DC, USA 659 pp.

KNIPLING, E.F., and McGUIRE, J.U., Jr. 1968. Population models to appraise the limitations and potentialities of Trichogramma in managing host insect populations. U.S. Department of Agriculture technical bulletin 1387, Washington DC, USA. 44 pp.

KOGAN, J., SELL, D.K., STINNER, R.E., BRADLEY, J.R., Jr., and KOGAN, M. 1978. The literature of arthropods associated with soybean. V. A bibliography of *Heliolhis zea* (Boddie) and *H.virescens* (F.) (Lepidoptera:Noctuidae). International Agricultural Publications, University of Illinois INTSOY Series 17, Urbana, Ill, USA. 242 pp.

KROMBEIN, K.V., HURD, P.D., Jr., SMITH, D.R., and BURKS B.D. 1979. Catalogue of Hymenoptera in America north of Mexico. Washington, DC: Smithsonian Institution Press. 2735 pp. (3 volumes.)

LASTER.M.L. 1972. Interspecific hybridization of *Heliothis virescens* and *H. subflexa.* Environmental Entomology 1:682-687.

LASTER, M.L. 1974. Increasing natural enemy resources through crop rotation and strip cropping. Pages 137-149 *in* Proceedings, Summer Institute on Biological Control of Plant Insects and Diseases, eds. F.G. Maxwell and F.A. Harris. Jackson, Miss, USA: University Press of Mississippi. 647 pp.

LAWSON, F.R., RABB, R.L., GUTHRIE F.E., and BOWERY, T.G. 1961. Studies of an integrated control system for hornworms on tobacco. Journal of Economic Entomology 54:93-97.

LEA, A.M. 1928. The cotton bollworm in South Australia. Journal of Agriculture South Australia 31:608-615.

LEWIS, W.J., and BRAZZEL, J.R. 1968. A three-year study of parasites of the bollworm and the tobacco budworm in Mississippi. Journal of Economic Entomology 61 ;673-676.

LEWIS, W.J., SPARKS, A.N., JONES, R.L., and BARRAS, D.J. 1972. Efficiency of *Cardiochiles nigriceps* as a parasite of *Heliothis virescens* on cotton. Environmental Entomology 1:468-471.

LINCOLN, C., PHILLIPS, J.R., WHITCOMB, W.H., POWELL, G.C., BOYER, W.P., BELL, K.O., Jr., DEAN, G.L., MATTHEWS, E.J., GRAVES, J.B., NEWSOM, L.D., CLOWER, D.F., BRADLEY, J.R., Jr., and BAGENT, J.L. 1967. The bollworm-tobacco budworm problem in Arkansas and Louisiana. Arkansas Agricultural Experiment Station Bulletin 720. 66 pp.

LINGREN, P.D. 1969. Approaches to the management of *Heliothis* spp. in cotton with *Trichogramma* spp. Pages 207-217 *in* Proceedings, Tall Timbers Conference on Ecological Animal Control by Habitat Management. 26-28 Feb 1969, Tallahassee, Fla, USA.

LINGREN, P.D. 1977. *Campoletis sonorensis:* maintenance of a population on tobacco budworm in a field cage. Environmental Entomology 6: 72-76.

LINGREN, P.D., and KIM, J.G., 1970. Inundative releases of *Trichogramma* sp. for control of bollworm and tobacco budworm attacking cotton. Presented at the Annual Meeting of the Entomological Society of America, Miami, Fla, USA, 30 Nov-3 Dec 1970. 6 p.

LINGREN, P.D., RIDGWAY, R.L., and JONES, S.L. 1968. Consumption by several common arthropod predators of eggs and larvae of two *Heliothis* species that attack cotton. Annals of the Entomological Society of America 61: 613-618.

LINGREN, P.D., GUERRA, R.J. NICKELSEN, J.W., and WHITE, C. 1970. Hosts and host age preference of *Campoletis perdistinctus.* Journal of Economic Entomology 63: 518-522.

LOPEZ, J.D., Jr., RIDGWAY, R.L., and PINNELL, R.E. 1976. Comparative efficacy of four insect predators of the bollworm and tobacco budworm. Environmental Entomology 5: 1160-1164.

McKINION, J.M., BAKER, D.N., HOSKETH, J.D., and JONES, J.W. 1974. SIMCOTT II, A simulation of cotton growth and yield, a user's manual. Agricultural Research

Service, U.S. Department of Agriculture, ARS-52, Southern Region.

MORRISON, R.K., JONES, S.L., and LOPEZ, J.D. 1978. A unified system for the production and preparation of *Trichogramma pretiosum* for field release. Southwestern Entomologist 3: 62-68.

NEUNZIG, H.H. 1963. Wild host plants of the corn earworm and the tobacco budworm in eastern North Carolina. Journal of Economic Entomology 56: 135-139.

NEWSOM, L.D. 1975. Pest management: concept to practice. Pages 257-277 *in* Insects, science and society, ed. D. Pimentel. New York, USA: Academic Press. 284 pp.

NEWSOM, L.D., and SMITH, C.E. 1949. Destruction of certain insect predators by applications of insecticides to control cotton pests. Journal of Economic Entomology 42: 904-908.

NOBLE, L.W., and GRAHAM, H.M. 1966. Behavior of *Campoletis perdistinctus* (Vierick) as a parasite of the tobacco budworm. Journal of Economic Entomology 59: 1118-1120.

NORDLUND, D.A., JONES, R.L., and LEWIS, W.J. (eds.) 1981. Semiochemicals: Their role in pest control. New York, USA: John Wiley. 306 pp.

OATMAN, E.R., and PLATNER, OR. 1971. Biological control of the tomato fruitworm, cabbage looper, and hornworms on processing tomatoes in southern California, using mass releases of *Trichogramma pretiosum.* Journal of Economic Entomology 64: 501-506.

PATEL, R.C. 1975. To assess the effectiveness of mass releases of laboratory bred *Chelonus heliopae* Gupta and to maintain cultures and improve breeding methods of other parasites for use in future releasing programs. Final Technical Report, Project No. A-ENT-90, Gujarat Agricultural University, Gujarat, India.

PINTO, J.D., PLATNER, G.R., and OATMAN, E.R. 1978. Clarification of the identity of several common species of North American *Trichogramma.* Annals of the Entomological Society of America. 71: 169-180.

QUAINTANCE, A.L., and BRUES, C.T. 1905. The cotton bollworm. U.S. Department of Agriculture Division of Entomology Bulletin 50, Washington DC, USA. 155 pp.

RABB, R.L., STINNER, R.E., and VAN DEN BOSCH, R. 1976. Conservation and augmentation of natural enemies. Pages 233-254 *in* Theory and practice of biological control, eds. C.B. Huffaker and P.S. Messenger. New York, USA: Academic Press.

RAO, V.P. 1974. Biology and breeding techniques for parasites and predators of *Ostrinia* spp. and *Heliothis* spp. CIBC Final Technical Report, U.S. PL-480 Project, Bangalore, India. 86 pp.

RIDGWAY, R.L., and LINGREN, P.D. 1972. Predaceous and parasitic arthropods as regulators of *Heliothis* populations. Southern Cooperative Series Bulletin 169: 48-56.

RIDGWAY, R.L., and VINSON, S.B. (Eds.) 1977. Biological control by augmentation of natural enemies. New York, USA: Plenum Press. 480 pp.

RIDGWAY, R.L., and LINGREN, P.D., COWAN, C.B., Jr., and DAVIS, J.W. 1967. Populations of arthropod predators and *Heliothis* spp. after applications of systemic insecticides to cotton. Journal of Economic Entomology 60: 1012-1016.

RIDGWAY, R.L., KING, E.G., and CARRILLO, J.L. 1977. Augmentation of natural enemies for control of plant pests in the western hemisphere. Pages 379-416 *in* Biological control by augmentation of natural enemies eds. R.L Ridgway and SB. Vinson. New York. USA: Plenum Press. 480 pp.

RIDGWAY, R.L., ABLES, JR., GOODPASTURE, C, and HARTSTACK, A.W. 1981. *Trichogramma* and its utilization for crop protection in the United States. *In* Proceedings, Soviet-American Conference on Use of Beneficial Organisms in Control of Crop Pests. Entomological Society of America publication. 62 pp.

ROACH, S.H. 1975. *Heliothis* spp.: Larvae and associated parasites and diseases on wild host plants in the Pee Dee area of South Carolina. Environmental Entomology 4: 725-728.

ROBINSON, R.R., YOUNG, J.H., and MORRISON, R.D. 1972. Strip-cropping effects on abundance of predatory and harmful cotton insects in Oklahoma. Environmental Entomology 1: 145-149.

ROOM, P.M. 1979. Parasites and predators of *Heliothis* spp. (Lepidoptera: Noctuidae) in cotton in the Namoi Valley, New South Wales. Journal of the Australian Entomological Society 18: 223-228.

ROSSLER, Y., BAR, D., GERLING, D., and GONZALEZ, D. 1975. Integrated control in cotton: Early season pest and natural enemies complexes. *In* Proceedings. Sixth Scientific Conference of the Israel Entomological Society, Tel-Aviv, Israel.

SABROSKY, C.W. 1981. A partial revision of the genus *Eucelatoria* (Diptera, Tachinidae), including important parasites of *Heliothis.* U.S. Department of Agriculture technical bulletin 1635, Washington DC, USA. 18 pp.

SHCHEPETIL'NIKOVA, V.A. 1974. Primenenie trikhogrammy v SSR. Pages 138-158 *in* Biologicheskie motodika zashchity rastenii, Kolos, Moscow, USSR.

SHEPARD, M., and STERLING, W. 1972. Incidence of parasitism of *Heliothis* spp. (Lepidoptera: Noctuidae) in some cotton fields of Texas. Annals of the Entomological Society of America 65: 759-760.

SHEPARD, M., LAWN, R.J., and SCHNEIDER, M. (In press). Insects on grain legumes in North Australia: a survey of potential pests and their enemies. University of Queensland Press: Brisbane, Australia.

SHEPARD, M., McWHORTER, R.E., and KING, E.W. (In press). Biology of *Pristhesancus papuensis* Stal (Hemiptera: Reduviidae) and a description of the immature and adult stages. Canadian Entomologist (in press).

SMITH, J.W., KING, E.G., and BELL, J.V. 1976a. Parasites and pathogens among *Heliothis* species in the Central Mississippi Delta. Environmental Entomology 5:224-226.

SMITH, J.W., STADELBACHER, E.A., and GANTT, C.W. 1976b. A comparison of techniques for sampling beneficial arthropod populations associated with cotton. Environmental Entomology 5:435-444.

SMITH, J.W., and STADELBACHER, E.A. 1978. Predatory arthropods: seasonal rise and decline of populations in cotton fields in the Mississippi Delta. Environmental Entomology 7:367-371.

SNOW, J.W., HAMM, J.J., and BRAZZEL, J.R. 1966. *Geranium carolinianum* as an early host for *Heliothis zea* and *H. virescens* (Lepidoptera: Noctuidae) in the southeastern United States, with notes on associated parasites. Annals of the Entomological Society of America 59:506-509.

STINNER, R.E. 1977. Efficacy of inundative releases. Annual Review of Entomology 22:515-531.

STINNER, R.E., RIDGWAY, R.L., COPPEDGE, J.R., MORRISON, R.K., and DICKERSON, W.A. 1974. Parasitism of *Heliothis* eggs after field releases of *Trichogramma pretiosum* in cotton. Environmental Entomology 3:492-500.

STINNER, R.E., BRADLEY, J.R., Jr., and VAN DUYN, J.W. 1980. Sampling *Heliothis* spp. on soybean. Pages 407-421 *in* Sampling methods in soybean entomology, eds. M. Kogan and D.C. Herzog. New York, USA: Springer-Verlag. 587 pp.

TODD, E.L. 1978. A checklist of species of *Heliothis* Ochsenheimer (Lepidoptera: Noctuidae). Proceedings, Entomological Society of Washington 80: 1 -14.

VAN DEN BOSCH, R., and HAGEN, K.S. 1966. Predaceous and parasitic arthropods in California cotton fields. California Agricultural Experiment Station Bulletin 820, University of California, Berkeley, Calif, USA. 32 pp.

VAN DEN BOSCH, R., LEIGH, T.F., GONZALEZ, D., and STINNER, R.E. 1969. Cage studies on predators of the bollworm in cotton. Journal of Economic Entomology 62:1486-1489

WANG, F.C. 1979. Use of *Trichogramma* to control cotton bollworm (Shanshi Province). Shanxi People's Publishing House. 70 pp.

WENE, G. 1943. *Sagaritis provancheri* (D.T.), an important parasite of the tobacco budworm. Journal of Economic Entomology 36:2.

WHITCOMB, W.H. 1974. Natural populations of entomophagous arthropods and their effect on the agroecosystem. Pages 150-169 *in* Proceedings, Summer Institute of Biological Control of Plant Insects and Diseases, eds. F.G. Maxwell and F.A. Harris. Jackson, Miss, USA: University Press of Mississippi. 647 pp.

WHITCOMB, W.H., and BELL, K. 1964. Predaceous insects, spiders, and mites of Arkansas cotton fields. Arkansas Agricultural Experiment Station bulletin 690, University of Arkansas, Fayetteville, Ark, USA. 84 pp.

WHITCOMB, W.H., and EASON, R. 1967. Life history and predatory importance of the striped lynx spider (Araneida: Oxyopidae). Arkansas Academy of Science Proceedings 21: 54-58.

YOUNG, J.H., and PRICE, R.G. 1975. Incidence, parasitism, and distribution patterns of *Heliothis zea* on sorghum, cotton, and alfalfa for southwestern Oklahoma. Environmental Entomology 4: 777-779.

YEN, D.F. 1973. A natural enemy list of insects of Taiwan. Taipei, Taiwan: National Taiwan University. 106 pp.

The Prospects for the Use of Nuclear Polyhedrosis Virus in *Heliothis* Management

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Abstract

The choice and development of insect viruses for use in controlling pests is outlined, and the major information sources cited. Although viruses are specific and do not have the harmful effects of many chemicals, they are likely to supplement, rather than replace, chemicals. Difficulties in field methodology, lack of information on the crop, pest, and beneficials, and gaps in understanding of viruses are barriers to progress in viral control of insect pests.

Viruses isolated from Heliothis *include cytoplasmic polyhedrosis viruses (CPVs), granulosis viruses (GVs) and nuclear polyhedrosis viruses (NPVs). Two NPVs have been safety-tested and one-Elcar-is commercially available* as a *viral pesticide. To develop another virus or to* use *local production would involve unknown hazards, but the risk could be reduced by simple precautions and quality control. Releasing infected insects or using baits would avoid the real or fancied danger. Some efficacy testing would be required. Full field evaluation and the estimation of "success" present practical difficulties. An assessment of published results is given. Although cotton is probably the most difficult crop for virus trials, two successful examples are quoted of virus use for the control of* Heliothis armigera. *The development of a baculovirus as a pest-management tool appropriate for the local* Heliothis armigera *requires research; however, there is a sound information base, and the potential tor success appears great.*

Résumé

*Perspectives d'utilisation du virus de la polyédrose nucléaire dans la lutte contre l'*Heliothis*: Le choix et le développement des virus d'insectes dans la lutte contre les ravageurs sont exposés et les principales sources d'information sont citées. Bien que les virus soient spécifiques et n'aient pas les effets nuisibles des produits chimiques, ils devraient servir de complément, plutôt que remplacer ces produits. Les problèmes de méthodologie sur le terrain, le manque d'information sur les cultures, les ravageurs, les avantages et les lacunes dans notre connaissance des virus sont des entraves au progrès dans la lutte virale contre les ravageurs.*

*Les virus isolés d'*Heliothis *comprennent les virus de la polyédrose cytoplasmique, virus de la granulose et virus de la polyédrose nucléaire. Deux virus de la polyédrose nucléaire ont subi une évaluation d'innocuité et l'un d'eux, Elcar, est disponible sur le marché comme pesticide viral. Le développement d'un autre virus ou l'utilisation de la production locale entraîneraient des risques inconnus. Cependant, ils pourraient être réduits grâce à des précautions simples et un contrôle de la qualité. Le lâcher d'insectes infectés ou l'utilisation d'appâts permettrait d'éviter les dangers réels ou imaginaires; il faudrait en évaluer l'efficacité. Une évaluation complète sur le terrain et une estimation du ''succès'' présentent des difficultés d'ordre pratique. Un bilan des résultats publiés est présenté. Bien que le coton soit probablement la culture la plus difficile pour des essais sur les virus, deux exemples fructueux d'utilisation de virus contre* **Heliothis armigera** *sont cités. Des recherches sont nécessaires pour développer un baculovirus servant de moyen de lutte approprié contre* **Heliothis armigera** *indigène. Cependant, il y a dans ce domaine une information de base solide et un grand potentiel de succès.*

The development of insect viruses for use in insect pest control is clearly illustrated by the history of one such virus, *Baculovirus heliothis,* the singly embedded nuclear polyhedrosis virus (NPV) iso-

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lated from *Heliothis zea* in the USA. The main development started in 1961 and reached fruition in 1973, when the Environmental Protection Agency granted a label for the use of this product on cotton. Currently it is marketed by Sandoz as Elcar in the USA, and there has been some use of this material in Europe and Australia also.

Insect viruses comprising seven major groups occur naturally and produce diseases in Lepidoptera, Coleoptera, Diptera, and several smaller groups. Viruses have now been isolated and described from some 800 species. Of these known viruses, many are closely related to others pathogenic to man, domestic animals, a wide range of invertebrates, and plants. Only viruses in the *Baculovirus* group have no such dangerous relationships (Table 1), attacking neither intact organisms nor culture cells or tissues from outside the Arthropoda, and commonly showing a very narrow host range within the Insecta. By common consent, research aimed at insect pest control is limited to the *Baculoviruses* (NPVs and granulosis viruses or GVs) and to a few of the related cytoplasmic polyhedrosis viruses (CPVs), although these are treated with caution (Table 2).

Research and development of viruses have passed through a number of phases: discovery and description, efficacy testing, persistence evaluation, characterization and identification by biochemical and serological means, genetic analysis, and investigation of their behavior in the cell. During the last 8 years, considerable work has been carried out on the practical use of these viruses, including application technology, safety testing, field testing, and use in pest management.

The general status of viruses of invertebrates was reviewed by David (1975); Falcon (1976) reviewed the problems associated with their commercialization. Tinsley (1979) has reviewed viruses in their role as potential pesticides, giving the most concise account available. The technology of virus use is a difficult and rather neglected subject, reliance having inevitably been placed on using the often inappropriate methods used for applying chemicals. Although some of the work has been done on *Bacillus thuringiensis,* an attempt has been made to fill this gap, and two symposia were held by the Entomological Society of America, covering application and formulation (Ignoffo and Falcon 1978) and the related topic of persistence in the environment (Hostetter and Ignoffo 1977). A broader and more complete account of some aspects of the whole field of control with microbials is given by Burges (1981) in which the chapters on viruses include the topic of *Heliothis* virus, virus production, and the role of virus in insect pest control. This last textbook follows on from Burges and Hussey (1971), which contains definitive chapters on experimental technique. Basic methods have recently been described in compact form, particularly useful for training, by Kalmakoff and Longworth (1980).

The same advantages are stressed in all introductions to publications on the use of viruses in pest control. Viruses are self-replicating and can produce epizootics; are naturally occurring and so nonpolluting; are nonpersistent; may be cheap; and do not depend for their production on petrochemicals. However, real epizootics hardly ever occur outside forests, application in annual crops is seldom followed by useful persistence to the next season, and intensive safety testing pushes costs up. Viruses are slow-acting compared with chemicals, so that a higher than normal level of crop damage is inevitable. Chemicals used widely are quick-acting and can give excellent control. Some chemicals are nonpersistent and do little damage to some ecosystems, their degradation pathways having been studied, although one suspects that this is just a matter of relative damage.

Viruses, like all microbials, are potentially very effective, but they are far more difficult to use than chemicals and must be considered in relation to other components. The use of viruses will never replace other systems, including chemical pesticides. Nevertheless, the full potential of baculoviruses has not been fully exploited yet (Tinsley 1979). In particular, the fundamental mechanisms by which infection takes place and the phenomena of latency and induction are not understood, and their elucidation, although the province of the specialist, may be entirely relevant to the practical application of viruses. Although a number of attractive strategies of virus use were suggested by some of the earliest workers in this field and have been constantly advocated (Ignoffo 1978), insecticidal approaches are still more commonly used, being relatively straightforward; however, some of the alternatives such as the release of infected larvae and the dispersal of virus by the adult insect deserve more attention.

The motive behind the decision to use a virus or other microbial has rarely been mere curiosity, and most integrated systems have been developed following disasters or potential disasters when chemical control fails. Although seldom absolute, the

Table 1. The Insect pathogenic viruses.

Group	Nucleic acid	Insects affected	Biochemical and biophysical affinities		Comments
			Vertebrates	Plants	
Nuclear polyhedrosis virus (NPV) and Granulosis virus (GV) (Baculovirus)	DNA	Lepidoptera, Hymenoptera, Diptera	None	None	Moderately fast acting, persistent
Cytoplasmic polyhedrosis virus (Rheoviridae)	RNA	Lepidoptera, a few Diptera, Hymenoptera, Coleoptera	Rheovirus Blue Tongue in cattle	Plant rheoviruses	Highly infective, slow-acting; infected larvae excrete virus, possibly more genetically labile
Iridovirus (Iridoviridae)	DNA	Diptera, Coleoptera, Lepidoptera	African swine fever, frog virus	Algal and fungal viruses	Low infectivity
*Entomopox** (Poxviridae)	DNA	Coleoptera, Diptera, Lepidoptera	Birdpox, smallpox, cowpox	None	Possibly stable in field. Relationships with mammalian viruses tentative
Densovirus (Parvoviridae)	DNA	*Galleria, Juniona* (Lepidoptera)	Rodent viruses	None	
Enterovirus (Picoaviridae)	RNA	Bees	Polio Gastroenteritis	Small RNA viruses	*Nodamura* virus in mosquito kills test mammals
Sigma virus (Rhabdoviridae)	RNA	*Drosophila*	Rabies	Plant rhabdo viruses	

*Asterisks indicate level of importance as microbial pesticides.

Table 2. Viruses in large-scale use for Insect pest control.

Pest	Pathogen	Crop attacked	Country	Status
Agrotis segetum	GV	Cereals, etc.	Pakistan, Denmark	
Choristoneura fumiferana	NPV	Trees	Canada	Fully tested
Autograph a californica	NPV	Vegetables, soybean, sugarbeat, cotton	USA	Registration application (on soybean, sugarbeet and cotton)
Heliothis zea, Heliothis virescens	NPV	Cotton	USA	Registration EPA 1975 (Elcar)
Heliothis armigera. Heliothispunctigera	NPV	Cotton, sorghum	Australia	Registration
Lymantria spp	NPV	Forest	USA, Denmark, Sweden	Registration EPA 1978 (Gypcheck)
Hemerocampa pseudotsugata	NPV	Forest	USA	Registration EPA 1976 (Biocontrol 1)
Neodiprin spp	NPV	Forest	Canada	Fully tested, large scale use.
Trichoplusia ni	NPV	Cotton	Colombia, S. America	Large-scale (pest eradicated)
Oryctes spp	CPV	Coconut	Samoa	Large-scale use
Rhinoceros beetle	CPV	Coconut	Seychelles	Large-scale experimental
Spodoptera spp	NPV	Vegetables, cotton etc.	People's Republic of China	Large-scale use
Mythimna separata	NPV	Cotton	People's Republic of China	Large-scale use
Heliothis armigera	NPV	Cotton	People's Republic of China	Large-scale use

appearance of resistance to chemicals provides the strongest motivation. However the motive is usually a mixture of scientific and political reasons, as when a response is made to a strong environmentalist pressure group, or is rejected because of the presence of a particularly effective insecticide industry. Now that there is a general awareness of its dangers, pollution is rarely so severe that it cannot be abated by a change of chemical. Decisions to turn to microbials rather than to modify the chemical system in pest management will, with the present state of the art, largely be made as a policy or political decision. My selection of relevant points from the voluminous literature will itself be guided by my own preferences and my own experience with *Heliothis* and Spodopfera *littoralis* and their viruses in Africa, Crete, and Egypt. My aim then is to express an opinion, and hopefully to stimulate discussion, rather than to suggest answers.

Viruses of *Heliothis* Species

The genus *Heliothis* includes a number of important crop pests; of these, *Heliothis zea* and *Heliothis virescens* in the New World, and *Heliothis armigera* in the Old World have been the most closely studied. Viruses have been isolated from all the species that have been sufficiently studied. One *Iridovirus* (nonoccluded), at least two cytoplasmic polyhedrosis viruses (CPVs), one granulosis virus (GV), and two distinct groups of nuclear polyhedrosis viruses (NPVs) have been isolated from the genus. The NPVs have been compared by modern techniques, including serology and DNA analysis using restriction endonuclease, and it is clear that there are structural differences between them. What is less clear is what these structural differences mean. Although cross-infectivity has been shown, precise comparison of their efficacy, which can only be made using the LD50s from individual feeding bioassays, is not complete. Work is underway, however, in Columbia, Missouri, and at the Glasshouse Crops Research Institute, UK, where it has been found that singly embedded NPVs have very similar LD50s and are slightly more effective than the multiple-embedded NPV when tested with *Heliothis armigera* (Payne and Williams, personal communication).

Baculovirus heliothis, the NPV in Elcar, is singly embedded and is known to kill *Heliothis armigera, paradoxa, phloxiphaga, punctigera, virescens,* and *zea* (Burges 1981). It has been found to have no effect when fed to 37 other insects, spiders, and mites, or injected into the hemocoel of four other insects. There is also confirmation of effectiveness from field and laboratory studies in Australia, but some contrary reports from India. Unless it is planned to produce a local virus, Elcar would seem to be the obvious first choice for any new work, since it is a well-formulated and tested product. A laboratory evaluation should however be made comparing the LD50 of this virus with others using local insects.

The Question of Safety

There are now a great deal of data to support the thesis that the baculovirus group is the safest of all the known viruses. The definition of safety varies, however, with political outlook and social attitude. Burges (1981) describes how microbials, including *Heliothis* virus, are locally produced and used on communes in China without any local safety testing. Although many field trials have been carried out everywhere using crude or purified virus without any safety testing, the USA, UK, and a few countries in Europe regulate the use of viruses and have laid down protocols for mammalian safety testing. These protocols are based on the WHO/FAO (1973) recommendations, and a series of guidelines produced by the U.S. Environmental Protection Agency (EPA). The evolution of these protocols is described by Burges (1981). Although there are differences in that some countries tend to test purified virus and others to batch-test impure virus that includes insect cells and many bacteria, the systems used so far have all been thorough-some would say too elaborate—and have been based on safety-testing systems for insecticides and pharmaceuticals. They have used small mammals and tissue-culture systems and there have been no adverse findings. Since the reports issued are often highly complex documents, the Society for Invertebrate Pathology, in an attempt to clarify the situation, has issued a statement that says, "Absolutely no health or environmental hazard has yet been demonstrated which would prevent the replacement of toxic chemical pesticides by baculoviruses in the control of certain pests" (Kreig et. al. 1980).

Safety testing is expensive, probably unnecessarily so, but the whole development of *Baculovirus heliothis* is said to have been one-fifth as expensive as the development of a conventional insecticide.

Safety testing also requires a high degree of organization; where this is lacking, or where a relatively minor or local pest is the subject, or where the crop attacked is of relatively low value, it is tempting to cut costs and to simplify both production and application by using crude methods and omitting safety testing and quality control. In almost every case, the early attempts at using viruses, often in quite large field trials, made use of virus suspensions prepared from insect cadavers and at best crudely filtered.

In Zimbabwe, farmers are instructed to control *Plusia* spp on soybean by spraying with a suspension of diseased larvae stored in the freezer since the last season, or since the last crop cycle. In Sabah the macerated bodies of the limacodid caterpillars of *Dama trima* are used to control this pest, which attacks oil and coconut palm grown in large plantations. Unskilled labor is used, and it is thought that only the simplest testing has been carried out. Examination of samples of the spray have shown the presence of three viruses (Harrap and Tinsley 1978), a granulosis virus, and two small RNA viruses, one of which is like an enterovirus.

The *Darna trima* control method appears to be very effective and cheap, and there is no evidence that any of the workers have suffered any harm, although human blood samples have shown positive antigen-antibody reactions with one or other of the two RNA viruses. What are the objections to this method? The example of *Darna trima* and the fact that virus samples of the NPVs of *Trichoplusia ni* (Morris et al. 1978) and *Heliothis armigera* (Rubinstein 1979) have also been found contaminated with small viruses confirm the idea that more than one virus can appear in a batch of insects infected with an NPV. The presence of these viruses is likely to vary from batch to batch, especially if a sample do-it-yourself system is used, if no purification other than filtration is carried out, even baculoviruses that are intended to be present will be very difficult to count, so that the presence of other viruses, even insect pathogens, will not be detectable by bioassay. Although the virus contaminants in the specific examples quoted have not been causes of mammalian disease, small viruses isolated from *Melolontha* were injected into rabbits and caused a fatal disease. *Rickettsia* are also known to occur in insects, and *Rickettsia* similar to those producing fatal fevers in man have been isolated from a Saturniid.

Finally, spray liquids prepared by crude methods, especially in a warm climate, will contain bacteria from the insect's gut, and inevitably bacteria of decay, which rapidly multiply in this highly nutritious insect soup. The decay bacteria in particular may be-hazardous. The pathogenicity of unidentified virus, of a mixture of known or unknown viruses plus bacteria, cannot be predicted. In fairness, these bacteria will be no worse than in a natural outbreak, no more hazardous than bacteria in dung heaps or open drains. However, one important difference is that spraying often produces a fine mist of small droplets; spray operators may be exposed to these for hours at a time. The pathology of the inhalation of such mixtures deep into the human lung is not known, and neither is the possibility of allergenicity. Although purified viruses are tested by inhalation tests and for allergenicity, the contents of crude mixtures are variable and unknown.

In developing an insect pathogen, preliminary field testing is usually done on materials that have not been safety-tested and that have only been crudely purified. The risks are probably no greater than when performing any operation with crude materials, and I for one have often taken them. The difficulty is when one expands the experiment into a recommendation for control, someone has to issue the details, which will involve suggesting exposure of workers to an undefined hazard. In some countries the concern is that the illness of a farmer, especially with undefined symptoms, would be followed by legal action, which in turn might cause loss of faith in the insect control method.

The decision to make no regulations or recommendations regarding the safety-testing is logical, but is one that might be difficult to justify, although it can be explained on the grounds of expediency, or a choice of the lesser of two evils. In circumstances where this seems to be the right policy, simple precautions—especially the wearing of masks and overalls—would reduce the risk, and early steps should be taken to train the spray operators. Care should also be taken to select the least hazardous method of virus application. Sprayers producing large droplets and thickened spray liquids would reduce what appears to be the worst hazard—the generation of aerosol-sized droplets. The use of semisolid baits would further protect operators, and the release of infected insects would eliminate the inhalation risk altogether. Perhaps the finest actual example of a low-risk situation would be the control of *Oryctes* spp in Samoa, where piles of rotting sawdust that attract the insects are treated with virus and fungus *Metarrhizium anisopliae* (Marschall 1980). In Crete I have obtained a high level of larval kill of *Spodoptera littoralis* larvae by scattering a porridge-like bait containing NPV on the ground under lucerne.

My own preference would be to use a low-risk method of application and a highly purified virus in a simple formulation for laboratory investigations and small-scale field trials, eliminating the worst hazards and making the determination of virus concentration simple, thus giving the required degree of precision for both types of study. If this preliminary assessment shows efficacy, the next step would be large-scale field operations, which would follow safety testing. If the virus is produced locally, the quality of the product should be carefully checked.

Where a virus is used in the field, not only the target pest but other invertebrates and vertebrates will be exposed to the virus as well. Obviously the kill of other pests would be an advantage, but what of the dangers to beneficials, to food chains, and to the environment generally? Being specific, viruses are likely to cause less harm than chemical pesticides, many of which are general poisons. This topic was reviewed by Bailey (1971). Natural virus epizootics and the repeated use of some viruses have given no indication of disease outbreaks in any beneficial. In my own field trials in Crete, *Spodoptera littoralis* larvae from unsprayed fields were collected and compared with those collected from fields treated with different levels of virus, by rearing to death or pupation on artificial diet. Large numbers of parasites were obtained from batches of both uninfected (control) and lightly infected larvae. Burges (1981) reports that extensive pathological examinations on honeybees showed no sign of any virus disease. In general, further investigations would be required when a virus is introduced to new areas but can be confined to types of beneficial organisms that are not present in the native habitat of the virus. *Baculovirus heliothis* (Elcar), being registered by the EPA, has been most completely tested, while a similar NPV, isolated from *Heliothis armigera,* has been safety-tested in the UK.

Are Viruses too Great a Risk?

The use of virus inevitably involves risk—the risk that someone involved in the program will become ill, though not necessarily from the virus, and the risk of losing money. A list of the major successful viruses (Table 2) that have been developed to the stage of widespread use or official recognition without serious loss is encouraging. I have dealt with the need to safety-test the actual insect pathogen, but one constantly voiced concern is that a virus that has been developed, safety-tested, and used may, through a chance mutation, change into a human pathogen. As viruses are self-replicating they cannot be recalled once released.

Viruses are self-replicating in the insect host, are variable, and, like all organisms that have the nucleic-acid-based gene system, show genetic variation and have the potential for mutation. However, most insect pathogens have been known and observed for many years without the appearance of such a hazard. In safety tests, no replication has occurred in normal intact animals, immunosuppressed intact animals, or in tissue culture systems. Where tests have been performed, e.g., Carey and Harrap (1979), insect viruses have been found not to persist in the vertebrate body. Without prolonged exposure to the vertebrate's internal environment, there is no selection and so no chance of adaptation to this environment. There are enormous numbers of viruses in our habitat that cause disease in invertebrates and vertebrates, including animals that are our close companions. Although man shares certain diseases produced by viruses with domestic and wild animals, e.g. rabies, the appearance of new virus diseases is rare. Such a possibiity can never be eliminated, but circumstantial evidence suggests that it is unlikely, and that the danger should come from a baculovirus seems very improbable. Modern research on viral genetics—not on genetic engineering, which has received official discouragement, but in the selection of lines from single nucleocapsids, coupled with testing in mammals—should reveal any such hazard, if it exists, more quickly than it would appear in the control situation.

Another, more tangible, cause for concern is that the selection of viral and insect strains will lead to the appearance of insect resistance as it has done so often with chemical pesticides. It is quite easy to compose a strong argument for or against this possibility. In the laboratory, however, populations of *Heliothis zea have* been subjected to heavy selection pressure using *Baculovirus heliothis* for 20 to 25 generations without the appearance of resistance (Ignoffo and Allen 1972) and similar results were obtained with *Heliothis armigera* (Whitlock 1977). It has been reported that different strains of *Baculovirus heliothis* exist with a 56-fold range of activity towards the insect. In *Spodoptera* *frugiperda,* Reichelderfer and Benton (1974) demonstrated the existence of strains with a fivefold difference in activity. The existence of virus strains differing in their protein structure has also been demonstrated in *Spodoptera littoralis* (Merdan et al. 1977). In our work on the susceptibility of wild populations, preliminary work has shown only an approximate fivefold difference that would be accounted for by the natural vigor of wild insects. Selection of a codling moth virus for resistance to ultraviolet light was achieved after only four passages (Brazzel and Benz 1979).

Although it is difficult to generalize, it would seem that some viruses are relatively easily selected for certain characters, but that selection for resistance usually fails. Part of the difficulty here is that the infection mechanisms, the disease process, and the cause of differences in susceptibility between insects are not understood, and this lack of knowledge is a serious barrierto progress (Tinsley 1980). Until this barrier is overcome or until a well-authenticated case of appearance of a resistant strain of insect is described, the risk remains hypothetical.

Another risk is that of financial loss. Development of a control system is greatly aided if the virus is produced in a standard formulation, and this is a field in which commercial organizations have most of the expertise. Virus development is usually regarded as being commercially unattractive, because the virus itself cannot be patented at the moment, and many viruses have a narrow host spectrum, which limits the potential market (Surges 1981; Falcon 1976). At present, viruses must be produced in live insects, which is expensive, although production costs have been cut in the USA for some insects through automation of the rearing process. Production in tissue culture systems is the subject of intensive research in the USA and Europe, and a breakthrough in this technology could significantly reduce costs of production and purification. However unattractive virus production appears, the first registered viral pesticide, Elcar, was produced by a commercial company, Sandoz (Elcar currently costs $ 7.8/ha treatment), and there has been some interest shown in the development of broad-spectrum viruses such as *Autographa californica,* which may soon be registered. There has also been commercial interest in the production of novel formulations. Generally, a period of world trade recession is not a time to expect commercial innovation. The alternative, which may be suitable in some countries, is for the virus to be produced by government agencies, as in Canada (sawfly viruses by the Canadian Forestry Service) and the USA (Douglas fir tussock, moth NPV by the USDA), or by groups of farmers, as in the communes of the People's Republic of China.

Efficacy Testing

The establishment of LD50s using a healthy insect colony is an essential part of any control program with viruses. It is only the LD50, involving the dosing of individual insects, that can give an absolute means of checking the virus for activity, and the target population for changes in susceptibility. With the *Heliothis* viruses, testing techniques have been worked out in detail, and if known viruses are used, these need to be checked against the published value. Once this has been done, only periodic checks are needed, using an established test colony.

Mass-dosing (LC50) bioassays, which are easier to perform, should be used to determine the persistence of virus deposits on artificial and natural targets under local conditions. A comparative technique, making use of standard suspensions, is appropriate. The exposure of virus samples to the environmental conditions in a particular place or on a particular crop should be reinforced by physical measurements of ultraviolet light, temperature, etc., but these measurements are secondary, and simple instruments will suffice.

Viruses used in control should be characterized so that precise identification is possible. Several kinds of *Heliothis* virus have already been characterized, and the task is easy if done by specialists. Identification does not have to be repeated often, so that the relatively specialist techniques involved are not a serious disadvantage. The relatively new serological technique, ELISA (enzyme-linked immunosorbent assay) (Kelly et. al. 1978; Crook and Payne 1980), is being developed for the assessment of virus samples, e.g. in infected larvae, or on sprayed leaves, and requires little expertise, is very quick and simple, and should be widely used.

Is Heliothis Virus Successful?

The heading is deliberately vague. Exact definition of success is difficult, and aims should be clearly understood as a guide to research. In general, damage thresholds should be established, and acceptable levels agreed upon in advance. Viruses hardly ever give the same quickly established control and undamaged crops that chemical insecticides can. In the last two decades between 150 and 200 field tests were carried out using *Baculovirus heliothis,* 60% on cotton, 30% on maize, and the rest on soybean, sorghum, tobacco, and tomato. The tabulation of these results given by Burges (1981) is condensed in Tables 3, 4, and 5. It is clear from these that results are often not equal to those obtained with chemicals. In the USA in 1978, entomologists using this virus had mixed opinions about it, the verdict of some being that *Heliothis* populations on some of the cotton trials were not sufficient to cause significant crop loss, and agronomic factors and the presence of other pests were more important. However, even on cotton, which is a difficult crop, some successes are clear. It is also evident that crop selection is important, and successes on cotton were less evident than on maize; control on sorghum was frequently better, and control on soybean best of all.

My own experience of using *Heliothis* virus against *H. armigera* was that although good persistence on cotton was easily demonstrated with leaf bioassays and test insects, larval kill under very heavy attack could not be demonstrated. Using NPV to control *Spodoptera littoralis* in Egypt, we have demonstrated crop protection in terms of leaf damage, but in two seasons of low populations we have found no demonstrable crop loss even on untreated controls. However, trials in the Republic of South Africa against *H. armigera* on cotton were very encouraging, showing yield increases comparable to those obtained with chemicals.

Table 3. Mean cotton yield ratios (treated: control) for 38 field trials of Baculovirus *heliothis* on cotton, 1963-67.

Dose (PIB/0.4 ha)	Light to moderate *Heliothis zea* infestations	Heavy *H. zea* infestations
6×10^{10}	1.06	1.07
60×10^{10}	1.24	2.17
600×10^{10}	1.34	2.26

Source: Burges (1981)

In Australia, successes were obtained using *Heliothis* NPV on cotton, following a laboratory-screening program; yield increases were obtained although it was necessary to accept a moderate standard of control and the associated level of damage.

Cotton is generally accepted as being a difficult crop on which to test the control of individual pest species and on which to use viruses. The plants compensate for early damage, and virus inactivation on the cotton leaf is particularly rapid due to the interaction of ultraviolet light, high temperature, and the moderate to high alkaline conditions that sometimes occur (Yearian and Young 1974). A bud and boll feeder like *Heliothis* is difficult to kill with any pesticide acting through the gut, and an unusually efficient spray cover is necessary. Considerable

Table 4. Yield ratios[a] from cotton and maize trials with virus and Insecticide treatment for *Heliothis* control.

Crop and treatment	Infestation level Light	Medium	Heavy
Cotton			
A	1.11	1.48	2.22
B	0.97	1.01	0.97
Maize			
A	18.12	2.63	1.08
B	0.62	0.78	1.56

Source: Burges (1981).

a. A = virus treated: control;
B = virus treated: insecticide treated.

Table 5. Effect of application of *Baculovirus heliothis* on Heliothis populations and damage on soybeans.

Virus application rate (PIB/0.4 ha)	Reduction in larval population (%)	Reduction in pod damage (%)
6×10^9	92	75
600×10^9	100	90

Source: Burges (1981).

effort is being put into developing more efficient application techniques. In our cotton trials in Egypt we have obtained much improved spray cover by developing our own spray lance and by adopting a fan-assisted ultralow-volume sprayer. Almost all trials in which ultraviolet protectants have been tested have shown marked improvements, but even greater benefits have been obtained through the addition of feeding stimulants such as Coax and molasses.

Successes with NPV applied to sorghum are related to the localized feeding of the larvae in the heads, which are easily covered with spray or dust, and to the absence of growth dilution. Even greater successes were obtained with NPV on soybean. Again, the advantage arises from the feeding behavior of the *Heliothis* larvae on these plants, possibly from the denser canopy and the chemical conditions on the leaves. Kill on tobacco was very high, but the inevitably slow action of the NPV resulted in unacceptable damage levels.

The overall picture of the success of *Baculovirus heliothis* is encouraging. There seems no doubt that the virus can give a high level of kill and sometimes effective control. The variable success on different crops or on the same crop in different areas or at different times, underlines a basic weakness. This weakness, recognized by most practical entomologists, is that in spite of a great deal of research effort, our understanding of the complex ecology of field-crop pests is very limited. This limitation is particularly apparent when we are trying to use a highly specific control agent such as NPV. Studies of the interrelationships between pest and virus have been neglected; where they have been undertaken, the results have been rewarding (Entwistle and Adams 1977), and lack of this information is the second great barrier to progress. On some crops, especially where they are attacked by a number of different pests, the results of using NPV in the same manner as an insecticide are difficult to assess. Where it is possible to choose, it would be best to carry out the first field tests using this approach on the most favorable crop, e.g., soybean or *Dolichos* bean, and to determine the effect of spraying on immediate kill, crop protection, and possibly on long-term population reduction.

In many countries it seems that insecticidal control of *Heliothis* still works well; here, the advantage of using NPV would be to reduce chemical applications and perhaps ward off the appearance of resistance to chemicals. It is mainly in such situations that a simple approach is adopted, often being extended to include the effect of mixed applications. In spite of many reports of synergistic effects from laboratory testing, none of these has been definitely proved in the field. Even a simple additive effect may be worth applying, however, and the combination of NPV, *Bacillus thuringiensis,* and chemicals in a simple routine seems to be a useful approach, exploiting the particular properties of each material.

Chemical control of *Heliothis* is producing clearly recognizable problems in many countries. In the Namoi Valley of Australia, problems have arisen with multiple resistance to chemicals and the destruction of an extensive predator fauna; in many southern states of the USA, pesticide used mainly to control boll weevil has resulted in severe *Heliothis* control problems; and in South Africa and Zimbabwe, serious outbreaks of cotton red spider mite result from the slightest mistake in the routine. Where problems are acute, or where the crop attacked by *Heliothis* is of real importance, positive action is required.

Ringing the changes with chemical pesticides is probably effective only in the short to medium term. One of the effects of the world economic recession has been a reduction in the rate at which new chemicals are being produced by industry. Where resistance is appearing, there is really no alternative to a policy of developing chemical use, classical biological control, cultural control, and microbial pesticides, including viruses, to produce an integrated system before it is too late. The system developed may be relatively cheap and simple, or relatively expensive, particularly in terms of trained manpower in the beginning, but in many areas, the long-term alternative is disaster.

Local and national politics may make such an integrated system unattainable, but there seems little justification for scientists not to try and initiate cooperation between institutions, states, or countries that have a common *Heliothis* problem, so that the cost of developing the individual components of such a system can be divided. It is now generally accepted that *Baculovirus heliothis,* other NPVs, and other microbials have great potential, provided they are used as components of IPM systems.

Use of *Heliothis* NPV in Pest-Management Systems

Baculovirus heliothis has been repeatedly field-tested on different crops in the USA in areas where

Heliothis is a problem. In the Mississippi Delta area, cotton is attacked by both the boll weevil and *Heliothis zea* and chemicals applied to control these pests results in the destruction of predators, resulting in heavy crop loss. The control of overwintering weevils was the first step; this was followed by the replacement of some early sprays against *Heliothis* by sprays of virus, giving reasonable control of this pest and eliminating destruction of beneficials. Virus application rates as low as 20 larval equivalents/acre on 20- to 30-acre plots gave final yields better than or equal to chemical application alone (Allen et al. 1966). Similar results were obtained in Arkansas, where NPV was used for early-season *Heliothis* control in a generally simpler pest situation. In the latest review in Burges (1981), these trials are mentioned, but there is no record of the establishment of an IPM system on farms in these areas. Publications show that work on the components of these systems continues, but it may be that resistance by the farming community, mentioned to me in 1978, has meant that farmers prefer to continue to rely on chemical programs. In Texas, there was a serious problem of resistance of *Heliothis* to chemicals, but this has apparently been mitigated by more controlled use of the synthetic pyrethroids, a massive release of *Trichogramma,* and some use of NPV sprays.

In the soybean-growing areas, e.g., Missouri and Florida, there has been an intensive effort to develop an IPM system using a computer program to predict populations and to make decisions. The crop is attacked by a number of pests, several of which are susceptible to pathogens, including *Baculovirus heliothis* and the fungus *Nomuraea rileyi.* Soybean was judged to be particularly suitable for the use of virus, and to be amenable to changes in agronomic practice. Conservation of the extensive fauna of beneficial arthropods, the use of chemicals, spraying with Elcar, and the application of *Nomuraea,* coupled with changes in crop spacing, are all parts of this system. Recent papers indicate that particular emphasis is now being placed on the *Nomuraea component. There* are no reports of expansion into commercial areas, perhaps because Elcar is not yet registered for use in crops other than cotton.

Finally, there are reports from Australia of general successes with *Baculovirus heliothis,* following screening of a number of NPVs. A complex IPM system using a computer has been developed and run for 2 years for the control of cotton pests in the Namoi Valley of New South Wales, where *Heliothis* is particularly destructive, where there is a serious problem of insecticide resistance, and where it is desirable to benefit from an extensive fauna of beneficials (Room 1979). The sampling data collected daily include records of *Heliothis* larval numbers in six age categories, records of 32 other arthropods, including pests, meteorological data, and plant-growth data. Predictions of pest populations were found to be correct on 93 out of 109 occasions, although they could only be made a few days ahead.

In order to maximize the effect of beneficials on *Heliothis* populations, Elcar was used to replace chemicals below a defined level. In the 2 test years, NPV was applied five times, with five applications of chemicals on managed fields, as compared with 16 applications of chemicals on commercial fields. Although *Heliothis* kill and the reduction of damage was only moderate on managed fields, the yields were slightly superior, and given realistic costing (bearing in mind that reduced costs will almost certainly result from improved methods of virus production in the future), costs should be lower than with commercial practice. There is considerable reluctance by farmers to adopt the pest-management technique, as they find it hard to relinquish the quick, clean results of chemicals and to accept what appear to be high larval populations and damage levels.

Conclusions

There are a number of *Baculovirus* isolates available for the control of *Heliothis* spp. Two of these have been safety-tested, one of which was isolated from *Heliothis armigera* (Kelley et al. 1980), and the other, more fully developed in the USA, is in commercial production by Sandoz and marketed at a present price of U.S. $ 40/kg and an estimated cost of $ 7.8/ha treatment. Results from field trials are somewhat mixed, depending on the crop treated and the other pests present. Further research is needed both on the fundamental mechanisms involved in the disease process and in the epidemiology. NPV has usually been employed in the same manner as chemicals but is usually less quick-acting and less efficient. Since it is highly specific, it avoids resistance problems and the destruction of beneficials, and since it is not a general poison, avoids harmful effects in food chains. Full assessment of the long-term benefits has not been made. Selection of the right crop, preferably one with few pests other than *Heliothis,* is important.

Costs are estimated to be lower than with *Bacillus thuringiensis,* but are relatively high in proportion to the kill obtained, although experience in Australia suggests that with chemicals control may be unnecessarily complete. Production costs are high, because the virus is produced in live insects, while stringent safety-testing requirements add to the costs. It is likely that proved production techniques, especially in cell cultures, will eventually reduce costs, and safety-testing requirements have already been modified.

Use of unpurified and untested virus in crops involves hazards that cannot be quantified, but in some circumstances techniques such as the release of infected larvae would reduce these hazards to those encountered in natural epizootics. The insecticide method (inundative release) of virus use is not likely to replace chemicals, but used against low *Heliothis* populations should often allow chemical applications to be reduced. Population reduction in multicrop areas and the development of integrated pest-control systems will depend on local conditions, but may initially involve complicated systems costly in terms of scientific manpower. In areas where the development of resistance to chemicals is a problem, the use of IPM seems almost inevitable.

Successful systems require not only scientific input but a farming community prepared to accept innovation and a cropping system that can be manipulated. Understanding of: (1) the beneficials complex, (2) the relationship between pest damage and yield, and (3) the economics of local agriculture, is essential. A phased research program on the use of virus of *Heliothis* should be planned to make full use of the considerable body of information available.

References

ALLEN, G.E., GREGORY, B.G., and BRA2ZEL, J.R. 1966. Integration of the *Heliothis nuclear* polyhedrosis virus into a biological control programme on cotton. Journal of Economic Entomology 59: 1333-1336.

BAILEY, L. 1971. The safety of pest insect pathogens for beneficial insects. Pages 491 -505 *in* Microbial control of insects and mites (eds. H.D. Burges and N.W. Hussey). New York: Academic Press.

BRAZZEL, J.R., and BENZ, G. 1979. Selection of a strain of the granulosis virus of the Codling Moth with improved resistance against artificial u-v radiation and sunlight. Journal of Invertebrate Pathology. 33:358-363.

BURGES, H.D. 1981. Microbial control of pests and plant diseases, 1970-1980. New York: Academic Press.

BURGES, H.D., and HUSSEY, N.W. (eds.) 1971. Microbial control of insects and mites. New York: Academic Press.

CAREY, D. and HARRAP, K.A. 1979. Safety tests on the NPVs of *Spodoptera littoralis* and S. *exempta. In* Invertebrate tissue culture, developments and applications (eds. E. Rurstak and K. Maramorosch). New York: Academic Press.

CROOK, N.C., and PAYNE, C.C. 1980. Comparisons of three methods of Elisa for *Baculoviruses.* Journal of General Virology 46: 29-37.

DAVID, W.A.L. 1975. The status of viruses pathogenic for insects and mites. Annual Review of Entomology 20: 97-119.

ENTWISTLE, P., and ADAMS, D. 1977. Prolonged retention of activity in the NPV of *Gilpina hercyniae* on foliage of spruce species. Journal of Invertebrate Pathology 29: 392-394.

FALCON, LA. 1976. Problems associated with the use of arthropod viruses in pest control. Annual Review of Entomology 21: 305-333.

FAO/WHO (Food and Agriculture Organization/ World Health Organization). 1973. Report of the Joint FAO/WHO Meeting on Insect Viruses, Nov 1972, Geneva, Switzerland. WHO publication VIR/VBC/73.1.35 pp.

HARRAP, K.A., and TINSLEY, T.W. 1978. The international scope of invertebrate virus research in controlling pests. *In* Viral pesticides: present knowledge and potential effects on public environmental health, (eds. M.D. Summers and C.Y. Kawanishi). Environmental Protection Agency-600/9-78-026, Washington, DC, USA.

HOSTETTER, P.L., and IGNOFFO, C.M. 1977. Environmental stability of microbial insecticides. Entomological Society of America miscellaneous publication 10(3): 1-128.

IGNOFFO, C.M. 1978. Strategies to increase the use of entomopathogens. Journal of Invertebrate Pathology 31(1):1-3.

IGNOFFO, C.M. 1979. The first viral pesticide: past, present and future. Pages 105-115 *in* Development of industrial microbiology. Monticello: Lubrecht and Cramer.

IGNOFFO, C.M., and ALLEN, G.E. 1972. Selection for resistance to a NPV in laboratory populations of the cotton bollworm *Heliothis zea.* Journal of Invertebrate Pathology 20:187-192.

IGNOFFO, C., and FALCON, K.A. 1978. Formulation and application of microbial insecticides. Entomological Society of America miscellaneous publication 10(5): 1-68.

KALMAKOFF, J., and LONGWORTH, J.F. 1980. Microbial control of insect pests. New Zealand Department of Scientific and Industrial Research Bulletin 228 Wellington, New Zealand.

KELLY, D.C., EDWARDS, M.L., and ROBERTSON, J.S. 1978. The use of enzyme linked immunosorbent assay to detect a NPV in *Heliothis armigera* larvae. Journal of General Virology 40: 465-469.

KELLY, D.C., BROWN, D.A., ROBERTSON, J.S., and HARRAP. K.A. 1980. Biochemical, biophysical and serological properties of two single enveloped nuclear polyhedrosis viruses from *Heliothis armigera* and *Heliothis zea.* 3: 319-331.

KREIG, A., FRANZ, J.M., GRONER, A., HUBER, J., and MILTENBURGER, H. 1980. Safety of entomopathogenic viruses for control of insect pests. Environmental Conservation 7(2):158-160.

MARSCHALL, K.J. 1980. Progress in microbial control: coconuts. Page 31 *in Proceedings,* Workshop on Insect Pest Management with Microbial Agents: Recent Achievements, Deficiencies, and Innovations Boyce Thompson Institute, Cornell University, Ithaca, NY, USA.

MERDAN, A., CROZIER, L., VEYRUNES, J-C., and CROZIER, G. 1977. Etude comparee des proteines des polyedres et des virions de trois isolats de baculovirus de *Spodoptera littoralis.* Entomophaga 22(4): 413-420.

MORRIS, T.J., HESS, R., PINNOCK, D., and SCHLEGEL, D.E. 1978. Isolation of a non-occluded virus associated with baculovirus infections in *Trichoplusia ni.* Page 564 *in* Abstracts of the Fourth International Congress for Virology, 30 Aug-6 Sept 1978, The Hague, Netherlands.

PESTICIDES SAFETY PRECAUTIONS SCHEME. 1979. Registration criteria for biological agents used as pesticides. London, UK: Ministry of Agriculture, Fisheries and Food.

REICHELDERFER, C.F., and BENTON, C.V. 1974. Some genetic aspects of the resistance of *Spodoptera frugiperda* to a nuclear polyhedrosis virus. Journal of Invertebrate Pathology 23:378-382.

ROOM, P.M. 1979. A prototype 'on-line' system for management of cotton pests in the Namoi Valley, New South Wales. Protection Ecology 1:245-264.

RUBINSTEIN, R. 1979. A nonoccluded virus of the American Bollworm *Heliothis armigera.* Phytophylactica 11:179-180.

TINSLEY, T.W. 1979. The potential of insect pathogenic viruses as pesticidal agents. Annual Review of Entomology 24: 63-87.

TINSLEY, T.W. 1980. Progress in microbial control: pathogens. A.Virus. *In* Proceedings, Workshop on Insect Pest Management with Microbial Agents: Recent Achievements, Deficiencies, and Innovations. Boyce Thompson Institute, Cornell University, Ithaca, NY, USA.

WHITLOCK, V.H. 1977. Effect of larval maturation on mortality induced by nuclear polyhedrosis and granulosis virus infections of *Heliothis armigera.* Journal of Invertebrate Pathology 30:80-86.

YEARIAN, W.C., and YOUNG, S.Y. 1974. Persistence of *Heliothis* NPV on cotton plant parts. Environmental Entomology 3(6):1035-1036.

The Potential Use of Microbials in *Heliothis* Management

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Abstract

Studies have shown that all of the major groups of entomopathogens contain organisms with some potential for use in Heliothis *management. The use of these microbials may vary considerably between crops and locations, depending upon climate, disease symptomatology, and economic thresholds of crop damage. In general, the microbials function naturally in the environment as population suppressors, and as such, ideally function as elements in integrated pest management (IPM) programs. The manipulation of pathogens in such management programs offers the greatest potential for their use at this time. The majority of the research on microbial control of* Heliothis has *been conducted in cotton using the bacterium,* Bacillus thuringiensis *Berliner, and nuclear polyhedrosis viruses. These pathogens are presently used to suppress low to moderate populations of larvae in cotton within the IPM framework. Recent studies have indicated that using gustatory-stimulant adjuvants can increase the effectiveness of the microbials, and can result in the control of higher populations of* Heliothis *than nonvally feasible. However, the current use of such induced epizootics as single-factor methods tor control is negligible, compared with the less costly chemical control methods. Although the immediate future tor sizable markets of microbials apparently lies within the IPM programs, the potential for use in unresearched areas remains high.*

Résumé

*Potentiel d'utilisation d'agents pathogènes dans la lutte contre l'*Heliothis*: Des recherches ont révélé que tous les principaux groupes d'entomopathogènes ont des organismes qui pourraient servir à lutter contre* Heliothis*. L'utilisation de ces agents pathogènes peut varier considérablement entre les cultures et les sites, en fonction du climat, de la symptomatologie des maladies et des seuils économiques des pertes culturales. En général, les agents pathogènes opèrent naturellement dans l'environnement comme destructeurs des populations et idéalement comme éléments de programmes de lutte intégrée contre les ravageurs. Jusqu'à présent, la manipulation des agents pathogènes dans le cadre de ces programmes de lutte offre le plus grand potentiel d'utilisation. La majeure partie de la recherche faite sur la lutte contre l'*Heliothis *avec des agents pathogènes portait sur le coton et la bactérie* Bacillus thuringiensis *Berliner et les virus de la polyédrose nucléaire. Ces agents pathogènes servent à supprimer des populations basse ou moyenne de larves chez le coton, dans le cadre de programmes de lutte intégrée. Des études récentes ont indiqué que l'utilisation d'adjuvants de stimulation gustative pourrait accroître l'efficacité de ces agents pathogènes et permettre de combattre des populations plus élevées d'*Heliothis*. Cependant, l'utilisation actuelle de telles épizooties induites, comme méthodes à facteur unique de lutte, est négligeable, comparativement aux mesures de lutte chimique moins coûteuses et plus efficaces. L'avenir immédiat des débouchés pour des agents pathogènes semble se limiter aux programmes de lutte intégrée. Cependant, le potentiel d'utilisation est grand dans des domaines non encore étudiés.*

Insect pathogens, or microbials, act naturally to limit populations of crop pests, as do other natural control factors. Most people who have been involved in agricultural field studies have, at some time, observed extensive epizootics, usually by the occluded viruses, in insect populations. Such an epizootic might have completely destroyed a population of lepidopteran larvae; however, the crop is often seriously damaged before the population is destroyed. These observations have spurred research into microbial control of insects.

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Theoretically, the pathogens may be useful in several ways. Most of the research, and the apparent potential for microbials in *Heliothis* management, involves the application of pathogen formulations in a manner similar to that of chemical insecticides. However, another method is the use of inoculative applications of microbials that result in subsequent colonization of the pathogen in the pest population. This method apparently fares best in situations where moderate populations or damage can be tolerated.

Microbials have many characteristics ideally suited for use in pest-management programs. They are usually specific and highly virulent on given hosts, pose little hazard to nontarget organisms, and are usually compatible with other management programs. Although some degree of success has been achieved with their use in the management of *Heliothis,* they are at present used very little compared with chemical pesticides. This is due not so much to the lack of the pathogens' potential as to the user's lack of understanding of the nature of the pathogens. Furthermore, methods for effective use have not yet been developed in many areas.

Available Entomopathogens

What can we expect from microbial control? In order to understand the potential of various pathogens in *Heliothis* management, we must consider their individual pathological characteristics. Studies have shown that most of the major groups of entomopathogens contain organisms with some potential for use in *Heliothis* management. Their use may vary considerably between crops and locations, depending upon climate, disease symptomatology, and economic thresholds of crop damage. The following are brief descriptions of the characteristics of representative microbials and subsequent diseases that have been studied for use in *Heliothis* management.

Viruses: Nuclear Polyhedrosis Viruses (NPVs)

The NPVs are considered to have good potential in insect-management programs. As one example, the NPV from the bollworm, *Heliothis zea* (Boddie), is registered for use in the United States. The advantages of NPVs include their relative host-specificity and high virulence. However, they also have disadvantages: they are often rapidly deactivated by environmental factors, they must be produced in living hosts, and they must be ingested by the host prior to infection. Further, the time from ingestion of a lethal dose until death under field conditions may range from 3 to 15 days; during this time, feeding generally continues up until the last 2 days. Plainly, the incubation period of nucleopolyhedrosis should be recognized and considered in a management program.

Bacteria: *Bacillus thuringiensis* Berliner

By far the most promising bacterium available for microbial control of insects is *Bacillus thuringiensis* Berliner *(B.t.).* This bacterium is already widely used against harmful Lepidoptera in several countries. Like the NPV viruses *B. thuringiensis* must be ingested by larvae before it can have any effect. However, the bacillus has a wider host range, it can be produced using fermentation techniques, and it is not as easily destroyed by the environment as a virus is. Further, since much of its effect is due to the action of a toxic, proteinaceous crystal, the incubation period is shorter and the effect more rapid, resulting in less plant damage. Since it does have a relatively wide host range, *B. thuringiensis* must be used with some care to keep it out of lepidopteran insect-rearing facilities.

Fungi: Fungi Imperfecti

The fungi imperfecti comprise many species in a variety of genera that are infectious to insects. Among these are several species that have been considered and tested for *Heliothis* management, including *Beauveria bassiana* (Bals.) Vuillemin, *Metarrhizium anisopliae* (Metsch.) Sorokin, and *Nomuraea rileyi* (Farlow) Samson, formerly known as *Spicaria rileyi.* These fungi are commonly observed as the causative agents of natural epizootics and have a relatively wide host range. They differ from the viruses, bacteria, and protozoa that have been considered for control of *Heliothis* in that ingestion is not usually required for infection, as these organisms can penetrate through the surface of the integument. Like *B.t.,* these fungi can be mass-produced, using fermentation techniques. Their use in *Heliothis* management is limited primarily by the length of the incubation period and the restricted environmental conditions that must be present in order for pathogen invasion to occur (McCoy 1974; Bell 1974).

Protozoa: *Microsporidia* Spp

Few protozoan pathogens of insects have been field-tested as microbial agents for crop pests, perhaps because the incubation period is so long that crop damage is usually not controlled (McLaughlin 1971). *Microsporidia have* been found to occur in natural field populations of *Heliothis,* and these pathogens are also often transmitted to progeny. Again, their use in microbial control of *Heliothis* is limited by the long incubation period, the chronic rather than acute nature of the disease, and the fact that they must normally be ingested before they can damage the larvae.

Demonstrated Potential of Microbials

We can say that all of the microbials that infect *Heliothis* offer potential for control; indeed, several of these pathogens are going to act naturally to manage populations of insects as a part of biological control in the wild. What we are interested in is the potential for managing the pathogens to maximize their effect in reducing crop damage by *Heliothis.* Of the microbials mentioned, the nuclear polyhedrosis viruses and the bacterium, *Bacillus thuringiensis,* are currently given the best chances of success in most *Heliothis* management programs. This does not mean that the other known pathogens have less potential for use. It is probable that in certain situations of crop, climate, and pest structures, other pathogens are likely to give superior population control. However, in most field trials, the viruses and bacteria appear to have been more consistent in their effect, and production methods have been developed for them. For these reasons, these microbials are favored from a commercial standpoint.

The potential of microbials, as well as their problem areas, may be examined by reviewing some of the reported field investigations involving induced or natural epizootics in *Heliothis.* For example, natural infections of *H. zea* and the tobacco budworm, *H. virescens* by *N. rileyi have* been reported in corn, soybeans, and cotton (Smith et al. 1976). Disease prevalence sometimes exceeded 50% during periods most favorable for development of the disease. In field-cage studies, damage to soybeans and corn by *H. zea* was reduced by applications of this fungus, with mortality due to this pathogen reaching 76% (Ignoffo et al. 1978; Mohamed et al. 1978). Although epizootics were induced, it was concluded that economic damage was not prevented, primarily due to the relatively long incubation period of the infection, and it was suggested that *N. rileyi* would be useful as a prophylactic agent.

In general, the fungi are going to have their greatest potential as microbial agents in situations where the microclimate in the area of the host provides high humidity with temperatures between 20 and 30°C, and where moderate feeding by pest larvae prior to death can be tolerated.

Similar results have been observed in field trials with protozoan pathogens, in that damage was incurred even when disease prevalence was apparently sufficient. The microsporidian, *Vairimorpha necatrix* (Kramer), was evaluated as a microbial control agent for *H. virescens* and *H. zea* in tobacco, soybeans, and sorghum (Fuxa and Brooks 1979). In that test, larval infection reached 65, 99, and 72% in those crops, respectively, without adequately reducing crop damage. The failure to control damage was attributed to the relatively long incubation period of the infection. The infected larvae eventually died, but not before a lengthy feeding period. Since the entomogenous protozoa tend to cause debilitative or chronic infections, their best potential for insect control might be in their effect on subsequent generations.

Most of the research effort involving microbial control of *Heliothis* in the United States has been in the use of *B. thuringiensis* and the NPV from *H. zea* (termed *Baculovirus heliothis).* These pathogens are registered for use against *Heliothis* and are utilized in limited quantities. Although not yet registered, the NPV isolated from the alfalfa looper, *Autographs californica* (Speyer) (AcMNPV) has also shown promise for use in controlling *H. virescens.* This virus has a wider host range than the *Heliothis* NPV, infecting several other lepidopteran pests (Vail et al. 1970; Vail and Jay 1973).

Field or cage tests have been conducted to evaluate *B. thuringiensis* and *Heliothis* NPV in controlling *Heliothis* in tobacco, corn, and soybeans (Gentry et al. 1969; Ignoffo et al. 1978; Oatman et al. 1970). In general, results of these tests were promising in that both pathogens caused significant reductions in plant damage by *Heliothis* larvae. However, the level of control obtained was not effective enough to compete with chemical insecticides. Although the potential for use on these crops obviously exists, further research has been limited.

As in other specialized areas of research into *Heliothis* management, the majority of work in microbial control with 8. *thuringiensis* and NPV has been associated with cotton production. Since the mid-1960s, considerable testing has been conducted in the use of these pathogens, resulting in their limited commercial use on cotton. However, the level of control of *Heliothis* spp on cotton produced by multiple applications of these microbials has been erratic. This has been especially true of NPV. In some tests, control comparable to chemical insecticides has been observed. Ignoffo et al. (1965) reported yields of 560 kg and 715 kg of seed cotton/acre (0.4 ha), respectively, from cotton plots treated with 6.0×10^{11} and 6.0×10^{12} polyhedral inclusion bodies (PIB) per 0.4 hectare. Yields from untreated plots were 294 kg/0.4 ha. Also, Allen et al. (1967) found that applications of NPV at 1.2×10^{11} PIBs per 0.4 ha were as effective as a toxaphene-DDT standard in small-plot tests. Other field studies indicated that applications of virus should result in satisfactory control on cotton when used with the naturally occurring predator-parasite complexes (Allen et al. 1966). Shieh and Bohmfalk (1980) found that seed cotton yields increased by 10 to 40% over check plots when multiple treatments of the NPV were applied to cotton under a relatively low infestation pressure. However, several other researchers have obtained marginal or no control in field tests whenever *Heliothis* NPV was used alone (McGarr and Ignoffo 1966; McGarr 1968; Pfrimmer 1979).

In general, the level of control of *Heliothis* spp in cotton obtained with 8. *thuringiensis* (isolate HD-1) has been more consistent than that obtained with NPV. Although the quantity of material used was not economically feasible, control comparable to chemical insecticides was reported by McGarr et al. (1970). Other field studies have shown that applications of 8. *thuringiensis* at rates of 3.6 to 7.3 x 10^9 International Units (IU)/0.4 ha will suppress a larval population and result in increased yield (Pfrimmer et al. 1971; Bull et al. 1979; Pfrimmer 1979). However, the level of control was generally less than that obtained with the recommended chemicals.

Most recent research in microbial control of *Heliothis* has been directed towards developing methods or techniques to increase the dependability and effectiveness of NPV and 8. *thuringiensis.* Various possibilities have been explored. Because of the known rapid inactivation of NPV, one possibility explored was of spray formulations that would improve the persistence of pathogens on field cotton (Yearian and Young 1974; Ignoffo et al. 1976b). Various formulations were developed that protected the polyhedra from sunlight and increased the field persistence of the virus (Bull et al. 1976). However, the use of these materials failed to significantly increase efficacy.

Since both the NPV and *B. thuringiensis* must be ingested, it is important to place the pathogens in close proximity to the *Heliothis* larvae. Various methods have been investigated, and their results demonstrated the importance of application techniques (Falcon 1978; Smith et al. 1977a; 1977b). Improved coverage alone, however, has not resulted in sufficient dependability of microbial control to significantly increase its use in *Heliothis* management programs.

Another method of improving the efficacy of 8. *thuringiensis* and NPV in the control of *Heliothis* in cotton has been through the use of gustatory stimulant formulations. It has long been recognized that the effectiveness of these pathogens might be improved through the use of bait-type materials to increase larval ingestion of the pathogens (Montoya et al. 1966; McLaughlin et al. 1971; Patti and Carner 1974). Ignoffo et al. (1976a) discussed the favorable properties of a microbial adjuvant; these included a feeding stimulant, a sunlight protectant, and an evaporation retardant, with the most important of these additions being the feeding stimulant capable of increasing foliar feeding of the larvae. We might also add that the properties of a commercial adjuvant should further include reasonable storage and spray characteristics and an economically feasible cost at the projected use rate.

Here, I would like to discuss my interest and work in the area of microbial control of *Heliothis* in cotton. In 1974 and 1975, we conducted field tests to determine the effectiveness of the AcMNPV in a bait formulation for controlling pink bollworms, *Pectinophora gossypiella* (Saunders) in cotton (Bell and Kanavel 1977). Although the microbial formulation failed to control pink bollworms, the results of that study again demonstrated the increased effectiveness of NPV in *Heliothis* control when applied in a feeding-stimulant formulation. The percent boll damage by *Heliothis* showed 87% reduction in plots treated with virus in bait, compared with 59% reduction in plots treated with virus alone. However, the bait was a liquid formulation, with poor storage characteristics.

In 1976, we began working toward developing a spray adjuvant for use with microbials against *Heliothis* in cotton, keeping in mind the properties that should be incorporated into such an adjuvant (Bell and Kanavel 1978). Our first step was to screen possible ingredients for feeding preference by first instar *H. virescens* larvae. A single larva was allowed to respond either to test material incorporated in agar solution or to an agar control. A sequential test for binomial data was used to establish limits to accept the hypothesis if 75% of the larvae responding preferred the treatment, *or* to reject it if 25% responded to the control (Ghosh 1970). Of the materials screened, cottonseed flour and soy flour appeared the most promising as bases for a spray adjuvant. We then conducted a greenhouse study to determine whether the various stimulants would increase the effectiveness of the AcMNPV against neonate *H. virescens.* The treatments consisted of virus applied to plants in water alone and in various combinations of cottonseed flour, cottonseed oil, soy flour, and sucrose. After the plants had dried, neonate larvae were placed on each and left for 2 hours. The larvae were then removed, placed in individual diet cups, and held to determine the percent viral mortality. In this test, the percentage of larvae infected was significantly greater when the virus was applied with an adjuvant (Table 1). A mixture containing 5 parts cottonseed flour (62.5%), 2 parts sucrose (25%), and 1 part crude cottonseed oil (12.5%) was prepared and used as the adjuvant in the following studies.

The first field test of this adjuvant was conducted in Phoenix, Arizona, in 1977 on late-planted cotton (unpublished data). A pretreatment count of 100 random terminals in the test area showed 356 *Heliothis* eggs (91% *H. virescens)* and 24 first-instar larvae. The treatments consisted of four replicates each of: virus alone (AcMNPV at 8.9 x 10^{11} polyhedral inclusion bodies [PIB] in 187 liters water/ha), virus + adjuvant (8.9 x 10^{11} PIB + 5.6 kg adjuvant in 187 liters water/ha), and an untreated control, in a random design. Treatments were applied on 30 September, 4 October, and 11 October, using a high-clearance sprayer. The effect of the treatments on the *Heliothis* population was evaluated by collecting five samples of live *Heliothis* larvae from each plot during the test period and holding them to determine mortality caused by the virus. The effect of the treatments on crop damage was evaluated by checking bolls and squares for *Heliothis* damage on 50 randomly selected plants in each plot on 14 October.

Table 1. Average mortality of neonate larvae of tobacco budworms after a 2-hour exposure to cotton plants treated with NPV In various formulations.[a]

Formulation ingredients[b] (% wt. in water)	Mortality (% after 10 days)
Water alone	33.3 a
5% cottonseed flour	51.5 ab
10% cottonseed flour	66.7 bc
5% cottonseed flour 2% sucrose	62.2 bc
2% sucrose 1% crude cottonseed oil	63.8 bc
5% soy flour 2% sucrose 1% crude cottonseed oil	76.0 cd
5% cottonseed flour 2% sucrose 1% crude cottonseed oil	93.3 d

a. Average of five replicates with 25 to 32 larvae per replicate. Means followed by the same letter do not differ at the 5% level (Duncan's multiple range test).

b. Tween 80 (surfactant) added (0.26 ml per liter) to all formulations.

The results of this test demonstrated that the addition of the adjuvant to the virus application significantly increased the percentage of field larvae that consumed an infective dose (Table 2). Further, the boll and square damage was significantly less in plots treated with virus plus adjuvant than in plots treated with virus alone. In this test, application of virus alone did not reduce the damage to squares although it did reduce boll damage. This was probably due to the rather long incubation period required by the nuclear polyhedrosis virus; that is, the virus did not act rapidly enough to significantly affect feeding on the squares, but did act to reduce feeding by larger larvae on bolls. This effect demonstrates the need for knowing the growth stage of the crop as well as the size and feeding habits of the larvae during the incubation period of the proposed microbial control agent. Other possible effects of *Heliothis* control based on the growth stage of cotton were discussed by Falcon (1974).

By the 1978 growing season, a commercial company (Traders Oil Mill Co., Fort Worth, Texas) had produced the adjuvant and provided it for our tests (trade name: COAX®). The objectives of our 1978

Table 2. Evaluation of microbial treatments on Heliothis larvae and cotton plant damage due to Heliothis.

Treatment	Rate/ha[a]	*Heliothis* larvae[b] infected with AcMNPV (%)	Boll[c] damage (%)	Square[c] damage (%)
AcMNPV[c]	8.9x10^{11} PIB			
Adjuvant	5.6 kg	76.8 c	11.0 c	27.8 b
AcMNPV	8.9 x 10^{11} PIB	48.6 b	21.6 b	47.0 a
Untreated		2.0 a	37.4 a	51.6 a

a. Treatments applied in 187 liters water/ha.

b. Average of four replicates over five sampling dates with 51 to 98 larvae per sample.

c. Average of four replicates with 50 plants per sample. Means within columns followed by different letters are significantly different at the 5% level of confidence (Duncan's multiple range test).

field tests were to evaluate the feeding adjuvant, the NPV from the alfalfa looper, and the HD-1 strain of S. *thuringiensis* in controlling *H. virescens* in cotton (Bell and Romine 1980). The tests were conducted on cotton planted late to maximize damage by *H. virescens.* The first test consisted of four treatments arranged in a Latin-square design with 0.025-ha plots. The treatments were: untreated, AcMNPV alone, AcMNPV + adjuvant, and AcMNPV + 8. *thuringiensis* + adjuvant. A total of eight applications was made between 1 September and 15 October and an application of malathion was made on 4 September to reduce levels of predators and parasites to insure maximum *Heliothis* damage. We evaluated the treatments by periodically examining 10 randomly selected plants/plot. The data recorded were: number of *Heliothis* eggs per terminal; total number of bolls and squares; and the number of bolls and squares damaged by *Heliothis.* Further, the effect on yield was determined by harvesting 15 row m/plot at the end of the season.

In this test, the average number of *Heliothis* eggs (93% *H. virescens)* ranged from four to six per terminal during the treatment period. Treatment with the mixture of AcMNPV + *B. thuringiensis* + adjuvant resulted in the best control, regardless of the method of evaluation. The yield of cotton obtained using this treatment (Table 3) was as good as could be expected for a late-planted crop. The seasonal averages of percent damaged squares in plots treated with NPV + B. *thuringiensis* + adjuvant, NPV + adjuvant, NPV alone, and in untreated plots were 6.1, 14.5, 28.2, and 43.0%, respectively. We believe that the level of control obtained by the pathogen mixture in this study was equal to the control normally obtained by chemical insecticides.

A second test in 1978 was conducted on 0.02-ha plots of late-planted cotton with three treatments-untreated control; *B. thuringiensis* alone; and *B.t.* + adjuvant—and four replicates. The spray dates and methods of evaluation were the same as in the above test. Also, the numbers of *Heliothis* eggs and larvae found on terminals were similar. No differences in the numbers of eggs per plant were ever noted among the treatments.

As in our previous studies, the addition of the adjuvant increased the effectiveness of the pathogen in controlling *Heliothis.* Square damage during the test period 6 September to 19 October was 8.8% with 8. *thuringiensis* + adjuvant; 18.3% with 8. *thuringiensis* alone, and 44.5% in untreated plots. The difference in yield (Table 4) in cotton plots treated with *B. thuringiensis* + adjuvant mixture represented a 32% increase over plots treated with B. *thuringiensis* alone.

In these tests, the mixture of bacillus and virus appeared to give more efficacious control than the other treatments, even though these two pathogens are antagonistic in laboratory bioassay studies (M.R. Bell, unpublished data). We felt that possibly the sublethal effect of *B. thuringiensis* (reduced growth rate) as described by Dulmage et al (1978) was involved; that is, the larvae, although not rapidly killed by the virus, remain small because of the stunting effect of *B. thuringiensis* during the

Table 3. Yield in late-planted cotton treated with microbials for control of Heliothis.[a]

Treatment	Rate per ha[b]	Yield seed cotton[c]
Bacillus thuringiensis AcMNPV Adjuvant	560 g 7.41×10^{11} PIB 3.36 kg	1427 a
AcMNPV Adjuvant	7.41×10^{11} PIB 3.36 kg	1066 b
AcMNPV	7.41×10^{11} PIB	774 c
Untreated control		332 d

a. Average of four replicates, 15 row meters hand-picked per replicate.

b. All treatments applied in 93.5 liters water/ha.

c. Means within columns followed by different letters are significantly different at the 5% level of confidence (Duncan's multiple range test—ANOV of latin square).

Table 4. Yield in late-planted cotton treated with *Bacillus thuringlensis* for control of *Heliothis.*[a]

Treatment	Rate/ha[b]	Yield seed cotton[c]
Bacillus thuringiensis Adjuvant	560 g 3.36 kg	1108 a
B. thuringiensis	560 g	837 b
Untreated control		328 c

a. Average of four replicates—15 row meters hand-picked per replicate.

b. All treatments applied in 93.5 liters water.

c. Means within columns followed by different letters are significantly different at the 5% level of confidence (Duncan's multiple range test).

incubation period, resulting in less feeding damage. Although much is still unknown regarding the most efficient use of these methods, we feel that the mixture of NPV and *B. thuringiensis* will find a place in future *Heliothis* management in cotton. We have also been further encouraged by the promising results of other researchers using such mixtures (Ummel 1981), and by the increasing quantity of annual sales of the adjuvant (over $1 million).

In summary, I feel that the potential exists for microbial control of *Heliothis* in almost any crop and any location. However, methods and microbials must be utilized to maximize their best features, based upon the characteristics of the crop, larval feeding habits, pathogen and disease symptomatology, and climate. For example, procedures that tend to increase the probability that *Heliothis* spp larvae will ingest an active microbial at the proper time have been relatively consistent in increasing the effectiveness and level of control. These procedures have included the use of feeding stimulants, optimum dosages, spray methods that result in maximum deposits in the target area, and proper timing of the application, so that it affects larvae as early as possible (Falcon 1971; Chapman and Ignoffo 1972; Stacey et al. 1977).

Obviously, climate can have much to do with the probability of successfully inducing an epizootic, not only by its effect on the inactivation of the microbial or climatic requirements for infection, but also physical actions such as washing the microbials from the target area by frequent rainfall.

Although we have learned much, and have progressed somewhat in the area of microbial control of *Heliothis,* much research remains to be conducted before the potential that was envisioned for insect pathogens is even partially realized. The development and evaluation of insect pathogens requires adequate funding, which generally has not been available. Even without increased funding, the use of microbial control should increase, though at a slower rate. Many efforts are being made to increase the effectiveness and use of microbial agents in insect pest management by isolating and identifying new, more virulent pathogens; improving methods of pathogen production; improving spray formulations and techniques; and determining plant-insect-pathogen interactions. The successful development of more effective methods, coupled with the user's increased knowledge of factors involved in microbial control, should result in more reliable usage of pathogens in *Heliothis* management.

References

ALLEN, G.E., GREGORY, B.G., and BRAZZEL, J.R. 1966. Integration of the *Heliothis* nuclear polyhedrosis virus into a biological control program for cotton Journal of Economic Entomology 59: 1333-1336.

ALLEN, G.E. GREGORY, B.G., and PATE, T.L. 1967. Field evaluation of a nuclear polyhedrosis virus in the control of *Heliothis zea* and *Heliothis virescens* on cotton. Journal of Invertebrate Pathology 9: 40-42.

BELL, J.V. 1974. Mycoses. Pages 185-236 *in* Insect diseases, Volume 1, ed. G.E. Cantwell. New York, USA: Dekker.

BELL, M.R., and KANAVEL, R.F. 1977. Field tests of a nuclear polyhedrosis virus in a bait formulation for control of pink bollworms and *Heliothis* spp. on cotton in Arizona. Journal of Economic Entomology 70: 625-629.

BELL, M.R., and KANAVEL, R.F. 1978. Tobacco budworm: development of a spray adjuvant to increase effectiveness of a nuclear polyhedrosis virus. Journal of Economic Entomology 71: 350-352.

BELL, M.R., and ROMINE, C.L. 1980. Tobacco budworm: field evaluation of microbial control in cotton using *Bacillus thuringiensis* and a nuclear polyhedrosis virus with a feeding adjuvant. Journal of Economic Entomology 73: 427-430.

BULL, D.L., HOUSE, V.S., ABLES, J.R., and MORRISON, R.K. 1979. Selective methods for managing insect pests of cotton. Journal of Economic Entomology 72: 841-846.

BULL, D.L., RIDGWAY, R.L., HOUSE, V.S. and PRYOR, N.W. 1976. Improved formulation of the *Heliothis* nuclear polyhedrosis virus. Journal of Economic Entomology 69: 731 -736.

CHAPMAN, A.J., and IGNOFFO. C.M. 1972. Influence of rate and spray volume of nucleopolyhedrosis virus on *control* of *Heliothis* in cotton. Journal of Invertebrate Pathology 20:183-186.

DULMAGE, H.T., GRAHAM, H.M., and MARTINEZ, E. 1978. Interactions between the tobacco budworm, *Heliothis virescens,* and the endotoxin produced by the HD-1 isolate of *Bacillus thuringiensis* var. *Kurstaki:* relationship between length of exposure to the toxin and survival. Journal of Invertebrate Pathology 32: 40-50.

FALCON, L.A. 1971. Microbial control as a tool in integrated control programs. Pages 346-364 *in* Biological control, ed. C.B. Huffaker New York. USA: Plenum Press

FALCON, L.A. 1974. Insect pathogens: integration intoa pest management system. Pages 618-627 *in* Proceedings, Summer Institute on Biological Control of Plant Insects and Diseases. Jackson, Miss, USA: University Press of Mississippi.

FALCON, L.A. 1978. Application technology: improving coverage with microdroplet applicators. Pages 113-117 *in* Proceedings, Microbial Control of Insect Pests: Future Strategies in Pest Management Systems. University of Florida, Gainesville, Fla, USA.

FUXA, J.R., and BROOKS, W.M. 1979. Effects of *Vairimorpha necatrix* in sprays and corn meal on *Heliothis* species in tobacco, soybeans, and sorghum. Journal of Economic Entomology 72:462-467.

GENTRY, C.R., THOMAS, W.W., and STANLEY, J.M. 1969. Integrated control as an improved means of reducing populations of tobacco pests. Journal of Economic Entomology 62: 1274-1277.

GHOSH, B.K. 1970. Sequential tests of statistical hypothesis. Reading, Mass, USA: Addison Wesley. 454 pp.

IGNOFFO, C.M., CHAPMAN, A.J., and MARTIN, D.F. 1965. The nuclear polyhedrosis virus of *Heliothis zea* (Boddie) and *Heliothis virescens* (Fabricius). III. The effectiveness of the virus against field populations of *Heliothis* on cotton, corn and grain sorghum. Journal of Invertebrate Pathology 7:227-235.

IGNOFFO, C.M., HOSTETTER, D.L., and SMITH, D.B. 1976a. Gustatory stimulant, sunlight protectant, evaporation retardant: three characteristics of a microbial insecticidal adjuvant. Journal of Economic Entomology 69:207-210.

IGNOFFO, C.M., YEARIAN, W.C., YOUNG, S.Y., HOSTETTER, D.L., and BULL, D.L. 1976b. Laboratory and field persistence of new commercial formulations of the *Heliothis* nucleopolyhedrosis virus, *Baculovirus heliothis.* Journal of Economic Entomology 69: 233-236.

IGNOFFO, C.M., HOSTETTER, D.L., BIEVER, K.D., GARCIA, C., THOMAS, G.D., DICKERSON, W.A., and PINNELL, R. 1978. Evaluation of an entomopathogenic bacterium, fungus, and virus for the control of *Heliothis zea* on soybeans. Journal of Economic Entomology 71: 165-168.

McCOY, C.W. 1974. Fungal pathogens and their use in the microbial control of insectsand mites. Pages 564-575 *in* Proceedings, Summer Institute on Biological Control of Plant Insects and Diseases. Jackson, Miss, USA: University Press of Mississippi.

McGARR, R.L. 1968. Field tests with a nuclear polyhedral virus against the bollworm and tobacco budworm, 1964-1966. Journal of Economic Entomology 61: 342.

McGARR, R.L., DULMAGE, H.T., and WOLFENBARGER, D.A. 1970. The δ-endotoxin of *Bacillus thuringiensis,* HD-1, and chemical insecticides for control of the tobacco budworm and the bollworm. Journal of Economic Entomology 63: 1357-1358.

McGARR, R.L., and IGNOFFO, C.M. 1966. Control of *Heliothis* spp. with a nuclear polyhedrosis virus, EPN. and two newer insecticides. Journal of Economic Entomology 59: 1284-1285.

MCLAUGHLIN, R.E. 1971. Use of protozoans for microbial control of insects. Pages 151 -172 *in* Microbial control of insects and mites, eds. D. Burges and N.W. Hussey. New York, USA: Academic Press.

McLAUGHLIN, R.E., ANDEREWS, G.L., and BELL, M.R. 1971. Field tests for control of *Heliothis* spp. with a nuclear polyhedrosis virus included in a boll weevil bait. Journal of Invertebrate Pathology 18: 304-305.

MOHAMED, A.K.A., BELL. J.V., and SIKOROWSKI, P.P. 1978. Field cage tests with *Nomuraea rileyi* against corn earworm larvae on sweet corn. Journal of Economic Entomology 71: 102-104

MONTOYA, E.L., IGNOFFO, C.M., and McGARR, R.L. 1966. A feeding stimulant to increase effectiveness of, and a field test with a nuclear polyhedrosis virus of *Heliothis.* Journal of Invertebrate Pathology 8: 320-324.

OATMAN, E.R., HALL, I.M., ARADAWA, K.Y., PLATNER, G.R., BASCOM, L.A., and BEEGLE, C.C. 1970. Control of the corn earworm on sweet corn in Southern California with a nuclear polyhedrosis virus and *Bacillus thuringiensis.* Journal of Economic Entomology 63: 415-421.

PATTI, J.H., and CARNER, G.R. 1974. *Bacillus thuringiensis* investigations for control of *Heliothis* spp. on cotton. Journal of Economic Entomology 67: 415-418.

PFRIMMER, T.R. 1979. *Heliothis* spp. control on cotton with pyrethroids, carbamates, organophosphates, and biological insecticides. Journal of Economic Entomology 72: 593-598.

PFRIMMER, T.R., FURR, R.E., and STADELBACHER, E.A. 1971. Materials for control of boll weevils, bollworms, and tobacco budworms on cotton at Stoneville, Mississippi. Journal of Economic Entomology 64: 475-478.

SHIEH, T.R., and BOHMFALK, G.T. 1980. Production and efficacy of baculoviruses. Biotechnology and Bioengineering22: 1357-1375.

SMITH, D.B., HOSTETTER, D.L., and IGNOFFO, C.M. 1977a. Laboratory performance specifications for a bacterial *(Bacillus thuringiensis)* and a viral *(Baculovirus heliothis)* insecticide. Journal of Economic Entomology 70: 437-441.

SMITH, D.B., HOSTETTER, D.L., and IGNOFFO, C M. 1977b. Ground spray equipment for applying *Bacillus thuringiensis* suspension on soybeans. Journal of Economic Entomology 70: 633-637.

SMITH, J,W., KING, E.G., and BELL, J.V. 1976. Parasites and pathogens among *Heliothis* species in the Central Mississippi delta. Journal of Economic Entomology 5: 224-226.

STACEY, A.L., YOUNG, S.Y., III, and YEARIAN, W.C. 1977. Effect of larval age and mortality level on damage to cotton by *Heliothis zea* infected with *Baculovirus heliothis.* Journal of Economic Entomology 70: 383-386.

UMMEL, E. 1981. Elcar and Thuricide HP combination for the control of the tobacco budworm in cotton in the Southwest. Pages 82-86 *in* Proceedings, Conference on Biological Control on Cotton, Dallas, Tex, USA. San Diego, Cal: Sandoz.

VAIL, P.V., and JAY, D.L. 1973. Pathology of a nuclear polyhedrosis virus of the alfalfa looper in alternate hosts. Journal of Invertebrate Pathology 21: 198-204.

VAIL, P.V., JAY, D.L., and HUNTER, D.K. 1970. Cross infectivity of a nuclear polyhedrosis virus isolated from the alfalfa looper, *Autographa californica.* Pages 297-304 *in* Proceedings, Fourth International Colloquium on Insect Pathology,

YEARIAN, W.C, and YOUNG, S.Y. 1974. Persistence of *Heliothis* nuclear polyhedrosis virus on cotton plant parts. Environmental Entomology 3:1035-1036.

Possibilities for Natural Enemies in *Heliothis* Management and the Contribution of the Commonwealth Institute of Biological Control

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Abstract

Some factors affecting the efficiency of natural enemies as control agents for Heliothis spp *are discussed, notably the effects of migration, feeding behavior, host plant, climate, and insecticide usage. Although a large number of insect natural enemies have been reported, only a few in each region are sufficiently abundant to be of interest as control agents. Recent research on natural enemies in the main areas where* Heliothis *spp are major pests is briefly reviewed and discussed in relation to the possibilities for their application in biological and integrated pest control by introduction or conservation. It is concluded that pathogens are only likely to be useful when applied as biological pesticides, and that predators are best manipulated by conservation and augmentation. On the other hand, there are possibilities for the introduction of insect parasitoids to occupy empty niches in some areas and for their conservation and augmentation in pest-management schemes. However, knowledge is at present insufficient to make full use of natural enemies. Further surveys are likely to reveal additional useful species, especially in South America, and in all areas quantitative ecological studies backed by investigations on the biology of the more important species of natural enemies are required before substantial progress can be made. The Commonwealth Institute of Biological Control, backed by the information and identification services of the Commonwealth Agricultural Bureaux, is able to assist in furthering these objectives.*

Résumé

*Possibilité d'utilisation d'ennemis naturels dans la lutte contre l'*Heliothis *et contribution de l'Institut de contrôle biologique du Commonwealth:* *Quelques facteurs affectant l'efficacité des ennemis naturels comme agents de lutte contre* Heliothis *spp sont discutés, en particulier les effets de la migration, le comportement alimentaire, la plante-hôte, le climat et l'utilisation d'insecticides. Bien qu'un nombre important d'ennemis naturels du ravageur ait été signalé, à part quelques rares exceptions dans chaque région, ils ne sont pas assez nombreux pour être intéressants comme agents de lutte. Les recherches récentes sur les ennemis naturels, dans les principales régions où* Heliothis *spp pose de graves problèmes, sont brièvement revues et discutées dans la perspective de leur utilisation possible, par introduction ou conservation, dans la lutte biologique et intégrée contre le ravageur. La conclusion indique que les agents pathogènes tendent à n'être utiles que comme pesticides biologiques et que les prédateurs sont le mieux manipulés par conservation et augmentation. D'autre part, des possibilités existent pour l'introduction de parasitoïdes d'insectes pour occuper des niches vides dans certaines régions et pour leur conservation et augmentation dans des programmes de lutte contre le ravageur. Cependant, notre connaissance présente est insuffisante pour tirer le meilleur parti des ennemis naturels. Des enquêtes additionnelles devraient révéler de nouvelles espèces utiles, surtout en Amérique du Sud, et dans toutes les régions des études écologiques quantitatives et des recherches sur la biologie des plus importantes espèces d'ennemis naturels sont des préalables à un progrès ultérieur. L'Institut de contrôle biologique du Commonwealth, appuyé par les services d'information et d'identification des Bureaux agricoles du Commonwealth, peut contribuer à un progrès vers ces objectifs.*

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International Crops Research Institute for the Semi-Arid Tropics. 1982. Proceedings of the International Workshop on *Heliothis* Management, 15-20 November 1981, Patancheru, A.P., India.

Heliothis spp are important pests in almost all warm temperate and tropical countries. The species in each area are closely related and are polyphagous, although each has preferred host plants. Usually, they form part of a complex of pests that must be included in any management program; therefore, they are not ideal targets for "classical" biological control, but natural enemies are important mortality factors and should play a part in any management scheme. This paper reviews the possibilities for enhancing natural enemy mortality, especially by arthropod parasitoids and predators, and outlines the possible contributions of the Commonwealth Institute of Biological Control (CIBC).

Host Biology and Natural Enemies

A number of biological features of *Heliothis* spp affect the prospects of biological control and need to be kept in mind in considering the likely effectiveness of biotic control agents.

Although diapause is widespread, the proportion of diapausing pupae tends to increase from zero in populations near the equator, where continuous breeding is possible, to close on 100% in populations from temperate regions at the end of the favorable season. *H. armigera* and *H. zea* are known migrants of the northern fringe of their ranges, but the degree to which they migrate elsewhere is controversial. Recent trapping studies in Africa (Bowden 1973) and India (Bhatnagar 1980), in which catch has been related to weather, have led some entomologists to assert that *H. armigera* is more mobile than has been realized and that it is at least a partial migrant throughout its range. Other entomologists are sceptical. However, in areas where *H. armigera* can be shown to be migrant, biological control will be less easy to achieve, as resident natural enemies are unlikely to be able to respond effectively to a sudden influx of ovipositing moths.

The possibility that some natural enemies are also migrant has hardly been investigated but should be explored. Certainly some groups of parasitoids, e.g., Ichneumonidae or Ophioninae, are periodically abundant in light-trap catches, which is suggestive of migration.

The *Heliothis* larva's habit of boring into fruits, maize cobs, buds, and other plant organs gives partial protection from natural enemies and reduces the likelihood of effective biological control in crops where the larvae are not feeding on the surface.

Again, there is little firm evidence available, but it seems likely that unnaturally large fruits and other plant organs in many crop plants enable pest larvae to escape ovipositing parasitoids, because they burrow out of range of ovipositors evolved to reach hosts in less fleshy wild progenitors of crop plants.

Crop and Natural Enemy

The natural enemy spectrum on particular crops is not only a consequence of host behavior but also of the searching behavior of the natural enemies and their microenvironmental preferences. For example, *Eucelatoria* sp is more strongly attracted to the host plant than to *H. virescens,* and okra is more strongly attractive than cotton (Nettles 1979). Even if the host is successfully parasitized on a particular host plant, the parasitoid may fail to survive; thus *Hyposoter exiguae* larvae in *H. zea* feeding on tomato are poisoned by α-tomatine present in the host haemolymph (Campbell and Duffey 1979).

Other plant defenses may affect the parasite directly. Bhatnagar (1980) notes that *H. armigera* eggs on chickpea and pigeonpea at ICRISAT are not parasitized and that with chickpea, at any rate, this may come about because parasite adults are trapped by the sticky exudation on the plant surface. These recent discoveries begin to explain the complex factors that account for the many observed differences in the parasite spectrum of *Heliothis* spp on different host plants.

Another factor that affects biological control of pests of annual crops is the timing of crop damage in relation to season. Thus, crops grown early in the season may be more severely affected than later plantings where time is required for natural enemies to build up numbers from low off-season levels. In some instances, natural enemies only become effective during the last pest generation—too late to be of any value. Heavy pesticide usage is a further factor affecting biological control prospects; thus Carl (1977) notes that the natural-enemy complex of *Heliothis* spp on agricultural crops in Europe and North America has been drastically reduced, probably as a result of the tendency towards monocultures, pollution with increasingly more powerful insecticides, and the extensive use of herbicides. He queries the value of searching for natural enemies on noncultivated plants. If these "weaker" links of the complex have been forced out of agricultural areas because of environmental pressures, it is unlikely that they can be reestablished, unless integrated control measures enhance their chances of survival.

Parasitoids and Predators

Large numbers of insect natural enemies of *Heliothis* spp have been reported wherever studies have been made, but most of those listed are incidental, contributing little to overall mortality. For example, Achan et al. (1968) list 37 species of insect parasitoids of *H. armigera* in India, of which only eight were classed as important (each achieving over 3% parasitism). Only "important" species—i.e., those consistently present and capable of causing significant mortality—are of interest, and only these will be discussed further.

Europe and the USSR

A recent survey by Carl (1977, 1978) in southern Europe and Morocco, where *Heliothis armigera* is resident, has shown that the diversity of parasite complexes is very reduced. Nonetheless, substantial rates of parasitism were found in southeastern Europe and Morocco. On tobacco in Bulgaria, *Hyposoter didymator* (Thunb.) (Ichneumonidae) and *Apanteles kazak* Telenga (Braconidae) together achieved rates of parasitism of 41 to 75% on the last host generation. In Morocco, *A. kazak* and possibly other *Apanteles* spp achieved 15 to 65% parasitism, the rate apparently increasing with host density in a highly polluted environment.

Recent studies in cotton fields in Israel have confirmed the importance of *Hyposoter didymator,* as it has been shown to be the most important biotic limiting factor on populations of *Heliothis armigera* (Bar et al. 1979).

Earlier studies in Turkmenia (Bogush 1957) detected 22 parasites, of which the most important were external *Bracon* spp. (*B. brevicornis* Wesm., 6. *hebetor* Say, 8. *smirnovi* [*Kok*.], and 8. *turkestanicus* [Telenga]), which are effective on cotton where they build up early in the season on *Spodoptera exigua* (Hbst.). Also important were *Therion (Exochilum)* sp on cotton and lucerne; *Litomastix* sp on lucerne, tomato, and chickpea; and *Apanteles kazak* on tomato.

India

Extensive studies on natural enemies of *H. armigera,* chiefly in Karnataka, were made by the Indian Station of CIBC during the 1960s for the U.S. PL-480 project. Eight important parasites of the larvae and pupae were recognized (Achan et al. 1968; Rao 1968), some of which were shipped to the USA and tested on *H. zea* (Table 1), but only *Palexorista laxa* and two egg parasitoids bred on this species (Manjunath 1972). Since 1974, studies have been made on *Heliothis* spp by ICRISAT (Bhatnagar 1980), indicating a similar complex in Andhra Pradesh and emphasizing the influence of the host plant on the relative abundance of different species.

A program for introduction of parasitoids from the USA started in 1976 at the Central Biological Control Station, Bangalore, assisted by the CIBC (Nagarkatti, these Proceedings).

Africa

Detailed studies of natural enemy mortality of *H. armigera* have been made by entomologists primarily interested in its control on cotton (Parsons 1940, in South Africa; Coaker 1959, in Uganda; and Reed 1965, in Tanzania). Many other records have been published, but are unreliable or fragmentary (see Greathead 1966 for a list of records). The more important parasites are listed in Table 2. Parsons noted that high egg parasitism had little effect on the larval population and that overall mortality was highest on cotton; Coaker, that in an area of relatively uniform rainfall and no severe dry season, overall parasitism was low, but so was host density; Reed, that following the dry season parasitism was low, built up too late to prevent serious damage to cotton, and reached a peak at the end of the season on pigeonpea. The impression gained is that in Africa severe dry seasons break synchronization of parasite with host, thus preventing parasites becoming effective until most crops have suffered severe damage.

The USA

The bollworm complex on cotton in the USA consists of *Heliothis zea* and *H. virescens,* which is also a pest of tobacco. The relative abundance of the two species varies with locality and time of year,

Table 1. Important parasites of Heliothis *armigera* In India.

Parasite	*Heliothis* stage affected and percentage parasitized
Hymenoptera	
Ichneumonidae	
Banchopsis ruficornis (Cam.)	Larvae, 10% no hyperparasites
Campoletis chlorideae Uchida[a]	Young larvae, 10-80%; hyperparasites
Enicospilus sp[a]	Old larvae, 6-11%
Eriborus sp[a]	Young larvae 3-6%; no hyperparasites
Braconidae	
Brecon brevicornis Wesm.	Larvae, 3-6%
Trichogrammatidae	
Trichogramma chilonis Ishii (*confusum* Viggiani)	Eggs, to 79%
Trichogrammatoidea armigera Nagaraja	Eggs, to 11%
Diptera	
Tachinidae	
Palexorista laxa (Curran)[a] (misident, as *Drino imberbis* Wied.)	Old larvae, 12-18% no hyperparasites
Carcelia illota (Curran)[a]	Old larvae 4-16% hyperparasites
Goniophthalmus halli Mesnil	Old larvae, 18-20%

Sources: Achan et al. (1968) and Manjunath (1972).

a. Shipped to the USA and tested on *H. zea;* only *P. laxa* was successfully bred.

and is influenced by the availability of alternative host plants (Lincoln 1972). Both were minor pests of cotton before 1945 and were easily controlled by the synthetic organic insecticides that appeared after the war, but increasing resistance and destruction of natural enemies eventually led to a spiral of increased pesticide usage, environmental pollution, secondary pest outbreaks, and disastrous crop losses, and to new research into the *Heliothis* problem.

Natural enemies are capable of exerting from 50 to 90% control of the *Heliothis* population (Ridgway and Lingren 1972). Several hundred species have been recorded, but fewer than 30 are important. The predators (Table 3) usually attack the eggs and smaller larvae, and none is specific to *Heliothis* spp. Some of the parasites (Table 4), such as the braconids *Cardiochiles nigriceps* and *Microplitis croceipes,* are more specific and attack the whole range of larval sizes. The composition of the natural enemy complex varies with location, crop, and season.

Because of the high degree of natural control, emphasis is now placed on the conservation and augmentation of natural enemies. Recent work (e.g. Plapp and Vinson 1977), has shown that the parasitoids can be much more adversely affected by insecticides than the bollworms, and reduction in the amounts of insecticides used by setting realistic damage thresholds is of primary importance in conserving the natural enemy complex (Newsom 1972). Strip-cropping experiments have shown

Table 2. Important parasites of *Heliothis* armigera In South Africa, Uganda, and Tanzania.

Parasite	Crop	*Heliothis* stage affected	Country
Ichneumonidae			
Charops sp I	Legumes, etc.	Larvae	Tanzania
Charops sp II	Cotton	Larvae	Uganda
Enicospilus sp *? communis* Szepl.	Cotton	Larvae	Uganda
Braconidae			
Apanteles rnaculitarsis Cam.	Cotton	Larvae	South Africa
Apanteles sp *ultor* group	Cotton	Larvae	Uganda
Apanteles sp nr *aethiopicus* Wilk	Peas	Larvae	South Africa
Bracon ?brevicornis Wesm.	Cotton, etc.	Larvae	South Africa
Cardiochiles nigricollis (Cam.)	Cotton, etc.	Larvae	South Africa
C. trimaculatus (Cam.)	Cotton	Larvae	Uganda
Chelonus curvimaculatus Cam.	Maize	Larvae	South Africa
Trichogrammatidae			
Trichogrammatoidea sp	Cotton	Eggs	South Africa
Scelionidae			
Phanurus sp.	Winter crops	Eggs	South Africa
Telenomus ullyetti Nixon	Winter crops	Eggs	South Africa
	Citrus	Eggs	South Africa
Tachinidae			
Palexorista laxa (Curran)	Cotton	Larvae	Tanzania
(*Drino imberbis* [wied.])			South Africa
Goniophthalmus halli Mesnil	Cotton	Larvae/ pupae	Tanzania

Sources: Parsons (1940); Coaker (1959); Reed (1965).

that planting sorghum with cotton encourages beneficial insects and reduces damage (Robinson et al. 1971). Inundative releases of laboratory-reared natural enemies at the correct time can also be effective, e.g., releases of *Chrysopa carnea* larvae at a rate of 292 000/acre (approximately 720 000/ha) reduced *Heliothis* populations by up to 96% and tripled cotton yields (Ridgway and Jones 1969). Development of cotton varieties with a shorter fruiting cycle and some resistance to *Heliothis* would reduce damage, and resistance to other pests would help reduce the amount of insecticide used (Newsom 1972).

South and Central America

In the coastal valleys of Peru, increasing reliance on insecticides after the war led to disastrous losses of the cotton crop in the mid-1950s, as in the USA. As a result, an integrated control program which included changes in cultural practices, conservation of natural enemies, and the minimum use of insecticides, was developed (Doutt and Smith 1971). Among the natural enemies of *H. virescens* in South America are several tachinids which, although not specific to *Heliothis* spp, play an important part in its natural control (Cortes, unpublished). Since some of them belong to endemic neotropical genera, they offer a possibility for introduction into other areas.

In the West Indies, braconid parasites of *H. zea* and *H. virescens* play only a small part in control, but *Trichogramma* spp and general predators have some effect (Bennett and Yaseen 1972). In 1971 *Campoletis chlorideae* and *Trichogrammatoidea armigera* were sent to Trinidad from India and

Table 3. Common predators of Heliothis spp In the United States of America.

Predator	*Heliothis* stage preyed upon
Hemiptera	
Lygaeidae	
Geocoris punctipes (Say)	Eggs, small larvae
Nabidae	
Nabis ferus (L.)	Eggs, small/medium larvae
N. alternatus Parshley	Eggs, small/medium larvae
Anthocoridae	
Orius insidiosus (Say)	Eggs, small larvae
O. tristicolor (White)	Eggs, small larvae
Neuroptera	
Chrysopidae	
Chrysopa carnea Steph.	Eggs, small/medium larvae
C. oculata Sav	Eggs, small/medium larvae
C. *rufilabris* Burm.	Eggs, small/medium larvae
Coleoptera	
Coccinellidae	
Coleomegilla maculata (Deg.)	Eggs, small larvae
Hippodamia convergens (Guer.)	Eggs, small larvae
Scymnus spp	Eggs, small larvae
Araneida	
Argiopidae	Small/medium larvae
Oxyopidae	Small/medium larvae
Salticidae	Eggs, small/medium/large larvae
Thomisidae	Small/medium larvae

Source : Ridgway and Lingren 1972.

released on various islands, but so far there have been no reports of establishment.

Australasia

In Australia, studies on natural enemies of *Heliothis armigera* and *H. punctigera* in the cotton agroecosystem began during the last decade and few results have been published as yet. Room (1979) lists 16 parasitoids and 24 predators in the Namoi Valley, New South Wales, but does not indicate their relative importance, and a list for southeast Queensland is provided by Bishop and Blood (1977). The parasitoids in both areas are similar (Table 5) and comprise much the same spectrum as is present elsewhere. The predators include the usual range of polyphagous arthropods, but coccinellids, present in Queensland, were not recorded in New South Wales.

In New Zealand, where larval parasites are absent, a biological control program is being conducted against *H. armigera,* based on parasitoids from Europe. The two parasitoids recommended by Carl (1977), *Hyposoter didymator* and *Apanteles kazak* are readily cultured and diapause can be avoided, which eases the transfer from the Northern Hemisphere to the Southern Hemisphere. *A. kazak* has been successfully cultured in New Zealand, and a release program carried out. The first recoveries have now been made. Unfortunately, the culture of *H. didymator* was lost, but reintroduc-

Table 4. Principal parasites of Heliothis spp in the United States of America.

Parasite	*Heliothis* stage parasitized
Hymenoptera	
Ichneumonidae	
Campoletis flavicincta (Ashm.)	Small larvae
C. sonorensis (Cam.)	Small larvae
Netelia brevicornis (Cushm.)	Larvae /pupae
Braconidae	
Apanteles marginiventris (Cress.)	Small larvae
Cardiochiles nigriceps (Vier.)	Large larvae
Chelonus texanus (Cress.)	Egg/larvae
Microplitis croceipes (Cress.)	Small larvae
Trichogrammatidae	
Trichogramma spp	Eggs
Diptera	
Tachinidae	
Archytas marmoratus (Towns.)	Larvae/pupae
Eucelatoria armigera (Coq.)	Large larvae
Lespesia aletiae(Ril.)	Large larvae
Winthemia rufopicta (Bigot)	Large larvae or larvae/pupae

Sources: Ridgway and Lingren (1971); Danks et al. (1979).

tion is being considered (R. Hill, personal communication).

Pathogens

Because of the need to reduce the amount of insecticide used in *Heliothis* control, a great deal of work has been done on pathogens that affect bollworms, notably by C M. Ignoffo and his coworkers (see Ignoffo 1975). *Bacillus thuringiensis* Berliner works well in the laboratory, but impractically large amounts have been needed to give effective control on cotton (Dulmage 1972). However, Gentry et al. (1969) achieved encouraging results against *H. virescens* on tobacco in a 2-year integrated control program, and there is every reason to believe that B. thuringiensis will soon be a practical alternative to insecticides for *Heliothis* control.

The *Heliothis* nuclear polyhedrosis virus (NPV), *Baculovirus heliothis,* is specific to *Heliothis* spp and is harmless to man, domestic and wild animals, beneficial insects, and plants. It compared well with insecticides in pilot field trials, but later gave inconsistent results because it was inactivated by sunlight. Various attempts have been made to overcome this problem, including mixing it with attractive baits, but the real breakthrough came when the virus was incorporated into a capsule with UV light screening agents, and now several improved commercial formulations are available in the USA. Ignoffo and Couch *(1981*) provide a comprehensive review of the research leading to the development of NPV as a commercially available product.

Trials with NPV were carried out on *H. armigera* in Uganda (Coaker 1958) South Africa (Whitlock 1977) and Botswana (Roome and Daoust 1976) but have not been followed up.

In the USA, experiments are being carried out to evaluate a microsporidian, *Vairimorpha* necatrix for control of lepidopterous pests, but in trials to date with *Heliothis* spp, it has been less effective than chemicals, in spite of achieving high rates of infection (Maddox et al. 1981).

Table 5. Primary parasitoids of Heliothis spp in Australian cotton fields.

Parasitoid	State	
	New South Wales	Queensland
Hymenoptera		
Ichneumonidae		
Heteropelma scaposum (Morley)	+	+
Lissopimpla excelsa (Costa)	+	+
Netelia producta (Brulle)	+	+
Pterocormus promisorius (Erichs.)	+	+
Braconidae		
Cardiochiles sp	+	-
Microplitis sp	+	+
Three undetermined spp	+	-
Trichogrammatidae		
Trichogramma sp	+	+
Trichogrammatoidea sp	-	-
Scelionidae		
Telenomus sp.	+	+
Diptera		
Tachinidae		
Carcelia noctuae (Curran)	+	+
Chaetophthalmus ? biseriatus Mali	+	+
Two undetermined spp	+	+

Sources : Bishop and Blood (1977); Room (1979).

Discussion

The predator complex attacking *Heliothis* spp is similar in all areas to that found in the USA (Table 3) and consists principally of predatory Hemiptera, *Chrysopa* spp, Coccinellidae, and spiders. Thus, prospects for introduction of species from one region to another are poor and could be detrimental in that they may turn their attention to beneficial species employed in biological control of other pests, including weeds.

For example, in Mauritius, releases of the reduviid, *Sycanus intagator* Stal., from India were stopped, because of concern that it would prey upon larvae of *Schematiza cordiaei* Barber (Chrysomelidae), which had been successfully introduced for control of a serious weed, *Cordia curassavica.* On the other hand, general predators are an important mortality factor to be conserved, and pesticide application strategies should be devised to minimize damage to them. There are also opportunities for enhancing their action by timed releases, as has been demonstrated with *Chrysopa carnea* in the USA. A further possibility is the discovery of pesticide-tolerant strains and their establishment in crops to replace pesticide-susceptible populations that have been eliminated.

Many of the parasitoids are specific to *Heliothis* spp or are oligophagous—attacking a narrow range of related hosts. Because of their intimate relationship with their hosts, these parasitoids are more reliable mortality factors, and their manipulation is likely to have a greater impact than that of general predators. Comparison of the parasitoid spectrum in different regions (Tables 1, 2, 4, 5) shows similarities both taxonomic and functional. In fact, some species are common to both Africa and India.

Very crudely, Table 6 compares the parasite spectra in different areas and suggests that there are a limited number of available niches to be filled,

Table 6. Comparison of parasite spectra of Heliothis spp In different areas.

Parasite	Area				*Heliothis* stage parasitized
	Africa	Australia	India	USA	
Ichneumonidae					
Campoletis, Eriborus,Charops	+	+	+	+	Small larvae
Enicospilus, Netelia	+	+	+	+	Large larvae
Braconidae					
Chelonus	+	-	(-)[a]	+	Egg/larvae
Apanteles. Microplitis	+	+	(-)[a]	+	Small larvae
Bracon	+		+		Larvae external gregarious
Cardiochiles	+	+	-	+	Large larvae
Trichogrammatidae					
Trichogramma. Trichogrammatoidea	+	+	+	+	Eggs
Scelionidae					
Telenomus	+	+	-	(-)[a]	Eggs
Tachinidae					
Palexorista, Carcelia, Eucelatoria, Lespesia	+	+	+	+	Larvae
Archytas. Winthemia Goniophthalmus	+	?	+	+	Larvae/pupae

a. Present but ineffective.

Some gaps appear to exist in some regions; notably, scelionids *(Telenomus* spp) are not recorded in India; *Chelonus* sp in India and Australia; *Apanteles* spp in Australia, and *Bracon* spp in Australia and the USA.

These gaps offer the best opportunities for introduction of exotic species. It is also possible that species from another continent may be inherently superior to native ones and so be able to displace them and raise overall mortality (DeBach 1966). A third possibility is the introduction of strains of species, native or otherwise, that are pesticide-tolerant. These prospects cannot be fully evaluated at present, as there are too few studies on regional parasite complexes, and undoubtedly many useful parasitoids remain to be discovered. For example, research currently under way in Bolivia is turning up new species of egg parasitoids (F.D. Bennett, personal communication).

Further bioecological studies are also needed in areas where no recent surveys have been made to enable reevaluation and detection of changes brought about by intensification of agriculture. Such studies must be backed by sound taxonomic research, as most parasitoid groups are poorly understood and much confusion exists *as* to the identity of common species. For example, recent studies on Trichogrammatidae have shown that more species exist than had previously been realized, and that many of them can only confidently be isolated and characterized following careful experimentation with live material under standardized conditions (Nagarkatti and Nagaraja 1977).

Bioecological studies are also essential to the development of management strategies to conserve and enhance the action of indigenous parasitoids and predators.

Records of nematode parasites, usually Mermithidae, are available from all regions where inventories of natural enemies are available. However, significant rates of parasitism are only achieved at irregular intervals, when climatic conditions are favorable, and it has so far not been possible to overcome this limitation or to culture mermithids for inundative release. Thus, for the time being, nematodes are not of practical value as biotic pest control agents.

Pathogens are present in most *Heliothis* spp populations, but they are not reliable control agents, except where epidemics can be induced, but as mortality rapidly falls to endemic levels, their use is principally as specific biological pesticides.

Recent advances in the handling, culture, and application of pathogens have made their use a practical reality and a valuable tool in pest management. However, relatively high cost, rapid deterioration in storage under tropical conditions, and ready inactivation by ultraviolet light limit their usefulness at present.

The CIBC and *Heliothis* Management

The Commonwealth Institute of Biological Control, founded in 1927, is a constituent of the Commonwealth Agricultural Bureaux (CAB), an international organization set up and funded by governments of the British Commonwealth countries, but its services are open to all. The CIBC is backed by the CAB Information and Identification Services and is developing a network of collaborating agencies through the unit set up in June 1981 at Imperial College, Silwood Park, Ascot, in the UK. Throughout its existence, the CIBC has built up expertise in the use of arthropod parasitoids and predators in arthropod pest and weed control, chiefly related to the introduction of natural enemies for "classical" biological control. As well as undertaking research on contract, the CIBC provides advice, information, and training. Since 1975, it has begun to actively widen its service with regard to the range of natural enemies studied and the ways in which they are used. Within its sister institutes in the CAB organization, expertise is now available on insect nematology and mycology; in addition, taxonomists undertake identification of insects, helminths (including nematodes), fungi, and some bacteria. In association with Imperial College, the UK Glasshouse Crops Research Institute, and the UK Institute of Virology, the CIBC now provides a service including all aspects of arthropod pathology, population dynamics, and computer-assisted analysis and modeling.

The CIBC has regional field stations in Trinidad, Switzerland, Kenya, India, and Pakistan, which provide bases for field studies and provide cultures of natural enemies. Work is also carried out from temporary substations set up to undertake specific projects—currently in Mexico, Ghana, and Malaysia. Besides carrying out research and information work itself, the UK unit also maintains links with collaborating institutes. In the past, the CIBC has made studies on *Heliothis* spp natural enemies at its stations and is currently involved in providing parasitoid cultures for India and New Zealand.

The CIBC would be glad to take part in new initiatives related to *Heliothis* spp management as suggested in this paper.

Conclusion

The few reported attempts at biological control of *Heliothis* spp by introduction of natural enemies were not successful. Recent CIBC projects have included the supply of parasites from India for release in Mauritius and of parasites from Europe for release in New Zealand. The results of these are awaited with particular interest, as the circumstances are favorable; both release areas are islands and presumably have predominantly, if not entirely, nonmigrant populations. In more complex conditions on continents, the prospects for straightforward classical biological control appear less promising.

It seems more likely that in most areas, the aim must be integrated control, particularly on crops such as cotton, where *Heliothis* spp are part of a diverse pest complex. *Bacillus thuringiensis* and NPV should provide treatments that will conserve natural enemies where arthropod natural enemies are inadequate. However, the recent investigations on the European parasites, which achieve substantial rates of parasitism in spite of heavy insecticide usage on intensively cultivated land, suggest the need for a critical reappraisal. New studies should include evaluation of other parasite species and strains for their ability to maintain effective population densities in pesticide-polluted agroecosystems. With the known differences in parasite fauna and abundance in different crops, particular attention should be paid to studies in target crops and associated alternative host plants.

A further need is to determine the extent of migration. If migration is significant, attention to the feasibility of periodic release of natural enemies will be necessary, unless natural enemies with similar migration patterns can be located. Alternatively, if infestations chiefly derive from breeding in other plants in surrounding cultivated areas, a search for natural enemies effective in these habitats will be indicated; suppression by alteration of the surroundings to discourage *Heliothis* spp also becomes a possibility, as does the encouragement of plants supporting those natural enemies that thrive within the crop.

In each instance, detailed ecological studies are required to seek out means of exploiting natural enemies. A less thorough approach is unlikely to lead to effective biological or integrated control. As *Heliothis* spp are of importance throughout subtropical and tropical regions on several major crops, a wide-ranging coordinated research program is most likely to achieve progress. The network of regional stations operated by the CIBC provides centers where such studies can be undertaken. Its UK unit and associated institutes can provide backup research and services on all aspects of pest management, information retrieval, and identification of arthropods and pathogens.

References

ACHAN, *P.O.,* MATHUR, K.C., DHARMADIKARI, P.R., and MANJUNATH, T.M. 1968. Parasites of *Heliothis* spp in India. Technical Bulletin of the Commonwealth Institute of Biological Control 10: 129-147.

BAR, D., GERLING, D., and ROSSLER, Y. 1979. Bionomics of the principal natural enemies attacking *Heliothis armigera* in cotton fields in Israel. Environmental Entomology 8: 468-474.

BENNETT, F.D., and YASEEN, M. 1972. Parasite introductions for the biological control of three insect pests in the Lesser Antilles and British Honduras. PANS 18: 468-474.

BHATNAGAR, VS. 1980. A report on research on the *Heliothis* complex at ICRISAT (India) 1974-1979. Presented at the All India Workshop on Consolidation of Pest Management Recommendations and Guidelines of Research. 24-26 Apr 1980, Udaipur, India.

BISHOP, A.L., and BLOOD, P.R.B. 1977. A record of beneficial arthropods and insect diseases in southeast Queensland cotton. PANS 23: 384-386.

BOGUSH, P.O. 1957. Parasites of the cotton bollworm, *Chlorides obsoleta* F., reared in Turkmenia. Entomologikekoe Obozrenie 36: 98-107. (In Russian.)

BOWDEN, J. 1973. Migration of pests in the tropics. Mededelingen Fakuteit Landbouwwetenschappen, Ghent 38: 785-796.

CAMPBELL, B.C., and DUFFEY, S.S. 1979. Tomatine and parasitic wasps: potential incompatibility of plant antibiosis with biological control. Science 205: 700-702.

CARL, K.P. 1977. Survey, propagation and importation of natural enemies of *Heliothis armigera* Hb. Annual report for 1976, Commonwealth Institute of Biological Control, Delemont, Switzerland.

CARL, K.P. 1978. *Heliothis armigera;* parasite survey and introduction of *Apanteles kazak* to New Zealand. Report of work in 1977-78. Report, Commonwealth Institute of Biological Control, Delemont, Switzerland.

COAKER, T.H. 1958. Experiments with a virus disease of the cotton bollworm *Heliothis armigera* (Hbn.). Annals of Applied Biology 46: 536-541.

COAKER, T.H. 1959. Investigations on *Heliothis armigera* (Hb.) in Uganda. Bulletin of Entomological Research 50: 484-506.

DANKS, H.V., RABB, R.L., and SOUTHERN, P.S. 1979. Biology of insect parasites of *Heliothis* larvae in North Carolina. Journal of the Georgia Entomological Society 14(1): 36-64.

De BACH, P. 1966. The competitive displacement and co-existence principles. Annual Review of Entomology 11: 183-212.

DOUTT, R.L., and SMITH, R.E. 1971. The pesticide syndrome—diagnosis and suggested prophylaxis. *In* Biological control (ed. C.B. Huffaker). New York, USA: Plenum Press. 511 pp.

DULMAGE, H.T. 1972. Pathogens. Pages 57-64 *in* Southern Cooperative Series Bulletin 169, Oklahoma Agricultural Experiment Station, Oklahoma State University, Stillwater, Okla, USA.

GENTRY, C.R., THOMAS, W.W., and STANLEY, J.M. 1969. Integrated control as an improved means of reducing populations of tobacco pests. Journal of Economic Entomology 62: 1274-1277.

GREATHEAD, D.J. 1966. Memorandum on the parasites and possibilities of biological control of East African boll worms, Commonwealth Institute of Biological Control, Kampala, Uganda. 21 pp.

HARDWICK, D.F. 1965. The corn earworm complex. Memoirs of the Entomological Society of Canada 40: 1 -247.

IGNOFFO, C.M. 1975. Entomopathogens as insecticides. *In* Insecticides of the future, ed. M. Jacobson. New York, USA: Marcel Dekker. 93 pp.

IGNOFFO, C.M., and COUCH, T.L. 1981. The nucleopolyhedrosis virus of *Heliothis* species as a microbial insecticide. Pages 329-362 *in* Microbial control of pests and plant diseases 1970-80 (ed. H.D. Surges). London, UK: Academic Press.

LINCOLN, C. 1972. Distribution, abundance and control of *Heliothis* spp. in cotton and other host plants. Pages 2-7 *in* Southern Cooperative Series Bulletin 169, Oklahoma Agricultural Experiment Station, Oklahoma State University, Stillwater, Okla, USA.

MADDOX, J.V., BROOKS, W.W., and FUXA, J.R. 1981. *Vairimorpha necatrix,* a pathogen of agricultural pests: potential for pest control. Pages 587-594 *in* Microbial control of pests and plant diseases 1970-1980, ed. H.D. Burges. London, UK: Academic Press.

MANJUNATH. T.M. 1972. Biological studies on *Trichogrammatoidea armigera* Nagaraja, a new dimorphic egg parasite of *Heliothis armigera* (Hubner) in India. Entomophaga 17:131-147.

NAGARKATTI, S., and NAGARAJA, H. 1977. Biosystematics of *Trichogramma* and *Trichogrammatoidea* species. Annual Review of Entomology 22:157-176.

NETTLES, W.C. 1979. *Eucelatoria* sp. females: factors influencing response to cotton and okra plants. Environmental Entomology 8:619-623.

NEWSOM, L.D. 1972. Theory of population management for *Heliothis* spp. in cotton. Pages 80-92 *in* Oklahoma Agricultural Experiment Station, Oklahoma State University, Stillwater, Okla, USA.

PARSONS, F.S. 1940. Investigations on the cotton bollworm *Heliothis armigera* Hubn. *(obsoleta* Fabr.) Part II. The incidence of parasites in quantitative relation to bollworm populations in South Africa. Bulletin of Entomological Research 31.89-109.

PLAPP, F.W., and VINSON, S.B. 1977. Comparative toxicities of some insecticides to the tobacco budworm and its ichneumonid parasite, *Campoletis sonorensis.* Environmental Entomology 6:381 -384.

RAO, V.P. 1968. *Heliothis* spp. and their parasites in India. PANS (A) 14:367-375.

REED, W. 1965. *Heliothis armigera* (Hb.) (Noctuidae) in Western Tanganyika II. Ecology and natural and chemical control. Bulletin of Entomological Research 56:127-140.

RIDGWAY, R.L., and JONES, S.L. 1969. Inundative releases of *Chrysopa carnea* for control of *Heliothis* on cotton. Journal of Economic Entomology 62:177-180.

RIDGWAY, R.L., and LINGREN, P.D. 1972. Predaceous and parasitic arthropods as regulators of *Heliothis* populations. Pages 48-56 *in* Southern Cooperative Series Bulletin 169, Oklahoma Agricultural Experiment Station, Oklahoma State University, Stillwater, Okla, USA.

ROBINSON, B.R., YOUNG, J.H., and MORRISON, R.D. 1971. Strip-cropping effects on abundance of *Heliothis* damaged cotton squares, boll placement, total bolls and yields in Oklahoma. Environmental Entomology 1: 140-145.

ROOM, P.M. 1979. Parasites and predators of *Heliothis* spp. (Lepidoptera: Noctuidae) in cotton in the Namoi Velley, New South Wales. Journal of the Australian Entomological Society 18:223-228.

ROOME, R.E.,and DAOUST, R.A. 1976. Survival of the nuclear polyhedrosis virus of *Heliothis armigera* on crops in soils in Botswana. Journal of Invertebrate Pathology 27:7-12.

WHITLOCK, V.H. 1977. Simultaneous treatments of *Heliothis armigera* with a nuclear polyhedrosis and a granulosis virus. Journal of Invertebrate Pathology 29:297-303.

The Utilization of Biological Control in *Heliothis* Management in India

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Abstract

Heliothis armigera *causes extensive losses to food and fiber crops in India. Indiscriminate pesticide use and the availability of monocultures of preferred host plants have aggravated the problem. In the last 2 or 3 years, efforts have been in progress to make inundative releases of exotic parasites and to utilize indigenous nuclear polyhedrosis virus against* H. armigera. *The use of egg parasites such* as Trichogramma *spp appears promising, but inundative releases ot egg-larval and larval parasites have limited scope because of difficulties in mass rearing. The regulatory action ot predators is poorly understood, but their conservation could be considered. Amongst recent introductions are* Eucelatoria bryani *(Coq.) and* Apanteles marginiventris *(Cresson), but only the former has been released and recovered in the field. Consideration should be given to importation of parasites such as* Telenomus sp *nr* triptus *Nixon from Australia,* Hyposoter didymator *Thbs. and* Apanteles kazak *Telenga -which show insecticide tolerance-from Europe, and several tachinid parasites from the neotropics that appear to be suitable candidates lor introduction. Amongst pathogens there is scope lor utilizing the indigenous nuclear polyhedrosis virus.*

The role of weeds in influencing natural enemy populations needs to be studied, and insecticides with selective action and greater safety to natural enemies need to be identified. In order to achieve biological control, several nonchemical approaches would have to be combined. Greater emphasis on exotic natural enemy introduction will require international cooperation, while a good surveillance and forecasting system will enable implementation of appropriate control measures in areas where migrations are imminent.

Résumé

*Utilisation de la lutte biologique contre l'*Heliothis *en Inde:* Heliothis armigera *cause des dégâts importants aux cultures vivrières et à fibre en Inde. L'usage aveugle d'insecticides et la disponibilité de cultures pures des plantes-hôtes préférées ont aggravé le problème. Depuis deux ou trois ans, des efforts ont été faits pour réaliser des lâchers inondatifs de parasites exotiques et utiliser le virus indigène de la polyédrose nucléaire contre* H. armigera. *L'utilisation de parasites des oeufs tels que* Trichogramma *(spp) semble prometteuse, mais les lâchers inondatifs de parasites des oeufs-larves ou des larves n'ont qu'une portée limitée, vu les problèmes posés par un élevage de masse. L'action régulatrice des prédateurs n'est pas encore bien comprise, mais leur conservation peut être envisagée.* Eucelatoria bryani *(Coq.) et* Apanteles marginiventris *(Cresson) sont de récentes introductions, mais seule la première a été lâchée et retrouvée sur le terrain. Il faudrait accorder une attention spéciale à l'importation de parasites tels que* Telenomus *sp nr* triptus *Nixon d'Australie,* Hyposoter didymator *Thbs et* Apanteles kazak *Telenga — ayant une tolérance aux insecticides — d'Europe et plusieurs tachinaires parasites néotropicaux qui pourraient être introduits. Parmi les agents pathogènes, l'utilisation du virus indigène de la polyédrose nucléaire est concevable.*

Il faudrait étudier le rôle des mauvaises herbes chez les populations des ennemis naturels et identifier les insecticides ayant une action sélective et plus sûrs pour les ennemis naturels. Plusieurs approches non chimiques devraient être associées pour réaliser une lutte biologique. Il faudra compter sur la coopération internationale si l'on veut accorder plus d'importance à l'introduction d'ennemis naturels. Un bon système de surveillance et de prévision devrait permettre l'établissement des mesures de lutte appropriées dans les régions où les migrations sont imminentes.

The noctuid *Heliothis armigera* (Hb) as a pest of an extensive range of cultivated crops has no equal. This and related species such as *H. zea* (Boddie), *H. virescens* Fab., *H. punctigera* Wall., etc., have

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probably drawn the attention of more economic entomologists than any other pest. In India, *H. armigera* is a limiting factor in pulse production, often causing total crop loss. Seshu Reddy and Channa Basavanna (1978) estimated that an average infestation of one larva per plant of pigeonpea can cause a yield loss of 1015 kg/ha. In sorghum, yield losses of 18 to 26% have been reported (Rawat et al. 1970), while in cotton in Madhya Pradesh, losses of 41 to 56% occur (Kaushik et al. 1969). In horticultural crops such as tomato, yield losses of 40 to 50% are reported in Tamil Nadu (Srinivasan 1959).

The problem has apparently been aggravated, as with many other pests, by indiscriminate pesticidal applications, including aerial spraying in some areas like Gujarat, which has adversely affected the natural enemy populations. Contributing factors in India include the continuous availability of monocultures of cotton, pigeonpea, chickpea, lucerne, maize, sorghum, potato, groundnut, etc., and the lack of crop rotation, which would break the *Heliothis* cycle.

Because of the high cost of protecting crops from *Heliothis* spp with chemical pesticides and the increasing concern over residues in food, there is growing interest in the use of natural enemies for controlling these pests. The prospects of using classical biological control, involving introduction of exotic natural enemies are not considered to be bright (Anonymous 1978), in view of the migratory behavior of moths and the sudden influx of populations to which resident natural enemies may not be able to respond readily. In India, it is only in the last 2 or 3 years that efforts have been in progress to see if exotic natural enemies can be utilized.

This paper is not intended to be a review of biological control efforts against *Heliothis* spp in India and elsewhere. Rather, an attempt has been made to see how best the available information could be utilized to enhance the regulatory action of natural enemies, particularly of *H. armigera,* which is the dominant pest species of the *Heliothis* complex in this country.

Inundative Releases of Indigenous Parasites and Predators

Egg Parasites

Utilization of egg parasites such as *Trichogramma* spp should be considered seriously, since damage to the crop can be greatly reduced if the releases are well-timed and adequate numbers released at frequent intervals. Ridgway et al. (1974) recommend 100 000 *Trichogramma* per acre (247 000/ha) at 2- or 3-day intervals, but earlier reports (Goretzkaya 1940) indicate that in Azerbaidjan, releases of 200 000 per acre (494 000/ha) in five batches of about 40 000 each at intervals of 3 days gave parasitism of 40 to 80% throughout the period of application. Bournier and Peyrelongue (1973) also reported that in Madagascar preflowering releases of T. *brasiliensis* Ashm. appeared very promising.

Amongst Trichogrammatidae, those most commonly reared from *Heliothis* eggs in India are *T. chilonis* Ishii, *T. chilotraeae* Nagaraja and Nagarkatti, and *Trichogrammatoidea armigera* Manjunath. In Gujarat, Manjunath et al. (1976) found that *T. chilotraeae* was abundant on *H. peltigera* (Schiff.) eggs laid on the weed starburr *(Acanthospermum hispidum).*

The use of *Trichogramma* spp has certain limitations, besides the fact that they have poor searching ability, which necessitates the release of massive numbers. Studies on natural parasitism have shown that adult *Trichogramma* avoid crops such as pigeonpea and chickpea. Bhatnagar and Davies (1978) found that while egg parasitism was as high as 80% on sorghum and cowpea, it was negligible on pigeonpea and chickpea, which suffered heavy damage by larvae of *H. armigera.* This is attributed to the glandular hairs on the leaves, which produce an acidic exudate. However, there is scope for using *Trichogramma* spp in such crops as cotton, sorghum, maize, sunflower, and groundnut, where such a problem does not exist.

During the 1980-81 cotton season in Gujarat, extremely encouraging results have been obtained from releases of T. *brasiliensis* and *T. achaeae* N. and N., in addition to larval parasites of bollworms, in an insecticide-free 2-ha plot at Karvan (Baroda district) by the Gujarat Agricultural University under the All India Coordinated Research Project on Biological Control. Yields were found to be comparable to those in pesticide-treated plots (Anonymous 1981), but confirmation of results in the current season is awaited.

Egg-Larval and Larval Parasites

Hymenoptera

While efforts have been made by various workers to study the biology of hymenopterous and dipterous parasites and develop mass-rearing techniques (Tikar and Thakare 1961; Gangrade 1964; Achan et al. 1968; Patel et al. 1970; Patel and Singh 1972; Patel et al. 1973), the egg-larval parasite *Chelonus heliopae* Gupta and larval parasites, such as *Campoletis chlorideae* Uchida and *Eriborus* spp are not amenable to mass-rearing, and the process is not economical. A problem with sex ratio favoring males is a major impediment in laboratory cultures. In some countries, particularly the USSR, use of larval parasites such as *Bracon brevicomis* (Wesm.) at the rate of 10 000 per hectare in cotton has been recommended (Skoblo 1940), but despite the ease of rearing this parasite, it has not been tried so far against *H. armigera* in India.

Diptera

Amongst the indigenous Diptera, breeding of *Palexorista laxa* (Curran) [= *Drino munda* (Wied.)] is relatively easy and has been standardized by entomologists in the USA (Chauthani and Hamm 1967), where it was introduced. However, no efforts have been made to undertake inundative releases of these species in India to my knowledge, but may be worth considering. Rearing methods for *Carcelia* (= *Senometopia) illota* (Curran) have been developed (Patel et al. 1970). *Goniophthalmus halli* Mesn., a microtype egg-laying species, can also be mass-bred (Patel and Singh 1972). For G. *halli,* a technique similar to that developed for the sugarcane borer parasite *Palpozenillia palpalis* (Ald.) by Simmonds (1958) can be utilized, but both are labor-intensive and would not be suitable for consideration in any inundative release program where economy of production has to be kept in mind.

The tachinid *Peribaea orbata* (Wied.), can also be mass-bred easily in the laboratory and being gregarious, yields of puparia are substantial. This species is not specific to *Heliothis,* being also parasitic on *Spodoptera* spp, and hence its impact on H. *armigera* is likely to be dissipated.

In general, however, the mass-rearing of larval parasites of *H. armigera,* particularly those that are solitary, is laborious and uneconomical, since the parasitized larvae have to be reared in isolation to avoid cannibalism. This makes the use of larval parasites for inundative release an unattractive proposition.

Predators

Although it is well known that *Chrysopa* spp, e.g., C. *carnea* Steph., C. *scelestes* Banks, etc., are common in cotton fields in India, no effort has been made hitherto to breed them for inundative release. A method for mass-rearing C. *scelestes* has since been developed (Krishnamoorthy and Nagarkatti, in press) based on the technique described by Ridgway et al. (1970), except that frozen eggs of *Corcyra cephalonica* St. are used instead of *Sitotroga cerealella* (Oliv.). At present, inundative releases of C. *scelestes* are in progress in cotton in Gujarat, although the numbers being released are not as high as recommended by Ridgway et al. (1970). The results of these releases will be known only after harvest is completed and yield data become available.

Predators such as nabids, pentatomids, and reduviids are known, e.g., *Sycanus indagator* Stal., *Rhinocoris fuscipennis* F., *R. marginatus F.,Andrallus spinidens* (Fabr.), etc., but may not show significant impact on *Heliothis* populations because they are general predators and are not likely to concentrate on *Heliothis* eggs or larvae as prey. At best, conservation of these general predators can be considered.

Importation of Exotic Natural Enemies

Classical biological control, involving importation of exotic natural enemies, has not been tried in India except in a limited way, and only in the last 2 or 3 years. The Commonwealth Institute of Biological Control, Indian Station, first imported the tachinid *Eucelatoria bryani* (Coq.) (earlier called *E. armigera)* from the USA in 1978 and found that it successfully parasitized *H. armigera.*

Subsequently, Pawar et al. (1981) reported that from January 1979 to April 1980, a total of 1560 mated females of *E. bryani were* released in tomato fields around Bangalore, along with 798 larvae parasitized by the dipteran. The authors also reported that recoveries were made on four occasions. The same parasite was also bred at the National Centre for Biological Control, Bangalore, and 435 mated females released in a tomato crop near Hessaraghatta, 26 km from Bangalore. Sporadic recoveries indicate that the parasite is adaptable to the climatic conditions around Bangalore and could possibly become a permanent component of the parasite complex. It is not known how the parasite will perform in relation to indigenous dipterous parasites and whether the fact that it is gregarious will give it any marked advantage over some of the indigenous species. Releases of *E. bryani* were also made in pigeonpea and chickpea at Patancheru, near Hyderabad, giving 14.2% and 4% parasitism respectively in field-cage studies (Sithanantham and Reed 1980). The next few years will show how effective the parasite is proving.

At the National Centre for Biological Control, we have recently obtained a culture of *Apanteles marginiventris* (Cresson) from the USA, where it attacks a wide range of Noctuidae, including *Heliothis* spp. Preliminary studies have shown that it accepts *H. armigera* as well as *Spodoptera litura* (F.). If the crop stature has any influence on the activity of the Diptera—as is indicated by reports of Bhatnagar and Davies (1977a), who found that parasitism on chickpea by Diptera never exceeded 4.4%—there is reason to believe that *E. bryani* may not perform well in chickpea, but may prove better in crops such as cotton, tomato, and pigeonpea. The performance of *A. marginiventris* in the field, particularly on crops like pigeonpea and chickpea, will have to be determined and more emphasis placed on importation of hymenopterous larval parasites for use on these crops.

Since egg parasitism by *Telenomus* spp on *Heliothis* in India has not been observed, importation of *T.* sp. nr. *triptus* Nixon from Australia, where it is reported to give as much as 92.7% parasitism of *Heliothis* spp (Twine 1973), must be considered. Its effectiveness in crops that are avoided by *Trichogramma* spp would have to be studied.

We propose to introduce several other exotic parasites of *Heliothis* over the next few years. If a good balance is to be struck between parasite and insecticide use, it would be desirable to test species that are relatively tolerant to insecticides. The European parasites *Hyposoter didymator* Thbs. and *Apanteles kazak* Telenga, which give high rates of parasitism even in heavily sprayed areas, may be suitable for use in integrated control programs and must be given preference. *A. kazak* also has the advantage of a short life-cycle (10-18 days), which compares favorably with that of *H. armigera.*

Sabrosky (1978) has listed a number of tachinid parasites of *Heliothis* spp from the western hemisphere. Amongst these, those species that show greater affinity for *Heliothis* than for other noctuids must certainly be considered for trials, since tachinids are powerful fliers and could conceivably migrate along with the pest. Three species of *Incamyia*—*I. charlini* Cortes, *I. chilensis* Ald. and *I. spinicosta* Ald.—which have been recorded from *H. gelotopoeon* (Dyar); *Actinophaga koehleri* Blanch., which has been recorded only from *Heliothis* spp; and *Lespesia aletiae* (Riley) which has been recorded from *H. zea, H. virescens,* etc., are some of the tachinids that may prove useful.

At a recent workshop on biological control of *Heliothis* spp held in Australia (Twine 1980) a number of papers were presented that include lists of natural enemies and details of their effectiveness in Australia and Africa. This compilation could be very useful in selecting candidate species for trials in India.

Use of Bacterial and Viral Pathogens

Although the bacterium *Bacillus thuringiensis* Berliner is known to occur naturally in the field and has been isolated from a number of lepidopterous hosts, including *H. armigera* in India, its use on field scale has been strongly opposed by the silk industry. Despite assurances that the pathogen is widely used in other countries—Japan and China, for instance—where silk forms an important industry, it is unlikely that the attitude of the concerned authorities, particularly in some of the states, will change. Even if this were to happen, it will be a long time before commercial production of an acceptable formulation is started. Meanwhile, it is necessary to screen strains of *B. thuringiensis* that are less toxic to silkworms and could be profitably used in agriculture.

The occurrence of nuclear polyhedrosis virus (NPV) in *H. armigera* was reported from India by Patel et al. as early as 1968. Although the disease is widely prevalent in laboratory cultures, natural incidence in the field has rarely been observed. Rabindra and Subramaniam (1973) also reported the presence of a cytoplasmic polyhedrosis virus (CPV) in laboratory cultures of *H. armigera.* More recently, cultures of the insect maintained at our Centre have revealed the presence of a granulosis virus.

Though the use of the NPV in cotton in Uganda (Coaker 1958) and Botswana (Roome 1971) has not been considered to be very effective, in India Narayanan (1980) described field studies on the NPV in chickpea. He states that application of the virus at 250 and 125 larval equivalents per ha during evening hours thrice at weekly intervals after appearance of young larvae caused significant reduction in infestation, treated plants showing

5.15 and 7.85 larvae per 10 plants, respectively, as against 27.65 in untreated controls. Moreover, virus-treated plots compared favorably with those treated with 0.07% endosulfan.

No efforts have been made thus far to utilize commercial preparations of *Baculovirus heliothis,* such as Elcar, that are already available in other countries, or to produce the indigenous virus on a commercial scale. The involved registration procedures, etc., would deter local firms from taking up commercial production. However, it seems likely that farmers would consider the use of crude suspensions of viral material which they themselves can prepare, as in the case of S. *litura.* (In cotton, both in Tamil Nadu and Gujarat, farmers have readily taken to the preparation and use of the NPV). At our Centre we have now produced sufficient NPV material to enable reasonably large-scale field trials. We now propose to undertake trials on different crops and standardize the treatment schedules, since these could vary from crop to crop. Lyophilization and preparation of formulated material, which will facilitate field trials, is also being undertaken. The scope of microencapsulation and use of suitable indigenously available protectants to prevent inactivation of the virus polyhedra by UV radiation is yet to be explored.

The Role of Weeds in *Heliothis* Management

Bhatnagar and Davies (1977b) have reported that *H. armigera* has been recorded on 50 cultivated plant species and 51 weed species. They state that the most significant carryover hosts in the hot summer are *Datura metel, Acanlhospermum hispidum,* and *Gynandropis gynandra.* There is, however, little information on the extent of parasitism of *H. armigera* present on these weeds, and so it is difficult to assess to what extent the weeds help in serving as reservoirs of the parasites or, alternatively, to what extent they are detrimental in serving as reservoirs of the pest itself. More information of the kind provided by Manjunath et al. (1976) would be required to make a proper assessment of the role of weeds.

There is some evidence in other countries that the elimination of weeds can help to reduce *Heliothis* infestation in cultivated crops. For example, Lozina-Lozinskii (1954) has stated that destruction of Dafura sfraemonium, Hyoscyamus *niger, Abutilon avicennae,* and *Solatium nigrum* in the spring effectively suppresses *H. armigera* populations on cotton and chickpea in the USSR. Such studies have apparently not been made in India in relation to *Heliothis.*

In addition to eradication of the weeds, another avenue of research that probably warrants effort, is control of *H. armigera* in weed stands, either by inundative releases of parasites such as *Trichogramma* where *H. armigera* abounds in the off-season, or by treatment with appropriate chemicals that will reduce the pest population before the major susceptible crops are sown.

Selective Use of Insecticides

The use of some insecticidal applications may be unavoidable, considering the increased demand for pulses, cotton, oilseeds, and cereals in the country, but the insecticides to be used should be selected with care so that they do minimal harm to predators and parasites. Sukhoruchenko et al. (1977) have reported that phosalone is harmless to natural enemies and is therefore suitable for use in integrated control programs. Endosulfan is frequently considered to be safe to natural enemies on the basis of its relative safety to honeybees, but our studies have indicated that this needs careful reappraisal, since the usually recommended dosages have been found highly toxic to some of the parasites under rearing in our laboratory. It is obvious that insecticides such as DDT have a pronounced effect on parasitism levels, whatever the crop may be; Bhatnagar and Davies (1977), reported that in areas of Andhra Pradesh, parasitism was as low as 1 to 3% in intercropped pigeonpea sprayed with DDT as against 22% in one unsprayed field. Although it is recommended time and again that use of such broad-spectrum and persistent insecticides in agriculture should be discouraged, farmers continue to use them. Extensive screening of insecticides readily available in India should be undertaken with the objective of utilizing only those that have a demonstrably higher degree of safety to natural enemies. Unless this is done and recommendations of insecticidal applications are based on such studies, it would be meaningless to consider augmenting natural enemy populations.

Discussion

In view of the large numbers of host plants involved, the occurrence of *H. armigera* throughout the year on cultivated crops and weed hosts, its migratory behavior, etc., there is little doubt that the management of this pest necessitates a judicious combination of biological control agents, insecticides, and cultural practices. All nonchemical approaches would have to be considered, such as:

1. Conservation of existing natural enemies by judicious use of chemicals and enhancing their regulatory action by suitable modification of the environment, e.g., by providing nesting sites for vespids, kairomones for increasing efficiency of *Trichogramma* spp, nectar-bearing flowering plants to provide food for adult parasites, etc.
2. Screening for and use of resistant varieties of the crop plants—the feasibility of which is already being studied in pigeonpea and chickpea by ICRISAT entomologists (Reed et al. 1980).
3. Adoption of crop rotation and field sanitation, which will exclude the availability of suitable host plants in quick succession.
4. Use of pheromone baits and light traps, both as monitoring devices and control measures.
5. Use of biocontrol agents such as egg and larval parasites and the nuclear polyhedrosis virus, the latter in the manner of an insecticide when outbreaks of the pest are to be reckoned with.
6. Adjustment of planting times, which will help crops to escape oviposition by migrating moths.

Introduction of exotic parasites should be considered as a long-range plan, and releases of any species under trial should not be abandoned prematurely and before sufficient numbers are released, as this could lead to wrong conclusions. In his review of natural enemy introductions into Canada, Beirne (1975) has stressed the importance of numbers released. He estimated that of the species released in totals of under 5000, only 10% became established; of the 5000 to 31 200 group, 40%; but of the over 31 200 group, as many as 78%. He therefore concluded that the greater the number released, the greater the likelihood of successful colonization, and that if the numbers were below some minimum (about 5000 individuals), the probability of success was small. The importance of the size of the founder population and its genetic makeup can hardly be overemphasized. A large heterozygous population of the introduced parasite would have the best chance of establishing an adequate breeding stock in the new environment and of further propagation.

It is generally believed that control of pests by introduced natural enemies is best achieved in habitats of intermediate stability, such as orchard habitats, or of even greater stability such as forest habitats (Hall et al. 1980). With a polyphagous pest like *H. armigera,* which in India occurs on one crop or another all through the year, the habitats in which it survives can hardly be called temporary agroecosystems, although the crops are short-term ones and periodical disturbances occur.

Concerted efforts would have to be made to obtain exotic parasites to suit each crop situation, and unless a team is specially assigned for foreign exploration, the process of obtaining parasite material would remain slow.

If inundative releases of parasites are to be done on a countrywide scale, particularly in crops such as cotton and pulses, the need for commercial-scale production of parasites will have to be fulfilled. In the East European countries, particularly the USSR, large numbers of state-run insectaries cater to the needs of farmers, while in the USA and UK private entrepreneurs operate efficient commercial insectaries. In India, only a few state-run parasite-breeding laboratories exist where *T. chilonis* Ishii and parasites *of Nephantis serinopa* Meyr. are mass-bred for use in sugarcane and coconut, and even these units are unable to meet the demand fully.

Estimates of numbers needed per hectare (in other words "dosages") have yet to be worked out for various crops and pest population levels, but information already available in the literature could provide guidelines.

H. armigera can survive and develop over a wide range of temperatures. Eggs can develop from 14 to 38°C, larvae from 14 to 36°C, and pupae from 11 to 34°C (Rubtzov 1941). This would indicate that unless the parasites can also tolerate and develop under these conditions, they would not be able to give satisfactory control of the pest. Hence, if the parasite is to be mass-bred for field release, it would be necessary to simulate field conditions to the maximum extent possible. If, on the other hand, an exotic parasite is being sought for inoculative releases, it must be ensured that it originates from an area with a climate similar to that of the area where it is to be introduced.

Forecasting systems are as yet poorly developed in India, and the need for these, particularly with a pest like *H. armigera,* cannot be underestimated. Studies on population dynamics, both of the pest and of its natural enemies, need to be done over large plots (since small plots do not seem to attract the pest) in different parts of the country, and this would require organized teamwork. If, in the meantime, the breeding grounds are identified and migratory patterns properly established, the feasibility of making inundative parasite releases—both in the locations where the buildup of the pest population is occurring and in the areas to which mass migrations are likely to occur—can be planned in advance and, conceivably, pest suppression achieved. These releases may also have to be planned according to the phenology of the crops. In such situations, prophylactic sprays of the NPV or inundative releases of *Trichogramma* may be given priority.

It is evident from the foregoing discussion that the biological control of *H. armigera* populations requires cooperation at the national as well as at the international levels. Within the country, a nationwide surveillance and forecasting system would help to alert entomologists in appropriate areas of prospective migrations, while international cooperation would greatly facilitate exchange of promising natural enemies.

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References

ACHAN, P.O., MATHUR, K.C., DHARMADHIKARI, P.R., and MANJUNATH, T.M. 1968. Parasites of *Heliothis* spp. in India. Technical Bulletin of the Commonwealth Institute of Biological Control 10:129-149.

ANONYMOUS. 1978. Possibilities of biological control of *Heliothis armigera* and *H. zea.* Commonwealth Institute of Biological Control status paper 13, Slough, U.K. 5 pp.

ANONYMOUS. 1981. Annual report of work under All India Coordinated Research Project on Biological Control of Crop Pests and Weeds carried out at Gujarat Agricultural University, Anand, 1980-81. 31 pp.

BEIRNE, B.P. 1975. Biological control attempts by introductions against pest insects in the field in Canada. Canadian Entomologist 107 (3)225-236.

BHATNAGAR, V.S., and DAVIES, J.C. 1977a. Parasitism levels on *Heliothis armigera* (Hubner) in some pigeonpea and chickpea fields of farmers (1976-77). Cropping Entomology Report 1977, ICRISAT, Patancheru, A.P., India.

BHATNAGAR, V.S., and DAVIES, J.C. 1977b. Cropping entomology, Annual Report, 1976-77, ICRISAT, Patancheru, A.P., India.

BHATNAGAR, V.S., and DAVIES, J.C. 1978. Cropping entomology, progress report, 1977-78. ICRISAT, Patancheru, A.P., India. 30 pp.

BOURNIER, J.P., and PEYRELONGUE, J.Y. 1973. Introduction, rearing and releases of *Trichogramma brasiliensis* Ashm. (Hym. Chalcidae) with a view to controlling *Heliothis armigera* (Hbn.) (Lep. Noctuidae) in Madagascar Coton et Fibres Tropicales 28(2):231-237.

CHAUTHANI, ABDUL, R., and HAMM, J.J. 1967. Biology of the exotic parasite *Drino munda* (Diptera: Tachinidae). Annals of the Entomological Society of America 60(4):373-376.

COAKER, T.H. 1958. Experiments with a virus disease of the cotton bollworm *Heliothis armigera* (Hbn.). Annals of Applied Biology 46(4):536-541.

EHLER, L.E., and MILLER, C.E. 1978. Biological control in temporary agroecosystems. Entomophaga 23:207-212.

GANGRADE, G.A. 1964. On the biology of *Campoletis perdistinctus* (Hymenoptera: Ichneumonidae) in Madhya Pradesh, India. Annals of the Entomological Society of America 57(5):570-574.

GORETZKAYA, I.N. 1940. The results of the use of the *Trichogramma* of the Azerbaidjan race as a control measure against the American cotton bollworm on cotton plants in Azerbaidjan. S.S.R. Bulletin of Plant Protection 1-2: 166-172.

HALL, R.W., EHLER, L.E., and BISABRI-ERSHADI, B. 1980. Rate of success in classical biological control of arthropods. Bulletin of the Entomological Society of America 26(2):111-114.

KAUSHIK, U.K., RATHORE, V.S., SOOD, N.K. 1969. Incidence of bollworms and losses caused to cotton in Madhya Pradesh. Indian Journal of Entomology 31(2): 175-177.

KRISHNAMOORTHY, A., and NAGARKATTI, SUDHA. 1982. A mass-rearing technique for *Chrysopa scelestes* Banks (Neuroptera. Chrysopidae). Journal of Entomological Research (In press.)

LOZINA-LOZINSKII, L.K. 1954. The role of nutrition in the development and reproduction of the cotton noctuid *(Chloridea obsoleta* Fabr.) Trudy vsesoyuznogo entomologicheskogo obshchestova, Moskva 44: 3-61.

MANJUNATH, T.M., PATEL, R.C., and YADAV, D.N. 1976. Observations in *Heliothis peltigera* (Schiff.) (Lep., Noctuidae) and its natural enemies in Anand (Gujarat State, India). Proceedings, Indian Academy of Sciences 83(B)(2): 55-65.

NARAYANAN, K. 1980. Field evaluation of a nuclear polyhedrosis virus of *Heliothis armigera* (Hubn.) on chickpea, *Cicer arietinum* L. *In* Proceedings, Workshop on Biological Control of *Heliothis* spp., Department of Primary Industries, 23-25 Sept 1980, Toowoomba, Queensland, Australia.

PATEL, R.C., PATEL, J.C., and PATEL, J.K. New records of parasites of *H. armigera* (Hbn.) and *H. peltigera* (Schiff.) from Gujarat. Indian Journal of Entomology 33(2): 223-224.

PATEL, R.C., PATEL, J.C., and PATEL, J.K. 1973. Mass rearing of *Chelonus heliopae* Gupta. Indian Journal of Entomology 35(2):119-126.

PATEL, R.C., and SINGH, R. 1972. Biology and breeding method of *Goniophthalmus halli* Mesnil (Diptera, Tachinidae), a larval parasite of *Heliothis armigera* (Hubn.) Indian Journal of Agricultural Sciences 42(B): 739-743.

PATEL, R.C., SINGH, R., and PATEL, P.B. 1968. Nuclear polyhedrosis of the gram pod borer, *Heliothis armigera.* Journal of Economic Entomology 61 (1): 191-193.

PATEL, R.C., SINGH, R., and PATEL, P.B. 1970. Bionomics of *Carcelia illota* (Curran), tachinid parasite of *Heliothis armigera* (Hbn.) larvae. Bulletin of Entomology 11(2): 161-168.

PAWAR, A.D., DIVAKAR, B.J., and SINGH, S.N. 1981. Field recovery of *Eucelatoria* sp. nr. *armigera* (Coq.) (Diptera: Tachinidae) from *Heliothis armigera* (Hubn.) (Lepidoptera: Noctuidae) in Karnataka, India. Entomon 6(2): 175-177.

RABINDRA, R.J., and SUBRAMANIAM, T.R. 1973. A cytoplasmic polyhedrosis of gram caterpillar, *H. armigera* (Hbn.). Madras Agricultural Journal 60(7):642-643.

RAWAT, R.R., JAKHMOLA, S.S., and SAHU, H.R. 1970. Assessment of losses of hybrid sorghum CSH 1 to earhead caterpillars, and comparison of insecticidal controls. PANS 16(2): 367-369.

REED, W., SESHU REDDY, K.V., LATEEF, S.S., AMIN, P.W., and DAVIES, J.C. 1980. Contribution of ICRISAT to studies on plant resistance to insect attack. Presented to the Scientific Working Group on the Use of Naturally Occurring Plant Products in Pest and Disease Control, 12-15 May 1980, Nairobi, Kenya. 14 pp.

RIDGWAY, R.L., KINZER, R.E., and MORRISON, R.K. 1974. Production and supplemental releases of parasites and predators for control of insect and spider mite pests of crops. Pages 110-116 *in* Proceedings, Summer Institute of Biological Control of Plant Insects and Diseases (eds. F.G. Maxwell and F.A. Harris). Jackson, Miss, USA: University Press.

RIDGWAY, R.L., MORRISON, R.K., and BADGLEY, M. 1970. Mass rearing a green lacewing. Journal of Economic Entomology 63: 834-836.

ROOME, R.E. 1971. A note on the use of biological insecticide against *H. armigera* (Hb.) in Botswana. *In* Proceedings, Cotton Insect Control Conference, 24-27 March 1971, Blantyre, Malawi. 287 pp.

RUBTZOV, I.A. 1941. Effect of temperature and humidity on the development of eggs and the larvae of the boll worm. Bulletin of Plant Protection, 1941. 1: 9-19.

SABROSKY, CURTIS, W. 1978. Tachinid parasites of *Heliothis* in the western hemisphere (Diptera. Lepidoptera). Proceedings of the Entomological Society of Washington 80(1): 37-42.

SANKARAN, T., and NAGARAJA, H. 1979. A note on *Eucelatoria* sp. nr. *armigera* (Coq.) (Dip., Tachinidae), imported from U.S.A. for trial against *Heliothis armigera.* (Hub.) (Lep., Noctuidae) in India. Entomon 4(4): 379-381.

SESHU REDDY, K.V., and CHANNA BASAVANNA, G.P. 1978. Studies on the estimation of loss in redgram due to *Heliothis armigera* (Hubner). University of Agricultural Sciences Technical Series 20, Hebbal, Bangalore, India.

SIMMONDS, F.J. 1958. The successful breeding *of Palpozenillia palpalis* (Ald.) (Diptera, Tachinidae) a parasite of *Diatraea* spp. Tropical Agriculture 35: 218-234.

SITHANANTHAM, S., and REED, W. 1980. Studies on the exotic parasite, *Eucelatoria* sp. (Tachinidae, Diptera) on *Heliothis armigera* (Hb.) at ICRISAT Center during 1979-80. Presented at the Third Workshop, All India Coordinated Research Project on Biological Control. Oct 1980, Punjab Agricultural University, Ludhiana, India.

SKOBLO, I.S. 1940. The ecology of *Habrobracon brevicornis,* a parasite of the larvae of the cotton Noctuid and the possibility of its practical utilization. Reports of the Scientific meetings of the Leningrad Institute of Agriculture. 5 Nos. Leningrad, 1940. (Russian).

SRINIVASAN, P.M. 1959. Control of fruit borer *H. armigera* (Hb.) on tomato. Indian Journal of Horticulture 16: 187-188.

SUKHORUCHENKO, G.I., NIYAZOO, O.D., and ALEKSEEV, Yu.A. 1977. The effect of modern pesticides on beneficial and injurious insect fauna of cotton. Entomologichekoe Obozrenie 56(1): 3-14.

TIKAR, D.T., and THAKARE, K.R. 1961. Bionomics, biology and immature stages of an ichneumonid, *Horogenes fenestrate* Holmgren, a parasite of gram caterpillar. Indian Journal of Entomology 23:116-124.

TWINE, P.H. 1973. Egg parasites of *Heliothis armigera* and *H. punctigera* in South eastern Queensland. Queensland Journal of Agricultural and Animal Sciences 30(4): 331 -336.

TWINE, PETER, H. 1980. Proceedings, Workshop on Biological Control of *Heliothis* spp. 23-25 Sept 1980, Toowoomba, Queensland, Australia. 125 pp.

Discussion—Session 3

It was suggested that there is a great deal spoken and written about the use of parasites for *Heliothis* control in many countries, including India, but there appears to be little evidence of practical utility in farmers' fields. Dr. King pointed out that *Trichogramma* is apparently widely used in the People's Republic of China for stem-borer control in maize and sugar. Although chemicals are the chief means used for the control of insects in cotton, there are reports that *Trichogramma* has also been successfully used for the control of *Heliothis* in this crop.

Following a recent visit to the USSR, Dr. Chhabra reported that he had seen a *Trichogramma* mass-production unit in Tashkent that produces enough parasites to cover the release demand of 100 ha/day. He had been told by the Head of the Biological Control Laboratory there that of 23 million ha of crops in the world that are treated with *Trichogramma* for *Heliothis* control, about 13 million are in the USSR. There is a plan to switch over totally from chemical control to biological control with this parasite. Recoveries of parasites from 80% of the eggs are claimed.

Dr. King confirmed that there are definite correlations between parasitism by *Trichogramma* and host density. This is apparently related to chemicals emanating from the host or host products. The minimum host density level for parasitic activity has not been generally determined, although levels for specific behavioral reactions probably exist. He also emphasized the need continually to monitor *Trichogramma* and other mass-produced parasites for vigor and essential behavioral characteristics. Experiments using hosts that lay large eggs, in attempts to produce larger and more fecund *T. pretiosum,* have been successful. But when these parasites were compared with others in cotton plots infested with *Heliothis,* there were no detectable differences in the parasitization.

Attempts to mass rear *Campoletis* have apparently been hindered by sex ratio problems. Dr. King pointed out that the utility of a parasite may depend upon using a factitious host for mass production and determining the means for maintaining a suitable sex ratio. In the long term, in vitro rearing techniques may be of possible use.

In discussions of the use of predators, the cost of mass production of *Chrysopa* in the USA was estimated to range from $1.50 to $2.50 per thousand, but some commercial dealers are selling these predators at considerably higher prices. Dr. Nagarkatti did not know of any attempts in India to spray artificial food on crops to augment *Chrysopa* spp activity but reported that she had successfully used the yeast, Saccharomyces *fragilis* in the laboratory for rearing *Chrysopa* spp. Dr. King commented that California workers have shown that a yeast mixture does help to increase chrysopid activity, but that it does not appear to be economically feasible.

In discussion of the compatibility of insecticide and parasite use, the judicious timing of pesticide use in relation to the release of parasites or predators, or the buildup of natural enemies, was stressed. The use of selective pesticides that are relatively ineffective against parasites and predators is obviously desirable. However, Dr. Nagarkatti said that in her laboratory tests the use of endosulfan at recommended concentrations was by no means as safe for the natural enemies as is generally believed. The possibility of selecting the parasites for pesticide resistance was considered worth pursuing, but Bartlett commented that if genes for resistance to pesticides were present in many parasites, then they would have been selected in the field conditions. Efforts to select in the laboratory had not met with much success.

In the discussion of the potential for insect pathogen use, Bell reported that although the *Autographa californica* NPV is not as effective as the *Heliothis* NPV against *H. zea,* it is pathogenic to a wide range of general leaf feeders and so may be commercially successful because of its wider market. Dr. Jayaraj had found *Heliothis* NPV to be promising when used on chickpea where *H. armigera* was the key pest; however, on *Lablab niger,* it did not kill a high proportion of the *H. armigera* larvae, and two other pests—*Maruca testulalis* and *Adisura atkinsoni*—which were not killed by this virus, were also damaging on this crop. Dr. Jayaraj also commented that the use of virus against H. *armigera* and *Spodoptera litura* was hampered by cannibalism, predation by birds and ants, and rain. However, McKinley considered that predation could help the natural spread of the virus and so could be useful.

Dr. Rothschild wished to record a plea for a more quantitative approach to biological control. The percentage parasitism or counts of predators are meaningless in the absence of knowledge of what contribution the individual species of natural enemies make towards the restriction of pest survival. A small change in an otherwise low parasitism at a critical stage may be more effective in regulating pest populations than a high parasitism at a less critical stage.

Session 4

Chemical Pesticides: Their Uses and Abuses

Chairman: T.S. Thontadarya
Cochairman: A.G.L. Wilson

Rapporteurs: C.S. Pawar
S.L. Taneja

A Critical Review of the Role of Chemical Pesticides in *Heliothis* Management

R.J.V. Joyce*

Abstract

The genus Heliothis, *which includes key pests of many major crops such as cotton, tobacco, and maize, has probably been more responsible for the greater use and abuse of insecticides than any other insect. More than any other genus, it has been responsible for the formulation of the integrated pest management concept, because of failures, in many parts of the world, of control by standard crop-spraying procedures.*

Heliothis *spp are essentially r-strategists, adapted to survive in unstable habitats, which they are able to discover through the great mobility of the adults and exploit through the polyphagous habit of the larvae. The strategy of crop chemotherapy is unsuitable for protecting crops against attack by such species, and attempts to employ it have generated the problems now faced.*

The development of an agroecosystem within an unstable ecosystem introduces more stability, and thus reduces the effectiveness of the major factor regulating the numbers of r-strategists. Catastrophic pest outbreaks in the crops can be prevented only by operating some new factor against the pest. In the case of Heliothis spp, *insecticides provide the only immediate factor, but they are environmentally acceptable and economic if they kill only the necessary numbers of those stages generating the damaging fraction of the total population of the species, with the minimum impact on other organisms. This requirement calls for physiological or ecological selectivity.*

The advantages and disadvantages of the various stages of the Heliothis *life cycle as targets for insecticides are discussed in relation to the insecticides available and their selectivity. Experience in protecting the cotton crop in Sudan from attack by* H. armigera *by killing adults, chosen as the best target stage, is described.*

Résumé

*Revue critique du rôle des pesticides chimiques dans la lutte contre l'*Heliothis: *Le genre* Heliothis *comprend des ravageurs de plusieurs cultures importantes, dont le coton, le tabac et le maïs. Comparativement à tout autre genre, il a probablement été la cause de la plus grande utilisation d'insecticides et d'abus. Plus que tout autre genre, il a été responsable de la conception de la lutte intégrée contre les ravageurs, suite aux échecs, dans plusieurs parties du monde, des mesures conventionnelles de lutte par pulvérisation des cultures.*

Les Heliothis *spp sont essentiellement des ''r-stratégistes''(r-strategists). Ils peuvent survivre dans des habitats instables qu'ils découvrent grâce à la grande mobilité des adultes et exploitent grâce aux habitudes polyphages de la larve. Une stratégie basée sur la chimiothérapie des cultures est inadaptée pour protéger les cultures contre les attaques de ces espèces et les tentatives faites pour l'utiliser ont causé les problèmes rencontrés actuellement.*

*Le développement d'un agro-écosystème dans un écosystème instable introduit une plus grande stabilité et réduit ainsi l'efficacité du principal facteur régularisant le nombre de ''r-stratégistes''. Il est possible d'éviter des pullulations catastrophiques dans les cultures en introduisant certains nouveaux facteurs contre le ravageur. Dans le cas d'*Heliothis *spp, les insecticides sont le seul facteur immédiat. Ils sont acceptables d'un point de vue environnemental et économique s'ils tuent seulement le nombre nécessaire de stades qui génèrent la fraction nuisible de la population totale des espèces, avec un impact minimal sur les autres organismes. Cette exigence nécessite une sélectivité physiologique et écologique.*

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International Crops Research Institute for the Semi-Arid Tropics. 1982. Proceedings of the International Workshop on *Heliothis* Management 15-20 November 1981, Patancheru, A.P., India.

*Les avantages et inconvénients des divers stades du cycle vital de l'***Heliothis***, comme cibles des insecticides, sont présentés en fonction de la disponibilité et de la sélectivité des insecticides. L'expérience acquise, au Soudan, dans la protection des cultures cotonnières contre les attaques d'***H. armigera*** par la destruction des adultes, stade choisi comme meilleure cible, est décrite.*

The genus *Heliothis* has a worldwide distribution in tropical and subtropical regions. *H. zea* occurs in the New World from Canada to Uruguay and *H. armigera,* which differs from *H. zea* only in the minute structure of the male genitalia, is found in southern Europe, the whole of Africa, the Near and Middle East, the Far East, Australia, New Zealand, and many of the Pacific Islands. These two species of a genus containing at least four more major pest species, have probably been responsible for the use and abuse of more insecticides than any other insects. This is because they are major pests of important crops, such as cotton, tobacco, and maize in many parts of the world, including the USA, which consumes some 45% of all pesticide production and nearly 50% of this on cotton (Furtick 1976). This overuse of insecticides on cotton in the Americas led, more than any other event, to the designation of the "disaster phase" of Luckman and Metcalf (1974) and the evolution of the integrated pest management (IPM) concept. However, despite the major efforts being devoted in the USA to control pests of major crops by cultural, biological, and genetic means and by plant breeding, the control of *Heliothis* spp in that country still relies heavily on crop spraying of synthetic insecticides.

I shall attempt to show in my paper that insecticides will continue in the foreseeable future to be essential for protecting crops against such pests as *Heliothis.* It is not insecticides per se that are responsible for the problems that have arisen, but the strategy, and tactics employed, which have failed to make use of available knowledge of the basic ecology and behavior of the species concerned. That is to say, for the most part, insecticides in this case have been directed at the wrong target, at the wrong time, and in the wrong way.

A critical review of the role of pesticides in *Heliothis* management cannot fail to conclude that this has been confined to a strategy of crop chemotherapy that aims at maintaining the crop as an environment lethal to the pest species. The performance specification given to the farmer or crop-protection agent is to spread a recommended quantity of pesticide over all crop surfaces—the "applicance" of Hartley and Graham-Bryce (1980). Applicance (kg/ha, for example) states nothing about the received dose, because losses to surfaces other than those of the crop are ignored; nor is account taken of the distribution of deposits in relation to the three-dimensional properties of the crop. In fact, the received dose is highly variable within the crop on any occasion, and at any level on different occasions. Consequently, the stated objective—an even cover—is never achieved.

Moreover, the objective itself is highly questionable and certainly inefficient in the use of pesticides. For example, the recommended applicance of DDT is 1 kg/ha. The economic injury level often is reached when there are 10 larvae per 100 plants, and over 90% of the plants are still uninfested. The crop will enjoy maximum protection if these larvae are killed before they do any damage, that is, on eclosion, when their total weight is about 10 g/ha. The theoretical amount of DDT required to kill this many larvae is about 10µg; we apply 10^9 µg/ha. It is difficult to conceive a strategy for chemical control less efficient in the use of pesticides, and a greater environmental burden.

We must also enquire whether such crop chemotherapy can be regarded as pest management, which I take to mean "the regulation of pest numbers." Certainly, we may kill a high, or very high proportion of the pest species present in the crops treated, and by residual toxicity kill some of the later invaders. Whether this procedure regulates the pest population depends on what fraction of the total area occupied by the population is treated at one time. As Knipling (1972) states, "100 percent control on 99 percent of the host acreage falls far short of the suppression that is achieved when 90 percent control is obtained on 100 percent of the host acreage." There is no evidence that the crop chemotherapy now practiced has ever regulated populations of *Heliothis* spp anywhere except on a time scale measured in days in small fractions of the area occupied.

We cannot speak of pest management by chemicals or any other means until we define the population that has to be managed, and measure its distribution in space. This distribution is subject to constant change. Taylor and Taylor (1977) consider it necessary to treat the anatomy of a real population as being three-dimensional—latitude x longitude through time, but having an internal reticulate structure analogous to that of a fern stele (Fig. 1).

Pest management, as emphasized by Rabb (1970), is rooted in ecology, and deals with ecosystems, population dynamics, and dispersal, though —as Taylor et al. (1980) point out in respect of migrant pests in the United Kingdom— "Conventional population dynamics has so far been of little value...because it is mainly concerned with temporal, not spatial change." It may also be added that most work on insect migration does not help much, since it deals primarily with exodus, while we are more concerned with entry into a habitat.

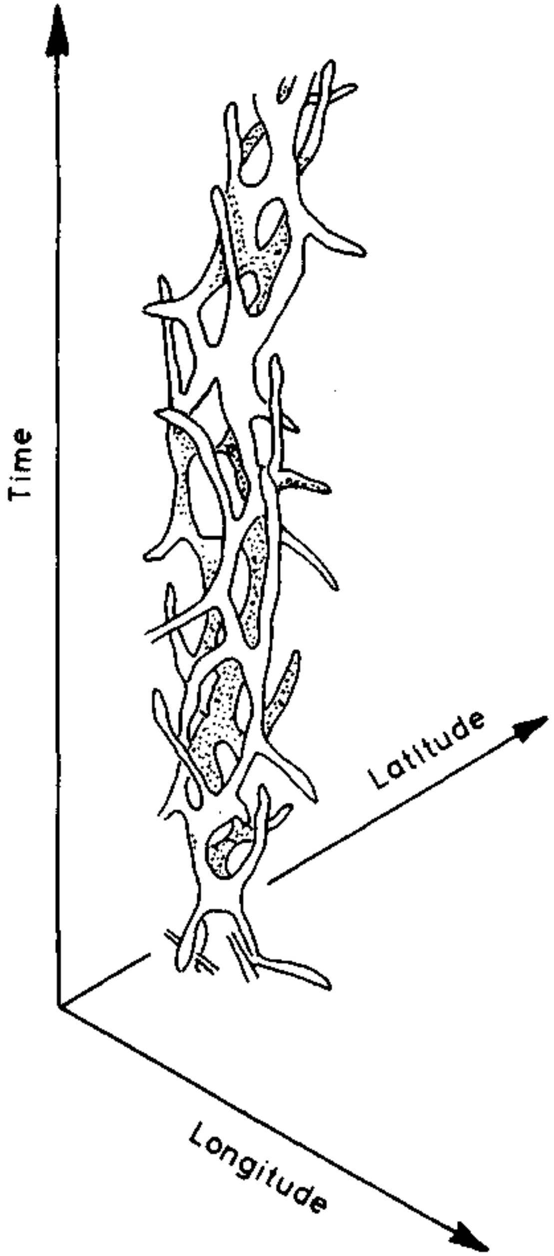


Figure 1. Conceptual model for pest population anatomy. Based on Rostowzew's drawing of the stelar structure of the adder's tongue fern. (Source: Taylor and Taylor 1977).

The theme of this paper is that while chemical pesticides are regularly employed in protecting crops against damage from *Heliothis* spp, they have, almost without exception, been used inefficiently to execute a strategy inappropriate for the ecology and behavior of the species. Accordingly, the intial easy successes of the strategy have frequently been followed by breakdown in control, through the emergence of strains highly resistant to a great range of chemicals (Wolfenbarger et al. 1971; Adkisson 1972) and resurgence of infestation following destruction of natural enemies (Knipling 1979).

The problems engendered by this crop chemotherapy might be largely surmounted if an insecticide were evolved that selectively kills *Heliothis* without damage to natural enemies. Chlordimeform most closely approaches this ideal. The nuclear polyhedrosis virus, *Baculovirus heliothis* (Smith et al.1978; Luttrell et al. 1979), is also promising, but is unlikely to be able to control severe outbreaks (Bull et al. 1979). Such insecticides, however, would still not provide pest management unless they were used in a strategy suited to the pest's ecology and behavior. This understanding is the first requirement. Moreover, with such understanding, existing chemicals may find a place in management of the pest if applied by methods that are ecologically selective. I will describe recently elucidated aspects of the ecology of *H. armigera* in the Sudan Gezira and how pesticides were used, with considerable ecological selectivity, to regulate the numbers of the pest so that economic injury levels were not reached in the crops at risk.

The Ecological Basis of *Heliothis* Management

The Objective of Pest Management

The objective of pest management is to prevent a species occurring in crops in numbers, and at a time when they can cause unacceptable crop loss. When chemical insecticides are used, they must be applied in such a way as to achieve (1) the greatest economy and (2) the minimum effect on nontarget organisms. We are not necessarily concerned with regulating entire populations, but in identifying that fraction of the total population that we must control to prevent damaging infestations from occurring.

This objective requires understanding of the origins of the fraction of the population that places the crop at risk, and the number and distribution of the stage or stages that, if killed, will prevent the occurrence of this fraction. Adults of *Dysdercus fasciatus,* for example, colonize a cotton field and, as a result of feeding on a suitable host, lose their wing muscles by autolysis. Damaging infestation develops from the multiplication of these initial immigrants thus trapped in the crop. Their destruction provides crop protection. Similarly, damaging levels of infestation of jassids and whitefly are also normally generated by small numbers of immigrants breeding in the crop. If their rate of increase can be predicted, they may be destroyed by suitable crop chemotherapy before they reach these levels (Joyce 1959, 1961), but only if treatments are on a scale commensurate with the insects' mobility. The damaging fraction of the population is that which occurs in the crops at risk. This type of life strategy has generated the concept of economic threshold, defined as the level of infestation at which control must be applied to prevent the occurrence of the economic injury level (Stein et al. 1959). In contrast, locusts, for example, cause damage by invasion in numbers far in excess of the economic injury level, and protecting crops against these insects demands measures very different from crop chemotherapy. The damaging fraction may be generated anywhere in the distribution area of the species, so that the entire world population of the species is potentially damaging and must be controlled.

We must enquire where *Heliothis* fits into the spectrum of life strategies.

Heliothis Spp as *r*--Strategists

"Habitat is the template against which evolutionary pressures fashion the ecological strategy of a species. The instability:stability spectrum gives rise to the *r-K* selection continuum of MacArthur (1960)," says Southwood (1974). Cotton is a crop grown in environments that produce habitats having a low degree of predictability and permanence, so it is not surprising that indigenous insects possess a high degree of migratory activity that enables them to seek out such short-lived opportunities as well as to escape from doomed ones, and a high intrinsic rate of increase, which permits the exploitation of these habitats.

Mobility of *Heliothis* Moths

Heliothis spp are highly mobile and highly fecund, and their larvae are polyphagous (cf. Hardwick 1965; Callahan et al. 1972; Sparks et al. 1975). They are well adapted to exploit unstable habitats and versatile in their life strategies. The fecundity and longevity of *H. armigera* have been shown by Hackett (1981) and Topper (1981) to be a function of the quality of their foods, which must include amino acids. During three seasons, Topper (1981) never recorded in any crop moth densities exceeding 100/ha, and in all crops, numbers changed from day to day and hour to hour. He calculated that the mean number of eggs laid each night was about 520/ha per female. Thus 30 moths/ha could generate damaging levels of larvae if half were ovipositing females. When food was abundant, flight activity was suppressed, with moths engaging only in short flights during the first 3 days after emergence, after which they reached sexual maturity. Moths engaged in prolonged flight (up to 720 minutes in the laboratory) only if they derived from larvae from poor host plants and had poor quality food during this first 3 days of life (Hackett 1981). Under some conditions, therefore, infestations of *H. armigera* may be largely derived from distant sources; under others, nearby sources alone are important. Nevertheless, all moths engage in short-distance flight, up to 80% of the night hours being spent airborne in search of food and oviposition sites (Topper 1981). In the Sudan Gezira, there was a nightly movement from groundnut, where most of the moths had developed, to a flowering legume, *Lens cajan,* for nectar, thence to cotton for oviposition, and back to groundnut for resting in the daytime.

During these flights moths are invariably oriented downwind, and thus can move in a single night several kilometers from their resting site of the previous day. Infestation levels tend to be displaced downwind. Moreover, in the Sudan, steady evening winds are often replaced at this time of the year by disturbances such as convectional storms and the passage of the intertropical discontinuity (ITD). The ITD was found capable of concentrating airborne insects by nearly 30%/hour (Rainey 1974, 1976). The cold outflows from storms, which often occur at times of maximum insect flight, were shown by Schaefer (1976) to produce a 60-fold increase in airborne insect density at a sharply defined front some 30 km ahead of the rain (Figs.2, 3). The effect of this on the displacement and subsequent oviposition of *H. armigera* has been described at this workshop (Haggis, these Proceedings).

Origins of Damaging Infestation Levels

Damaging larval infestations on cotton in the Sudan Gezira thus derive from highly mobile sources, so that, in any one field, new and variable infestations occur each day. Due to the ebb and flow of populations, large areas may have common infestation levels but the boundaries of these areas show rapid and abrupt change (Figs. 4, 5). In the Sudan Gezira the breeding of *H. armigera* on cotton was found to make only a small contribution to infestation levels, most of the moths immigrating into a field having come from other sources, such as groundnut or sorghum. In contrast, Lawson (1980) found that rainfed cotton in Thailand, once colonized by moths bred in maize, generated its own damaging populations, though flight activity probably resulted in redistribution of population over at least several kilometers, particularly from older cotton.

Studies such as these show clearly that damaging larval populations cannot be assumed to derive from the same fields as those in which the parent moths had bred, even if, as in Thailand, fields were several hundred hectares in area. In Sudan, the smooth change in the daily mean levels of oviposition over the whole Gezira (Haggis, these Proceedings) suggests the flux of a single population over several thousands of square kilometers. In this sense, *Heliothis* may be considered a migratory insect.

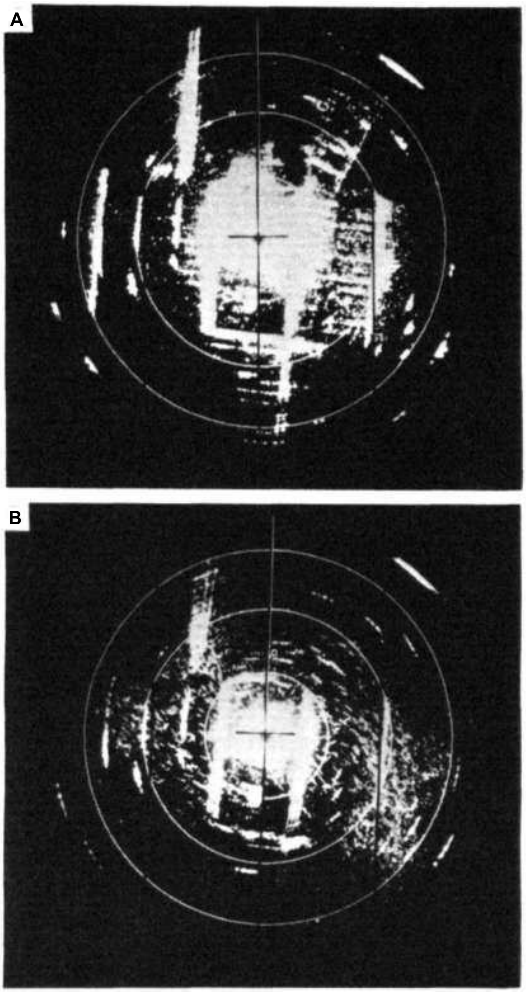


Figure 2. Beginning of evening takeoff of insects in the Sudan Gezira: mainly Noctuid moths **(Heliothis armigera, Spodoptera littoralis,** *etc.). Kumor,11 Oct 1973; range-rings 450m apart. A, 1806; single exposure at $1^{1}/_{2}{}^{0}$ elevation. B, 1808; triple exposure at 3° elevation. (Source: Schaefer 1976, with acknowledgments to Blackwell Scientific Publications, Oxford, UK, and the Royal Entomological Society of London.)*

Choice of Stage to be Attacked

The control of migratory pests may be sought either by killing them in their source areas or en route to, or on arrival in, the crops at hazard. Clearly, if crop protection is to be maximized, they must be killed before they do the damage. The food intake of *Heliothis* larvae increases exponentially with age, but the number of buds of cotton plants damaged per day varies little, since young larvae attack small, and older larvae large, buds (Russell-Smith,

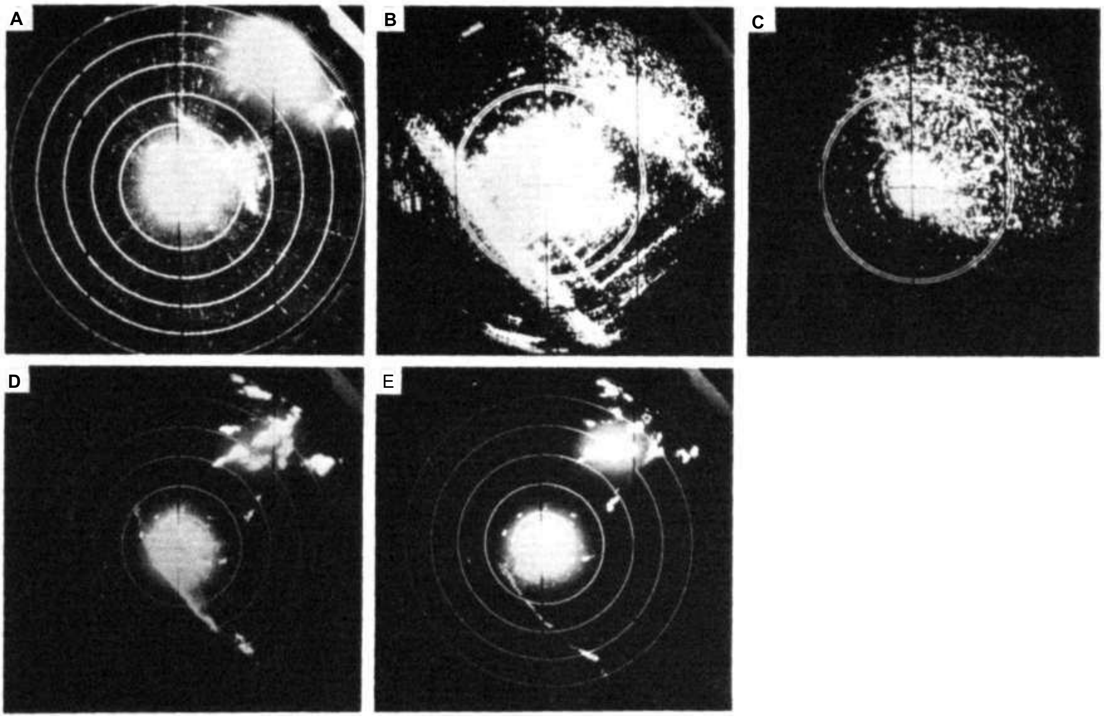


Figure 3. Insects at a storm-outflow cold front Probably mainly **Aiolopus**. *Radma, Sudan ,19 Oct 1971; single exposures. A. 2013; range-rings 7.5 km (8000 yd) apart and elevation 3°; rain-storm centered 35 km away to northeast and cold outflow at 8 km, also approaching from northeast, undercutting warm southwest wind. B. 2026; range-rings 450 m apart and elevation 1* $^{1}/_{2}^{0}$*; note dense leading edge of cold outflow approaching from northeast and now 850 m away; canal bank also shown, running southeast-northwest to southwest of radar site, and outlines of fields. C. 2028; range-rings 450 m apart; looking up at 30° elevation at very sharply defined leading edge as it reaches the radar; frontal slope of about 1 in 2 demonstrated by shape of sector of high-density echoes. D. 2041; range-rings 7.5 km apart and elevation* $^{1}/_{2}^{0}$*; cold outflow now 8 km away, receding to southwest, and with a visible length of at least 60 km. E. 2050; range-rings 7.5 km apart and elevation* $1^{1}/_{2}^{0}$*; cold outflow 13 km away, still receding to southwest, and visible to at least 45 km: storm collapsing period. (Source: Schaefer 1976, with acknowledgements to Blackwell Scientific Publications, Oxford, UK, and the Royal Entomological Society of London.)*

unpublished). Therefore, the latest stage that can be attacked to maximize crop protection is the first-instar larvae on eclosion, though it is necessary to examine whether more economical pest management may be achieved by attacking earlier stages in the development of the damaging population.

In contrast to this strategy, it is customary to establish a threshold level of larval infestation and then to treat the crop so that all surfaces are given a deposit lethal to the species, and so prevent establishment of the pest within the crop. This procedure has many disadvantages besides those already emphasized, the most important being:

1. The crop is made more or less lethal to species associated with it, especially parasites and predators of *Heliothis* eggs, larvae, and pupae.
2. *Heliothis* larvae, being polyphagous, are richly endowed with multifunctional oxidase enzymes, which provide the chemistry for the development of resistance to insecticide (Wilkinson 1968; Dahms and Nakatsugawa 1968; Cassida 1970; Brooks 1972).
3. Sublethal deposits are always available due to uneven distribution, degradation, and expansion of plant surfaces.
4. The crop grows, and new eggs are laid on uncontaminated foliage.

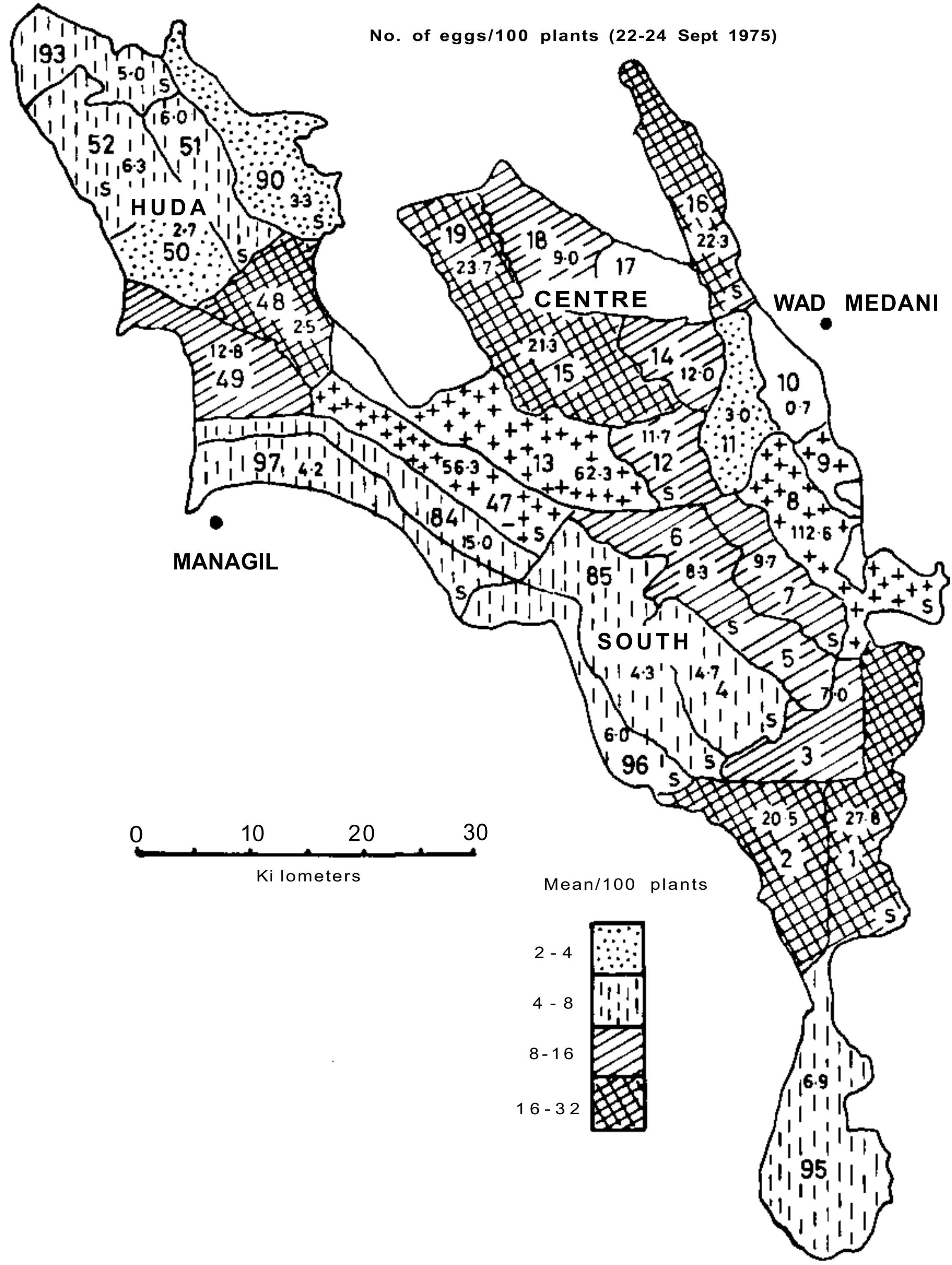


Figure 4. Distribution of Heliothis armigera eggs on cotton in the Sudan Gezira, 22-24 Sept 1975.

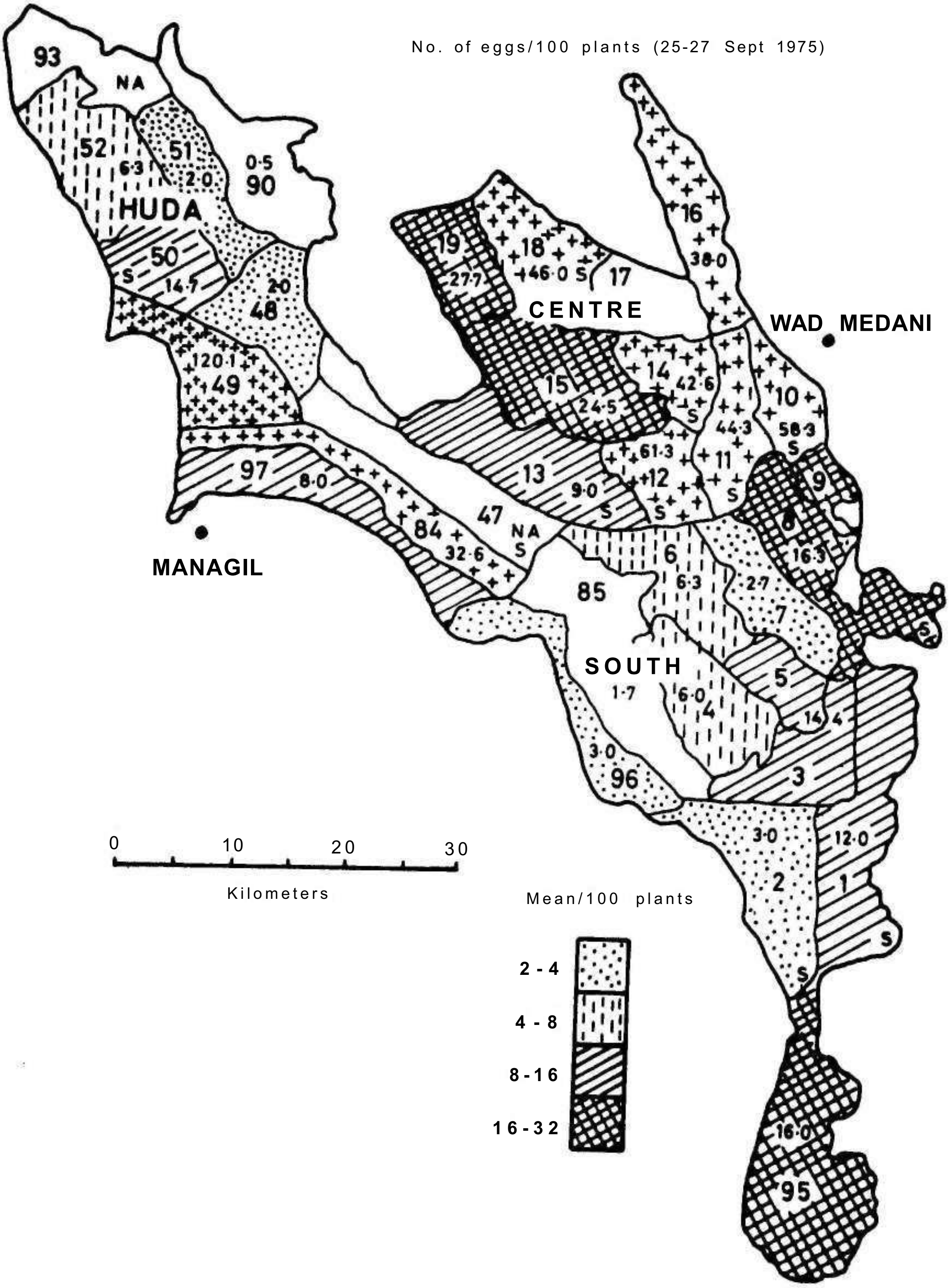


Figure 5. Distribution of Heliothis armigera *eggs on cotton in the Sudan Gezira, 25-27 Sept 1975.*

5. Unacceptable larval infestations can rarely be discovered and destroyed before they have perpetrated more than half of their potential damage.

Because of these inadequacies, I do not propose to discuss larvicides further. They have only a limited role to play in *Heliothis* management, although the vast majority of the hundreds of journal papers consulted deal with this strategy, which indeed, appears to represent the standard method of evaluating the performance of new insecticides against the species. The attractive stages for attack are the adult and the egg, and these will now be discussed.

Table 1. Dossage-mortality relations against L_3 larvae of *H. virescens* and *H.ZES*.

Active ingredient	μg/g
Methyl parathion	9.59
Methomyl	17.04
Monocrotophos	21.87
Toxaphene-methyl parathion (2:1)	34.40
Toxaphene-methyl parathion (3:1)	69.65
Toxaphene-DDT	217.60

Source: Lentz et al. 1974.

Targets for Insecticides

Heliothis Adults as Targets

Adult Noctuids are particularly attractive tor insecticidal control. Dittrich et al. (1980) found that larval resistance against monocrotophos in an R (resistant) strain of Spodoptera *littoralis* is characterized by 250x difference of LD50, compared with the sensitive (S) strain. Similarly, Wolfenbarger and McGarr (1970) found that the LD50 of methyl parathion to larvae of *H. virescens* reared from material collected from the field late in the season was 20 times higher than that to larvae collected early in the season. Wilson (1974) showed that the Ord Valley strain of *H. armigera,* which had been exposed to repeated sprays containing DDT, had 35-fold tolerance to DDT-toxaphene, 5-fold tolerance to methyl parathion, and 4-fold tolerance to endosulfan. According to Dittrich et al. (1979), this ability to develop resistance to metabolic toxicants is based on the presence in the larvae of at least two mechanisms: an efficient system of MFO enzymes and an insensitive cholinesterase (AChE). In moths, the resistance to the insecticides was much lower than in the larvae, and it appeared that the moth lacked the powerful MFO system, leaving only the insensitive AChE as the R mechanism, so that tolerance was able to develop only about 2- to 4-fold.

Though data are scarce and inadequate, the moths appear to be 10 to 100 times more sensitive to insecticides than S and R larvae, respectively. Table 1 gives the LD50 levels of insecticides widely used in *Heliothis* control in the USA and treated against laboratory-reared larvae (Lentz et al. 1974). When we consider the changes in these levels to be expected from the R factor, the advantages of adults as targets for insecticides are emphasized.

Adults may be killed by direct contact, indirect contact and vapor action, and by stomach entry. Stadelbacher et al. (1972) caged *H. virescens* and *H. zea* on cotton plants 24, 48, and 53 hours after their terminals had been sprayed with either monocrotophos, carbaryl + molasses, carbaryl-toxaphene + methyl parathion, or toxaphene-DDT. Mortality among moths was significantly greater on all sprayed than on unsprayed plants, except those treated with toxaphene-DDT, when moths were introduced 24 and 48 hours after treatment. Fifty-three hours after treatment, significant mortality was found only on plants sprayed with carbaryl + molasses and monocrotophos.

In the Sudan Gezira, where the applicance is 300 g monocrotophos/ ha, the median deposit of active ingredient on the cotton terminals immediately after spraying is about 300 (+ 120) ng/cm^2, and the deposit has a half-life of about 24 hours. This small applicance is adequate to make a substantial contribution to the mortality of moths visiting the crop 12 hours after spraying, because the moths, actively settling on one plant after another during feeding, mating, and oviposition, presumably accumulate a toxic dose. Accordingly, mortality is greatest among ovipositing females (Topper 1981). In the laboratory, Lawson (1980) found that deposits of monocrotophos as low as 50 ng/cm^2 killed 50% of laboratory-bred *H. virescens* in 15 hours. He also found that direct application of profenofos at 3 μg/g against the same species gave 50% mortality in 48 hours.

Uk and Outram (1979) investigated the contamination of the subbracteal nectar of G. hirsutum, variety Acala, in the Sudan Gezira followng the application of monocrotophos at 300 g ai/ha. They found that this approximated to 2 ppm, and that the contamination had a half-life of about 3.5 days. Laboratory studies by Bourgeois (unpublished) provided an LD50 of monocrotophos to *H. virescens* through stomach action at about 100 ppm. If feeding makes a contribution to mortality of *H. armigera* moths in the field, either they are more susceptible than the laboratory strain of *H. virescens* tested, or they can accumulate a toxic dose through voracious feeding. According to Outram (unpublished), adult *H. armigera* have been observed to take in as much as 0.5 ml of sugar solution in 24 hours. This is the right order of magnitude of food intake to enable some moths to accumulate a toxic dose from contaminated nectar in a single night.

Eggs and L1 Larvae as Targets

When eggs are targets for destruction, it is of little economic significance whether the insecticide is a true ovicide or destroys the L1 larvae immediately after eclosion, when the young larvae characteristically eat at least part of their egg shell and some of the leaf tissue in the immediate vicinity. Pitts and Pieters (1980) assessed various ovicides in terms of the percentage of eggs that hatched on sprayed cotton (Table 2). In subsequent field trials, methomyl was consistently the best ovicide at all rates. On the basis of Sudan data, the applicance used in these experiments could be expected to provide deposit densities of less than 500 ng/cm^2, but no measurements were reported.

No precise data have been found on the susceptibility to insecticides of L1 larvae on eclosion, but evidently they are easily killed. Sudan data indicate that 99% mortality can be expected from larvae emerging from eggs laid on leaves contaminated with monocrotophos to a level of about 2 ppm; probably they are also equally susceptible to many other larvicides. This would equate to about 1$\mu g/cm^2$ or about one-tenth of the quantity needed to kill an L3 larva by direct contact.

Clearly, eggs and L1 larvae represent targets far more attractive than later larval stages, but other aspects that emerge only from large-scale operations must be considered.

Table 2. Ovicidal activity of Insecticides against eggs of *H. virescens* on cotton, 1979.

Insecticide	Applicance (kg/ha)	Eggs hatching <%)
Methomyl	0.138	4
	0.034	26
	0.069	31
Thiodicarb	0.138	45
	0.069	54
	0.034	62
Chlordimeform	0.138	61
Permethrin	0.055	63
	0.014	79
	0.028	84
Methyl parathion	0.138	64
Fenvalerate	0.055	69
	0.014	88
	0.028	80
Profenofos	0.138	70
Control		96

Source: Pitts and Pieters (1980).

Adulticides and Ovicides in Field Use

Since adults are highly mobile and carry their eggs with them, adulticides will be most economically employed if they can be directed against moths on a scale commensurate with their nightly movements. Similarly, eggs, which have an incubation time rarely more than 4 and often less than 2 days, are a practical target only if they are laid synchronously over the areas to be treated, or if the ovicide has a persistence commensurate with the duration of the period of oviposition. The question of scale must then be resolved. Secondly, insecticides and methods of application have to be selected to minimize the effects on nontarget organisms

In the context of the latter, the physiological selectivity of chlordimeform is of special interest. The chemical is rapidly absorbed into the plant tissue (Ware et al. 1975), from which it is evidently released through the stomata as a vapor. It must be assumed that this vapor accumulates in the leaf boundary layer, the thickness of which is measured in urn, to concentrations that are lethal to species utilizing this layer. These include young Noctuid larvae. Most species of parasites and predators are little affected by chlordimeform. Sublethal concentrations also have potentially important effects. Lund et al.(1979) found that, while larvae of the tobacco hornworm, *Manduca sexta,* were rather insensitive to insecticidal action (LD_{50} to L_2 700 µg/g), at doses as low as0.24 ng/g, larvae showed signs of intoxication, such as tremors and lack of coordination. This reduced feeding (Campbell et al. 1979), larvae often spinning down and dropping from the plant. Adults, which could be killed with 3.3 µg/g by injection, were equally excited by sublethal doses, with reduced mating (Campbell et al. 1979) and fecundity (Lingren et al. 1976). These effects on behavior have important implications for chemical control. Larvae dropping from host plants are exposed to new hazards from both physical and biological environment, the latter being particularly important, because the cause of excitation has little effect on predators and parasites.

Target-Specific Methods of Pesticide Application in Commercial Practice

My argument is that chemicals cannot provide the management of highly mobile pests such as *Heliothis* spp if their use is confined to treating individual crops at hazard. On the contrary, chemicals are needed to reduce the numbers of those stages, the destruction of which will prevent the occurrence of unacceptable infestations in the crop. Whether these stages are attacked at the source, en route to, or on arrival in, the crops, a requirement of this strategy is that the scale on which the insecticide is applied has to be determined by the biology and habits of the pest species and the agronomy of the area, rather than by field or farm boundaries. A second requirement is that the insecticide must be transmitted selectively to the total population of the target stages with minimum loss to nontarget surfaces.

I will illustrate this approach by describing our experience in the management of *H. armigera* on cotton in the Sudan Gezira—an area particularly appropriate for this type of work because its million hectares of irrigated crops are under a single management that carries the responsibility, among others, of protecting the cotton crop against pests.

Sources of *H. armigera* Infestation on Cotton

The southern part of the Gezira, where annual rains exceed 450 mm, nearly 80% of which falls in July and August, is an island of irrigated crops within a vast sea of host plants of *H. armigera* (chiefly wild and cultivated sorghum spp), an area of thousands of square kilometers. Management of the pest in its source areas is unlikely to be practical or economic. Work by Hackett (1981) and Topper (1981), however, showed that irrigated cotton and sorghum generated an insignificant fraction of the larval infestations that damaged cotton, but in the years under study, the irrigated groundnut crop was the major source, so that moth invasion of cotton could be predicted by the numbers of fully grown larvae in that crop during the previous 10 days. The opportunity therefore exists for management of *H. armigera* through destruction of the potentially damaging fraction of the total population at its source, at least in some years, but no trials of this strategy have yet been possible. Moreover, lentils, which are grown around the edges of cotton fields, appear to be a preferred source of nectar, and their contamination might be usefully explored as a means of control.

Airborne insects are particularly attractive targets for insecticides (Rainey 1974) because many of the species investigated have been found to compose the major part of the biomass in the airspace selected by their life strategy to lead to survival—examples are locusts, grasshoppers, certain species of aphids, spruce budworms, etc. Radar, light-trap, and direct observations of the flight behavior of *H. armigera* in the Sudan have shown, however, that only a small fraction (probably less than 5%) of *H. armigera* adults fly above a height of 10 m, and, under the conditions of the Sudan Gezira, the remaining 90% are engaged in feeding, mating, and oviposition. This lower layer of air is occupied at the same time by so large a number of insect species, many of them predators, that *H. armigera* moths represent only a minute fraction of the total airborne biomass. It would be difficult to devise a system of insecticide application that would kill only these moths; accordingly, destructon of *H. armigera* moths en route is not likely to be a sound management strategy.

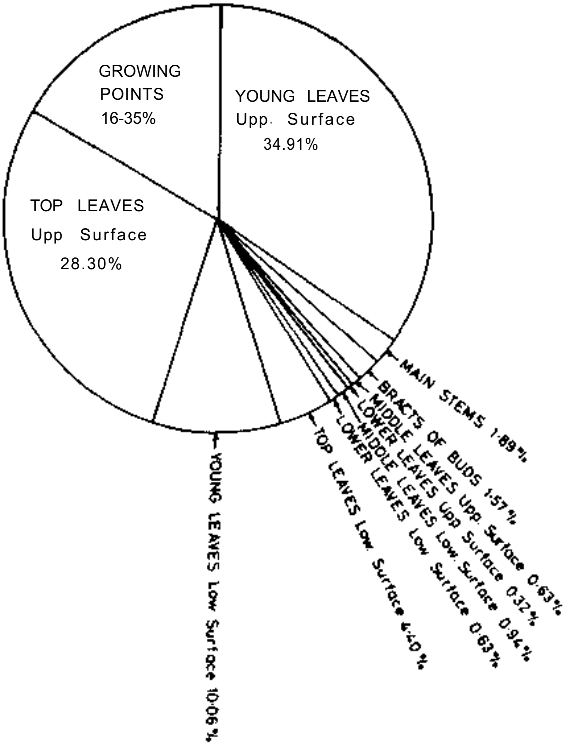
Management Strategy Adopted for *H. armigera*

The choice made was destruction on arrival of the population immigrating into the crop. The presence of eggs was selected as an indication of the recent presence of adults, though Lawson et al. (1979) showed that surveys for adults were equally practical. Both methods called for daily sampling of the whole area at risk, and therefore, for economic and statistically reliable methods for areas of hundreds of square kilometers containing over 100 thousand hectares of cotton. After analyzing the variability of egg numbers on single plant organs, on plants within rows, rows within 0.15-ha plots, plots within 4-ha holdings, holdings within 40-ha fields, and fields within administrative blocks up to 2000 ha, Russell-Smith (1975) calculated a sampling plant that provided an acceptable 20% standard error. Some of the results of these surveys are given in Figures 5 and 6, where it can be seen that areas of several hundred square kilometers had the same level of egg infestation, which had to be sprayed in the 2-day incubation period.

The spray procedure was designed so that the cotton terminals where most eggs are laid (Fig. 6) were contaminated with at least 40 ppm of monocrotophos which, under Sudan conditions, would provide a toxic dose to emerging L1 larvae over a period of 4 to 5 days (Joyce 1978). The greatest contribution to the deposit on the growing points, on which over 70% of the eggs were laid (Russell-Smith 1975), was made by droplets 40 to 60 Mm in diameter, which were collected efficiently by *H. armigera* adults. Accordingly, spraying monocrotophos at 300 to 350 g ai/ha was found to kill over 98% of the moths present in the crop at the time, and an equal number immigrating into the crop during the evening of that day. This moth destruction brought oviposition on cotton to an abrupt halt. Moreover, this depletion of the overall *H. armigera* population was followed 10 to 14 days later by reduced larval infestation on sorghum and groundnut, which were not sprayed (Topper 1981).

The causes of moth mortality were investigated by Lawson (1980b) and Uk and Outram (1979). The latter found that the secretions from the extrafloral nectaries on cotton contained enough insecticide to provide a lethal dose to moths feeding for a single night. Lawson showed that both direct and indirect contact action made their contributions. He observed that the moths were disturbed by aircraft noise, as well as by the spray, and thus became more exposed to the spray cloud. Similar mass disturbances by aerial spraying were noted by Wardhaugh during his radar obsevations in Australia (personal communication). Because of the susceptibility of adults to insecticides, Lawson (unpublished) found it possible, in operations in Kenya, to reduce the applicance to 230 g ai/ha.

Hull (1980) conducted a large-scale trial in Sudan over about 1500 ha of cotton in which the spray program was determined by scouting for adult moths, against which the spray was subsequently directed. Mortality among moths is shown in Table 3. Subsequent larval numbers, and conseqent damage in the area treated in this way, compared favorably with what was achieved by directing spray at the cotton terminals (Table 4), but adults as targets required nearly 25% less chemical.



Period 269 - 14-10-72 Total No of Eggs 318

Figure 6. Distribution of eggs of American bollworm on cotton plants, Sudan Gezira.

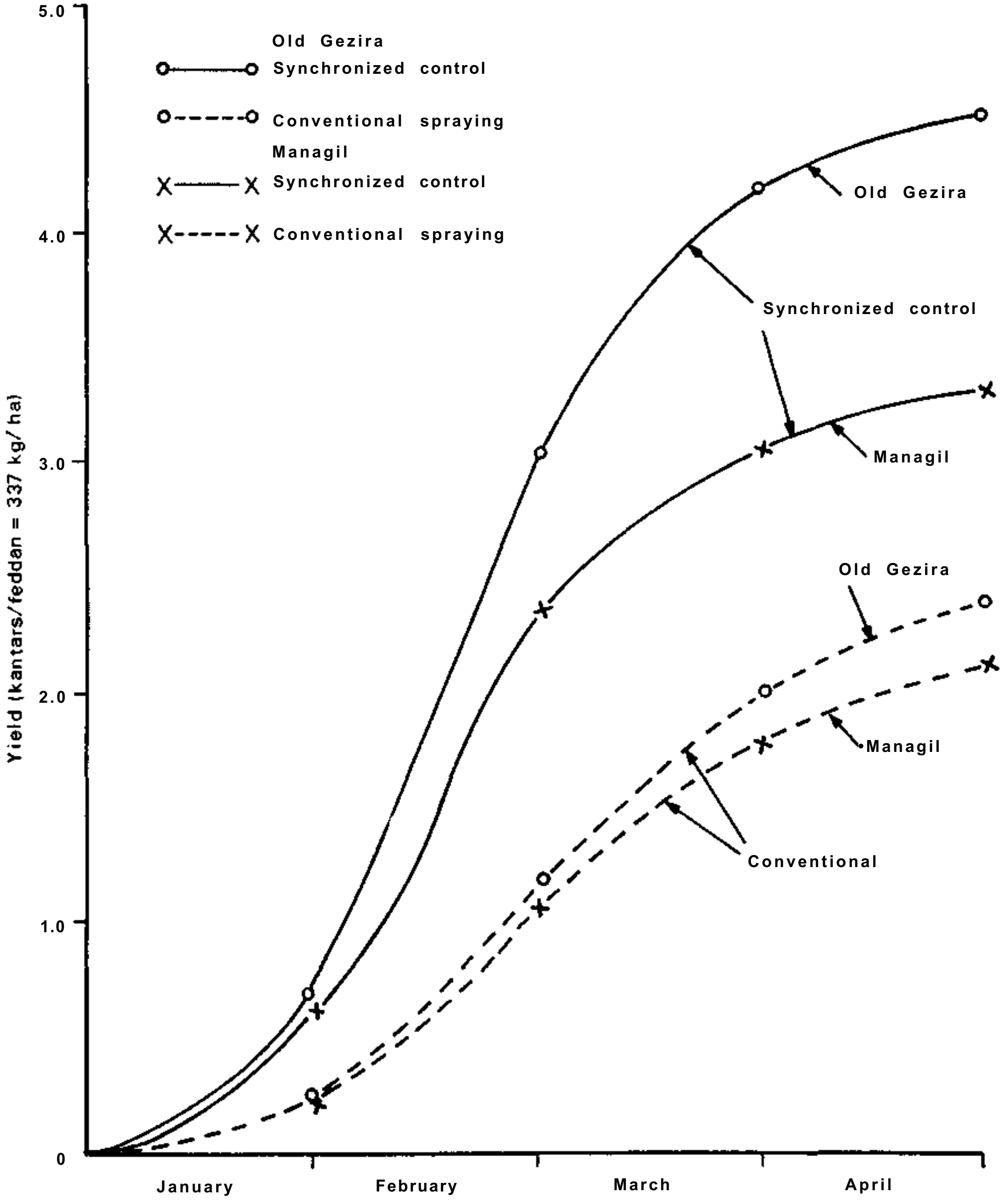


Figure 7. Accumulated monthly yields of seed cotton (G. barbadense), *1975-76 season, from areas in which pest control was based on synoptic survey and synchronized control versus conventional practice.*

Table 3. Percent mortality of ovipositing *H.* armigera in cotton in the Sudan Gezira after spraying with 230 g al/ha of profenofos.

	Mortality of ovipositing moths (%)	
Spray date	First night after spraying	Second night after spraying
2 Oct 79	73	100
7 Oct 79	82	100
12 Oct 79	(not available)	90

Source: Hull (1980)

Table 4. Mean number of eggs and larves of *H. armigera* per day par 100 plants recorded on cotton in the Sudan Gezira when sprayed (A) against ovipositing moths and (B) to contaminate plant terminals for destruction of L1 larvae (22 Sept-22 Oct 1979).

Heliothis stage	A[a] (Mean over 1500 ha)	B (Mean over 10 000 ha)
Eggs	2.5	6.2
Small larvae	0.5	1.3
Large larvae	0.2	0.8

Source: Hull (1980)

a. Procedure (A) used 25% less insecticide than procedure (B).

Results

The value of this approach to the management of *H. armigera* with insecticides is shown by the yields of seed cotton when compared with those from conventionally sprayed areas (Figure 7). Moreover, much of the increased yield came from earlier picks, which provide the best grade of cotton.

Since 1977, the situation in the Sudan Gezira has been complicated by the introduction of a new species of cotton, *Gossypium hirsutum* variety Acala, replacing *G. barbadense* variety Barakat, and catastrophic increase in whitefly *(Bemisia tabaci)* damage. The potential importance of parasites and predators in controlling this pest and its intractability to control by insecticides emphasize the need to reduce the amount of spray directed at the cotton crop and to explore further the possibility of managing *Heliothis armigera* numbers by attacking them away from the cotton crop.

References

ADKISSON, P.L. 1972. The integrated control of insect pests of cotton. Pages 175-188 in Proceedings, Tall Timbers Conference on Ecological Animal Control by Habitat Management, 4. Tallahassee, Fla, USA.

BROOKS, G.T. 1972. Pathways of enzymatic degradation of pesticides. Pages 106-164 *in* Environmental quality and safety (eds F. Coulston and K. Korte). New York, USA: Academic Press.

BULL, D.L., HOUSE, V.S., ABLES, J.R., and MORRISON, R.K. 1979. Selective methods for managing insect pests of cotton. Journal of Economic Entomology 72(6): 841 -846.

CALLAHAN, PS., SPARKS, A.N., SNOW, J.P., and COPELAND, W.W. 1972. Corn earworm. Vertical distribution in nocturnal flight. Environmental Entomology 1: 497-503.

CAMPBELL, W.R., COUNSELMAN, C.J., and RAY, H.W. 1979. Evaluation of chlordimeform (Galecron®) for *Heliothis virescens* control on cotton. *In* Proceedings, Beltwide Cotton Producers' Conference, Phoenix, Ariz, USA.

CASSIDA, J.E. 1970. Mixed function oxidase involvement in the biochemistry of insecticide synergists. Journal of Agricultural and Food Chemistry 18: 753.

DAHMS, P.A., and NAKATSUGAWA, T. 1968. Bioactivation of insecticides. Pages 89-110 *in* Enzymatic oxidation of toxicants (ed. E. Hodgson). Raleigh, NC, USA: North Carolina State University Press

DITTRICH, V., LUCTKEMEIER, N., and VOSS, G. 1979. Monocrotophos and profenofos: two organophosphates with a different mechanism of action in resistant races of the Egyptian cotton leafworm *Spodoptera liltoralis.* Journal of Economic Entomology 72: 380-384.

DITTRICH, V. LUCTKEMEIER, N., and VOSS, G. 1980. OP—resistance in *Spodoptera litloralis:* inheritance, larval and imaginal expression and consequences for control. Journal of Economic Entomology 73:356-362.

FURTICK, W. R. 1976. Insecticides in food production. Pages 1 -15 *in* The future of insecticides, volume 6. (Eds. R.L. Metcalf and John J. McKelvey). John Wiley Series in Advances in Environmental Science and Technology, New York, USA: John Wiley.

HACKETT, D.S. 1981. Studies in the biology of *Helicoverpa armigera* in the Sudan Gezira. Ph.D. thesis, University College of North Wales, Bangor, Wales, UK.

HAGGIS, M.J. 1981. Spatial and temporal changes in the distribution of eggs of *Heliothis armiger* (Hubner) (Lepidoptera: Noctuidae) on cotton in the Sudan Gezira. Bulletin of Entomological Research 71:181 -193.

HARDWICK, D.F. 1965. The corn earworm complex. Memoirs of the Entomological Society of Canada 40, Ottawa, Canada. 247 pp.

HARTLEY, G.S., and GRAHAM-BRYCE, I.J. 1980. Physical principles of pesticide behaviour, volume 1. London, UK: Academic Press

HULL, S.F. 1980. Adult control of *Heliothis armigera* in the Sudan. Agricultural Aviation Research Unit progress report 10/80, Cranfield, UK.

JOYCE, R.J.V. 1959. The yield response of cotton in the Sudan Gezira to DDT spraying. Bulletin of Entomological Research 50:567-594

JOYCE, R.J.V. 1961. Some factors affecting the numbers of *Empoasca lybica* de Berg (Homoptera: Cicadellidae) infesting cotton in the Sudan Gezira. Bulletin of Entomological Research 52:191-232.

JOYCE, R.J.V. 1978a. Work accomplished in the CIBA-GEIGY research programme. *In* Proceedings, Third Seminar on the Strategy for Cotton Pest Control in the Sudan. CIBA-GEIGY, Basel, Switzerland.

JOYCE, R.J.V. 1978b. Yield response of *Gossypium barbadense* in the Sudan Gezira to aerial spraying at ULV rates with Nuvacron 40®. Pages 229-242 *in* Proceedings, Third Seminar on the Strategy for Cotton Pest Control in the Sudan. CIBA-GEIGY, Basel, Switzerland.

KNIPLING, E.F. 1972. Entomology and the management of man's environment. *In* Proceedings, 14th Congress of Entomology, Canberra, Australia.

LAWSON, T.J. 1980a. The population dynamics of *Heliothis armigera* in Chaibadan, Thailand, 1979, and the development of a pest control strategy. Agricultural Aviation Research Unit research report 43/80, Cranfield, UK.

LAWSON. T.J. 1980b. The toxicity of Nuvacron 40 SCW and Curacron 375 ULV to adult *Heliothis virescens* and *Spodoptera littoralis.* Agricultural Aviation Research Unit progress report 103/80, Cranfield, UK.

LAWSON, T.J., and HULL, S.F. 1979. Adult *Heliothis armigera* and *Spodoptera littoralis* control trials, Hola, Kenya, 1979. Agricultural Aviation Research Unit progress report 93/79, Cranfield, UK.

LAWSON, T.J., TOPPER, C.P., and HULL, S.F. 1979. Adult *Heliothis armigera* control trials in the Sudan Gezira, 1979. Agricultural Aviation Research Unit progress report 88/79, Cranfield, UK.

LENTZ, G.L., WATSON, T.F., and CARR, R.V. 1974. Dosage-mortality studies on laboratory-reared larvae of tobacco budworm and the bollworm. Journal of Economic Entomology 67(6)719-720.

LINGREN, P.D.,and WOLFENBARGER, D.A. 1976. Competition between *Trichogramma pretiosum* and *Orius insidiosus* for caged tobacco budworm on cotton treated with chlordimeform sprays. Environmental Entomology 5(6):1049-1052.

LUCKMAN, W.H., and METCALF, R.L. 1974. The pest management concept. *In* Introduction to pest management (eds W.H. Metcalf and R.L. Luckman). New York, USA: Wiley-Interscience.

LUND, A.E., HOLLINGWORTH, R.M., and SHANKLAND, D.L. 1979. Chlordimeform: plant protection by a sub-lethal noncholinergic action on the central nervous system. Pesticides Biochemistry and Physiology 177-178.

LUTTRELL, R.G., YEARIAN, W.C., and YOUNG, S.Y. 1979. Laboratory and field studies on the efficacy of selected chemical insecticides-Elcar (*Baculovirus heliothis)* combinations against *Heliothis* spp. Journal of Economic Entomology 72(1):57-60

MACARTHUR, R. 1960. On the relative abundance of species. American Naturalist 94:25-34.

PITTS, D.L, and PIETERS, E.P. 1980. Ovicidal activity of insecticides against tobacco budworm eggs on cotton. Journal of Economic Entomology 73(4): 570-572.

RABB, R.L. 1970. *In* Concepts of pest management (eds. R.L. Rabb and F.E. Guthrie). Raleigh, NC, USA: North Carolina State University Press.

RAINEY, R.C. 1974. Flying insects as targets for ultra-low volume spraying. Pages 20-28 *in* British Crop Protection Course Monograph 11, Centre for Overseas Pest Research, London, UK.

RAINEY, R.C. 1976. Flight behaviour and features of the atmospheric environment. Pages 75-112 *in* Insect flight (ed. R.C Rainey). Symposia of the Royal Entomological Society of London 7. Oxford, UK: Blackwell.

RUSSELL-SMITH, N.A. 1975. Distribution and sampling of *Heliothis armigera* (Hb) eggs on cotton in the Sudan Gezira. *In* Proceedings, Seminar on the Strategy for Cotton Pest Control in the Sudan Gezira. CIBA-GEIGY. Wad Medani, Sudan.

SCHAEFER, G.S. 1976. Radar observations on insect flight Pages 157-197 *in* Insect flight (ed R.C. Rainey). Symposia of the Royal Entomological Society of London 7. Oxford. UK: Blackwell.

SMITH, D.B., HOSTETTER, D.L., and IGNOFFO, C M. 1978. Formulation and equipment effects on application of a viral (*Baculovirus heliothis)* insecticide. Journal of Economic Entomology 71(5): 814-817.

SOUTHWOOD, T.R.E. 1974. The dynamics of insect populations. *In* Insects, science and society (ed. D. Pimental) New York, USA: Academic Press.

SPARKS, A.N., JACKSON, R.D., and ALLEN, G.L.

1975. Corn earworm: capture of adults in light traps on unmanned oil platforms in the Gulf of Mexico (USA). Journal of Economic Entomology 68:431 -432.

STEIN, V.M., SMITH, R.F., BOSCH, R., and HAGEN, K.S. 1959. The integrated pest control concept. Hilgardia 29(2):81.

STADELBACHER, E.A., FARR, R.E., and LASTER, M.L. 1972. Bollworms and tobacco budworms. Mortality of adults exposed to insecticides on cotton. Journal of Economic Entomology 65(6):1682-1683.

TAYLOR, L.R., and TAYLOR, R.A.J. 1977. Aggregation, migration and population mechanics. Nature 265:415-421.

TAYLOR, L.R., FRENCH, R.A., WORWOOD, I.P., DUPUCH, M.J., and NICKLEN, J. 1980. Synoptic monitoring for migrant pests in Great Britain and Western Europe. Pages 41 -104 *in* Rothamsted Experiment Station report for 1980, part 2, Rothamsted, UK.

TOPPER, C.P. 1981. The behaviour and population dynamics of *Heliothis armigera* (Hb) (Lepidoptera, Noctuidae) in the Sudan Gezira. Ph.D. thesis, Cranfield Institute of Technology, Bradford, UK.

UK, S., and OUTRAM, I. 1979. Monocrotophos in the extra-floral nectar of cotton after field sprays of Nuvacron 40. Agricultural Aviation Research Unit progress report 98/79, Cranfield, UK.

WARE, G.W., ESTESEN, B., and CAHILL, W.P. 1975. Bulletin of Environmental Contamination and Toxicology 14(5):606-609.

WILKINSON, C.F. 1968. Detoxication of pesticides and the mechanism of synergism. Pages 113-142 *in* Enzymatic oxidation of toxicants (ed. E. Hodgson). Raleigh, NC_1 USA: North Carolina State University Press.

WILSON, A.G.L. 1974. Resistance of *Heliothis armigera* to insecticides in the Ord irrigation area of North Western Australia. Journal of Economic Entomology 67(2):256-258.

WOLFENBARGER, D.A., and MCGARR, R.L. 1970. The toxicity of methyl parathion, parathion, and monocrotophos applied topically to populations of Lepidopteran pests of cotton. Journal of Economic Entomology 63 (6)762-764.

WOLFENBARGER, D.A., LUKEFAHR, M.J., and GRAHAM, H.F. 1971. A field population of bollworms resistant to methyl parathion. Journal of Economic Entomology 64(3): 755-756.

A Determination of an Economic Injury Level of *Heliothis armigera* (Hubner) in Sorghum for Southeast Queensland

P.H. Twine and I.R. Kay*

Abstract

A pest density-crop loss relationship lor Heliothis armigera *in sorghum (cv Texas 610) in southeast Queensland, Australia, was calculated from a series of trials, using caged heads or natural larval infestations. The loss of 1.56 g per larva derived from this regression has been developed into an economic threshold, and an appropriate sequential sampling program utilizing these values is proposed.*

Résumé

*Détermination d'un seuil économique de nuisibilité d'*Heliothis armigera *(Hübner) chez le sorgho au sud-est de Queensland: Suite à une série d'essais, un rapport densité des ravageurs-pertes culturales a été établi pour* Heliothis armigera *chez le sorgho (cv Texas 610), au sud-est de Queensland en Australie, en utilisant des panicules encagées ou des infestations naturelles de larves. La perte de 1,56 g par larve provient de cette régression et a permis d'établir un seuil économique. Un programme d'échantillonnage séquentiel approprié, utilisant ces valeurs, est proposé.*

The genus *Sorghum* includes a wide variety of grain-bearing plants, ranging in type from tall, tussocky grasses to thick, juicy-stemmed sweet sorghums. The main members of the genus cultivated throughout the world are grain sorghums, grown chiefly as a cereal; sweet or fodder sorghums, for green feed or silage; sudangrass for grazing, hay, and silage; broom millet for brooms and brushware; and, more recently, columbusgrass, principally for grazing.

Cultivated sorghum is a crop of great antiquity. It is thought to have been grown by the Chinese earlier than 2000 B.C., and was grown in Egypt in Biblical times. The main centers from which it has spread into modern cultivation are southern Asia, Asia Minor, and north and south Africa. In most of these countries it has provided a staple cereal for human food, as well as grain and fodder for animals. It is only in more highly developed modern communities where wheat, oats, and other cereals are plentifully available, that sorghum grain has been relegated to the position of stock feed.

During the latter half of the nineteenth century, many sorghum collections were made by botanists travelling in Africa and Asia, most of which found their way to the United States of America, where conditions were much better suited to their growth than in northern and western Europe. In the USA, they rapidly gained favor, particularly in the drier midwestern and southwestern states, where rainfall was often insufficient for successful maize crops. It is from the USA that many of Queensland's most successful importations have come.

In Australia, grain sorghum is grown commercially in many areas of Queensland and northwestern New South Wales, with about 80% of the total area under the crop in Queensland. Yields of grain sorghum vary considerably from year to year and from place to place. Official statistics in recent years for both New South Wales and Queensland show that the average yields range from 1.5 to 2.5 metric tons (tonnes)/ha (Table 1). These averages are extremely low when compared with the known performance of hybrid varieties. This may be a result of shortcomings in fertilizer use and cultural practices.

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International Crops Research Institute for the Semi-Arid Tropics. 1982. Proceedings of the International Workshop on *Heliothis* Management, 15-20 November 1981, Patancheru, A.P, India

Table 1. Sorghum production in Australia, 1971-1980.

Year	Grain sorghum						Hay			Silage
	Australia			Queensland			Queensland			Queensland
	Area (ha)	Production (tonnes)	Yield (t/ha)	Area (ha)	Production (tonnes)	Yield (t/ha)	Area (ha)	Production (tonnes)	Yield (t/ha)	Area (ha)
1971-72	638 392	1 228 000	1.92	423 234	833 473	1.97	1367	5700	4.17	106 535
1972-73	697 162	1 018 000	1.46	414 133	621 896	1.50	2599	8406	3.23	153 011
1973-74	539 700	1 060 600	1.96	331 656	654 225	1.97	2228	4257	1.91	111 788
1974-75	511 100	900 800	1.76	328 886	634 120	1.93	1813	6054	3.34	76 550
1975-76	504 000	1 123 700	2.23	338 988	739 896	2.18	942	3044	3.23	76 260
1976-77	532 100	956 000	1.80	377 092	605 188	1.60	735	2655	3.61	82 792
1977-78	714 100	394 100	1.81	293 145	503 992	1.72	1803	5895	3.26	61 765
1978-79	470 100	nya[a]	nya	279 961	712 908	2.55	1336	5604	4.19	60 206
1979-80	nya	nya	nya	368 698	711 315	1.93	1996	8992	4.50	76 974

a. nya = not yet available.

The Sorghum Pest Complex

The array of insect pests attacking sorghum has been well documented internationally (Young and Teetes 1977) and locally (Passlow 1973). Passlow (1973) claims that the sorghum midge *(Contarinia sorghicola* [Coq.]) is, without doubt, the most important of the insect pests attacking sorghum in Queensland. Although its incidence is somewhat sporadic, the losses resulting from the attacks have a significant effect on the overall annual production of sorghums. Of the other insects attacking sorghum, the sorghum head caterpillar, *Cryptoblabes adoceta* (Turn.), the yellow peach moth *(Dichocrocis punctiferalis* [Guen.]), armyworms *(Pseudaletia convecta* [Walk.] and *Spodoptera* spp), cutworms *(Agrotis* spp), aphids *(Rhopalosiphum maidis* [Fitch]), and false wireworms *(Gonocephalum* sp) also inflict damage sporadically. The corn earworm *(Heliothis armigera* [Hubner]) was once regarded as falling into this same category, but with the advance of agricultural development in the areas in question, the species is increasingly recognized as a more regular pest of sorghum.

Basically, *H. armigera* is a pest of the fruit or grain development stage, but in sorghum crops it can attack the plant at any stage of growth. Although larvae feeding on the leaves can give a very ragged appearance to a sorghum stand, such damage is unlikely to cause any real influence on grain yield.

Feeding by *H. armigera* commonly occurs on the head but attacks of this kind decrease as the grain approaches maturity. Feeding during the soft-grain stages, however, reduced the yield of the individual heads, and it is the purpose of this paper to quantify this relationship and to discuss the economic implications of the results. Although very few data are available on the economic importance of *H. armigera* in sorghum, Alcock and Twine (1980) estimated the cost of this pest to sorghum production in Queensland alone at some $4 811 000 annually. This comprised an estimate of $1 842 000 as direct spray and spray application costs, together with a residual loss of some $2 969 000. Obviously, the economic threat of the species to sorghum production in Queensland is quite significant.

Economic Threshold

Although one of the first discussions emphasizing the relationship between the density of a pest and the potential damage caused by the pest was made by Shotwell (1935), Stern et al. (1959) initiated immense discussion and interest in economic thresholds and economic injury levels. More recently, concepts such as action thresholds (Chant 1966) and control thresholds (Sylvern 1968) have been suggested, with Smith (1969) analyzing these various concepts and concluding the advantages of the term "economic" from the practical standpoint. Irrespective of theoretical considerations, the practical implications of the question, "When do we need to control a pest?" have led entomologists to study the effect of pest activity in crops and to develop realistic guidelines to assist producers.

Stem (1966) discussed three empirical methods of establishing economic thresholds, relying on visual estimations of crop loss, while Stone and Pedigo (1972) presented a fourth approach involving costs, marketing, and yield data. The method used here basically follows that of Stone and Pedigo (1972), thereby allowing for fluctuations in such parameters as market values, insecticide, and application costs.

Traditionally, the threshold for *Heliothis* in sorghum in Queensland was estimated to be of the order of four to six larvae per head. This value was arrived at from practical experience and observation, and has provided a realistic basis to date for pest-management decision-making. More recent reviews and specific studies of the damage to sorghum by *Heliothis* have suggested a somewhat lower density might be more applicable (Kinzer and Henderson 1968; Wilson 1976; Buckley and Burkhardt 1962). It was in this context that a series of experiments were undertaken from 1970 to 1980 to define more closely the relationship between *Heliothis* density and resulting damage.

Methods

Between 1970 and 1980, ten trials were undertaken using the closed-head cultivar, Texas 610. Six of these involved caging artificial larval infestations on heads during the grain-maturation stage and examining the resulting damage and yield loss.

The cages were similar to those used by Kinzer and Henderson (1968). Each cage was secured to the head, and a small quantity of vermiculite was provided in the bottom as a pupation site. Heads were infested with third-instar larvae from either laboratory colonies or natural infestations in the trial area. The number of treatments (larvae per head) used varied between trials from four to seven, with the treatment levels varying from zero to ten third-instar larvae per head. The number of replicates also varied from 13 to 66, depending on the availability of uniform heads and larvae.

Table 2. Treatment levels used In caged-head studies of the affect of *H. armigera* on grain sorghum production.

	Infestation level (larvae/ head)									
Trial	0	1	2	3	4	5	7	8	10	Replicates
1	x		x			x		x		33
2	x		x		x			x		33
3	x			x		x			x	66
4	x	x	x	x			x	x		14
5	x	x	x	x	x	x				13
6	x	x	x	x	x	x				15

a. Glasshouse trial.

Two of the caged-head trials were conducted in the glasshouse. A summary of the treatment information is set out in Table 2.

Larvae were allowed to complete development and pupate in the cage. At this stage, the cages were removed and the pupae counted. The developed grain was harvested, threshed, weighed, and counted at maturity.

The remaining four trials were conducted using natural head infestations in the same variety. Heads of similar sizes were selected at random and labeled according to the number of larvae present. (All trials were carried out at a time when the larval cohort was in the third instar.) As a result, the number of replicates of each larval infestation level was not constant, but rather varied with the overall infestation situation. As with the caged-head trials, the heads were harvested at grain maturity, threshed, and the grain weighed and counted.

A summary of the treatment information for these trials is set out in Table 3.

Results

Regression Analyses

Regression analyses were carried out for seed weight per head in grams (Y) (corrected to 12% moisture content) and larval infestation per head

Table 3. Treatment levels used for field trials on the effect of *H. armigera* on grain sorghum production.

Trial	Infestation level (larvae/head)						Total heads used
	0	1	2	3	4	5	
7	x	x	x	x	x		135
9	x	x	x	x	x	x	213
11	x	x	x	x	x	x	119
12	x	x	x	x			181

(X) for each of the ten trials. The critical parameters for these regressions are listed in Table 4, together with the values from the pooled regressions for the trials involving cages, natural infestations, and all trials combined. As indicated from the intercept values, these trials covered a wide range of potential yield situations. The within-sets slope for all trial data would indicate that grain-yield loss attributed to each additional larva amounts to some 1.56 g per head.

This value differs somewhat from previously published values. Kinzer and Henderson (1968) found from the results of two trials that each larva decreased head grain yield 3.9 g at harvest. Wilson (1976), on the other hand, found that each additional *H. armigera* larva decreased yield by 5.4 g for cv RS-610 and by as much as 8.4 g for cv Pickett. However, these data were generated from mean weekly larval infestations in large plots (20 m x 100 m) rather than from studies of infestations in individual heads.

For each of the caged trials the number of pupae, prepupae, or larvae present in the cage at the conclusion of the trial was recorded . From these values, it was apparent that the survival of larvae in the cages varied considerably, and several causal agents associated with this phenomenon have been identified (Phillips 1931). Therefore, in order to consider more closely the potential damage caused by individual larvae, grain weights were correlated with a "larval feeding equivalent," which was based on the makeup of the recovered bodies in each cage. Pupae and prepupae were assigned a larval feeding equivalent of 1.0, whereas larval feeding equivalents of 0.6, 0.2, and 0.1 were assigned to each sixth-, fifth-, and fourth-instar body recovered respectively. These values were derived from preliminary dry-matter intake laboratory studies of artificial diet by the six instars of *H. armigera.* These values also compare favorably with those of Kinzer and Henderson (1968) for *H. zea.*

Table 4. Regression analyses of larval Infestation (larvae par head) and grain weight (g) per head of sorghum.

Trial	dF	Slope	se_b	Correlation coefficient	Intercept
1	130	-0.113	0.248	-0.0397	26.15
2	130	0.064	0.132	0.0422	7.24
3	251	-2.471	0.240	-0.5403	61.99
4	82	-1.538	0.152	-0.7445	10.55
5	76	-0.976	0.494	-0.2208	21.91
6	88	-2.430	1.178	-0.2149	76.06
7	133	-2.603	1.730	-0.1294	99.62
8	211	-0.732	0.689	-0.0729	26.81
9	117	-4.335	1.319	-0.2906	100.85
10	179	0.119	0.762	0.0117	37.01
Within sets					
Caged trials	773	-1.515	0.145	-0.3527	
Natural infestations	640	-1.924	0.578	-0.1303	
All trials	1403	-1.565	0.169	-0.2393	

Table 5. Regression analyses of larval loading equivalent and grain weight (g) per head for caged trials.

Trial	dF	Slope	se_b	Correlation coefficient
1	130	-0.6748	0.625	-0.0942
2	130	-0.2488	0.306	-0.0712
3	195	-2.2013	0.473	-0.3161
4	82	-3.4267	0.338	-0.7456
5	76	-1.0973	0.779	-0.1595
6	88	-4.1402	1.119	-0.3668
Within sets	701	-2.1178	0.264	-0.2889

The results of the regression of grain weight (Y) in grams and larval feeding equivalent (X) for the six caged trials are shown in Table 5.

These data then indicate the potential loss caused by each *H. armigera* larva in a head to be 2.11 g, in the absence of any natural mortality agents. Analysis of the number of *H.armigera* recovered from the cages indicate an overall average mortality of 67%, with values for each trial varying from 29 to 80%. Because of the exclusion of parasites and predators by the cages, this mortality could be attributed to the cannibalistic habit that has been well documented for *Heliothis* in sorghum (Barber 1936; Buckley and Burkhardt 1962.)

Economic Considerations

In the establishment of truly meaningful economic thresholds, proper consideration should be given to a wide spectrum of direct and indirect economic variables and social costs of pest control. Headley (1975) has presented an overall review of the economics of pest management and has stressed the complexity of the considerations and the need for appropriate research to investigate these. The urgent need for some practical guidelines in the adoption of pest-management principles for the control of *Heliothis* in sorghum, however, dictate that at least some degree of simplicity or first estimation should be taken and appropriate thresholds derived. It is in this light that the following thresholds are calculated.

Stern et al. (1959) simply define the injury level as the lowest density that will cause economic damage, justifying the cost of artificial control. Alternatively, it is the density at which the value of the grain potentially at loss equals the cost of control. Or, in mathematical terms:

$$T = \frac{C \times 10^6}{P \times E}$$

where T = Threshold as larvae/ha

C = Cost of control ($/ha)

P = Value of commodity ($/tonne)

E = Consumption per larva (g)

Such an equation satisfied the situation where the amount spent on control simply equals the value of the potential losses. Obviously a farmer will not be willing to accept this position, as he would need to see more value in the potential loss than the outlay for a spray application. Such considerations involve a benefit:cost ratio. Accordingly, the formula can be amended to take this ratio into account:

$$T = \frac{C \times 10^6}{P \times E} \times BC$$

where BC = Benefit : cost ratio

From previous discussions, it is seen that each third-instar larva per sorghum head is likely to reduce yield by 1.56 g. The threshold for *Heliothis* in sorghum can be derived from:

$$T = \frac{C \times BC \times 10^6}{1.56 \times P}$$

Using the sorghum head as the ideal sampling unit for *Heliothis* infestations, it is not unreasonable to adjust the formula further to:

$$D = \frac{C \times BC \times 10^6}{1.56 \times P \times N}$$

where D = Density of infestation per head

N = Number of heads per hectare

Because of the number of variables involved, one example is prepared.

For a control cost of $20/ha, a benefit: cost ratio of 2.1, value of sorghum at $80/tonne and 200 000 heads/ha, the threshold would be 1.6 larvae per head.

Sampling

The utilization and establishment of economic thresholds and, often, the selection of control strategies or tactics will depend on the availability of reliable estimates of pest population densities. Since the collection of data for management decision-making differs from that for research purposes in that a rapid classification of the situation is necessary, some practical, unbiased, and reliable method of estimating larval densities per hectare is required.

Sample Unit

Southwood (1966) has suggested that taking many small sample units offers an advantage overtaking only a few large ones in the determination of population parameters. For sorghum, since most of the *Heliothis* infestation occurs in the developing head, it seems reasonable that this constitutes the ideal sampling unit. The unit is easily defined, stable, readily examined, and lends itself to easy conversion to unit areas.

Dispersion Pattern

A detailed knowledge of the dispersion pattern of *Heliothis* in sorghum heads is necessary to indicate the intensity of sampling required in order to estimate the population parameters for a set level of accuracy. Infestations of *H. armigera* in sorghum were examined in all the trials reported here, and the data subjected to "goodness of fit" tests to several standard classes of statistical distributions. As for several insect infestation situations, the negative binomial type of distribution most reasonably described the observed data, and, using the methods of Bliss and Fisher (1953) a value for k = 1.8 has been calculated.

Sampling Plan

Pieters (1978) and Sterling and Pieters(1979) have given a review of the application of the sequential sampling method of Wald (1945) of categorizing pest infestations against economic thresholds in pest-management decision-making. Using the value of k from the negative binomial fit, and an economic injury level of kpo = 1.2 for the level below which no action is required, and kp_1 = 2.0 for the level above which control should be applied, a sequential sampling plan has been constructed using Error I and Error II levels of 0.1 by the Morris (1954) method (Figure 1).

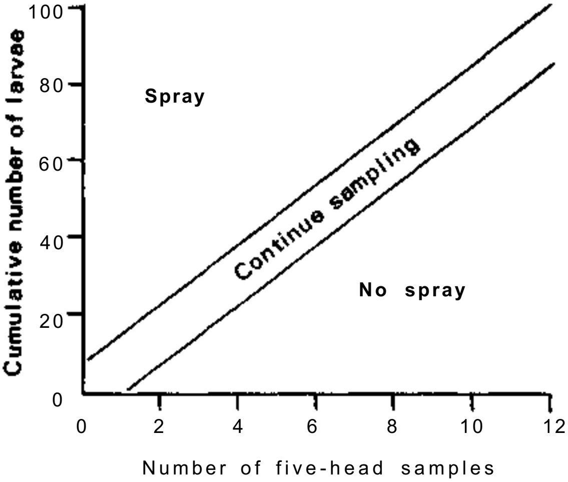

Figure 1. Sequential sampling plan **for Heliothis** ***spp in sorghum in southeast Queensland, Australia.***

Obviously the success of such a sequential sampling plan depends on the accuracy of the determination of the economic thresholds. Of equal importance is the need for unbiased sampling of heads. With a wide range of head sizes present in the field at any one time, there is a strong sampling bias to sample only those heads "likely" to be infested. To overcome this bias, the sampling plan has been amended to use a sample size of five consecutive heads. Under these circumstances, given any bias in the selection of one head in the sample, the inclusion of the four adjacent heads will help minimize the effect of such bias.

The major criticism of the practical implementation of the sequential sampling method is the inordinate amount of time spent in making a decision when the infestation approximates the economic threshold. Onsager (1976) and Sterling (1976) have evolved a form of truncation of the sampling plan to minimize this problem.

Conclusion

With a significant trend towards implementing pest-management programs, particularly in local sorghum production, one major deficiency is becoming apparent. This is the lack of reliable decision-making techniques for *Heliothis* infestations. The trials undertaken have endeavored to establish some knowledge of infestation level-damage relationships and to develop this datum into a simple first approximation to an economic injury level. In association with these trials, studies of the dispersal patterns of *H. armigera* in sorghum have allowed us to suggest a sequential sampling program as a practical guideline in *Heliothis* management decision-making in sorghum.

References

ALCOCK, B., and TWINE, P.H. 1980. The cost of *Heliothis* in Queensland crops. Report on Workshop on Biological Control of *Heliothis* spp. 23-25 Sept. 1980, Toowoomba, Queensland, Australia.

BARBER, G.W. 1936. The cannibalistic habits of the corn earworm. Pages 3-18 *in* U.S. Department of Agriculture Bulletin 499, Washington, DC, USA.

BLISS, C.I., and FISHER, R.A. 1953. Fitting the negative binomial distribution to biological data and note on the efficient fitting of the negative binomial. Biometrics 9: 176-200.

BUCKLEY, B.R., and BURKHARDT, C.C. 1962. Corn earworm damage and loss in grain sorghum. Journal of Economic Entomology 55: 435-439.

CHANT, D.A. 1966. Integrated control systems Pages 194-218 *in* Scientific aspects of pest control. National Academy of Science, National Resources Council Publication 1402, Washington, DC, USA.

HEADLEY, J.C. 1975. The economics of pest management. *In* Introduction to insect pest management, eds. R.L. Metcalf and W. Luckmann. New York : Wiley. 587 pp.

KINZER, H.G., and HENDERSON, C.F. 1968. Damage by larvae of the corn earworm to grain sorghum. Journal of Economic Entomology 61: 263-267.

MORRIS, R.F. 1954. A sequential sampling technique for spruce budworm egg surveys. Canadian Journal of Zoology 32: 303-313.

ONSAGER, J.A. 1976. The rationale of sequential sampling, with emphasis on its use in pest management. U.S. Department of Agriculture, Agricultural Research Service Technical Bulletin 1526, Washington, DC, USA. 19 pp.

PASSLOW, T. 1973. Insect pests of grain sorghum. Queensland Agriculture Journal 99: 620-628.

PHILLIPS, W.J. 1931. The corn earworm as an enemy of field corn in the Eastern States. U.S. Department of Agriculture Farmers' Bulletin 156, Washington, DC, USA.

PIETERS, E.P. 1978. Bibliography of sequential sampling plans for insects. Bulletin of the Entomological Society of America 24: 372-374.

SHOTWELL, R.L. 1935. Method for making a grasshopper survey. Journal of Economic Entomology 28:486-491.

SMITH, R.F. 1969. The importance of economic injury levels in the development of integrated pest control programs. Qualitas Plantarum et Materiae Vegetabiles (Den Haag). 17:81-92.

SOUTHWOOD, T.R.E. 1966. Ecological methods. London: Chapman and Hall. 391 pp.

STERLING, W.L. 1976. Sequential sampling plans for the management of cotton arthropods in south-east Queensland. Australian Journal of Ecology 1:10.

STERLING, W.L., and PIETERS. E.P. 1979. Sequential decision sampling. Southern Cooperative Series Bulletin 231, College Station, Tex, USA.

STERN, V.M. 1966. Significance of the economic threshold in integrated pest control. Proceedings. FAO Symposium on Integrated Pest Control 2: 41 -50.

STERN, V.M., SMITH, R.F., VAN DEN BOSCH, R., and HAGEN, K.S. 1959. The integration of chemical and biological control of the spotted alfalfa aphids. Part I. The integrated control concept. Hilgardia 29: 81 -101.

STONE, J.D., and PEDIGO, L.P. 1972. Development and economic injury level of the green cloverworm on soybean in Iowa. Journal of Economic Entomology 65:197-201.

SYLVERN, E. 1968. Threshold values in the economics of insect pest control in agriculture. Statens Vartskyoldsanstalt Meddelanden 14: 65-79.

WALD, A. 1945. Sequential tests of statistical hypothesis. Annals of Mathematical Statistics 16: 117-186.

WILSON, A.G.L. 1976. Varietal responses of grain sorghum to infestation by *Heliothis armigera.* Experimental Agriculture 12: 257-265.

YOUNG, W.R., and TEETES, G.L. 1977. Sorghum entomology. Annual Review of Entomology 22: 193-218.

The Likely Impact of Synthetic Pyrethroids on *Heliothis* Management

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Abstract

An estimated 55 million ha of crops have been treated with pyrethroids since the launch of the first products in 1976 to the end of 1980, when sales reached an estimated value of U.S. $350 million at end-user level. Most of the products have been used against Heliothis *spp, and in situations where this is the main pest, synthetic pyrethroids are expected to acquire a market share in excess of* 50%.

This *paper examines why farmers have found this new group of insecticides so useful and discusses how the chemicals should be used to obtain maximum benefit from their unique properties while avoiding problems that could emerge as a result of the indiscriminate use of a fairly homogeneous group of insecticides on such a large scale.*

Résumé

*Impact des pyréthrinoïdes dans la lutte contre l'*Heliothis*: Environ 55 millions d'hectares en culture auraient été traités avec des pyréthrinoïdes depuis le lancement des premiers produits en 1976 et la fin de 1980, alors que les ventes se seraient chiffrées à 350 millions $US, au niveau du dernier utilisateur. La majeure partie des produits ont été utilisés contre* Heliothis *spp. Là où c'est le pire ravageur, les pyréthrinoïdes devraient prendre plus de 50% du marché.*

Cette communication examine les raisons pour lesquelles les agriculteurs considèrent si utile ce nouveau groupe d'insecticides et montre comment ces produits chimiques devraient être utilisés, afin de tirer un bénéfice maximum de leurs propriétés uniques, tout en évitant les problèmes qui pourraient résulter d'une utilisation inconsidérée d'un groupe bien homogène d'insecticides sur une aussi grande échelle.

It has recently been estimated by Wood, MacKenzie & Co. (ECN 1981) that synthetic pyrethroids (SPs) will capture around 21% of the total insecticide market by 1986. The pyrethroid market has grown at an average rate of 55% per year during the last 2 years, as compared with total insecticide market growth from 1976-1980 of around 14% per year.

The *3000 tonnes* of product sold during 1980 has predominantly been used for the control of *Heliothis,* much of it on cotton in the USA.

The very rapid growth in use of SPs, however, has not been limited to highly developed agriculture and *to* cotton; the products have been equally well received by unsophisticated farmers in the tropics for use against *Heliothis* and other pests on cotton, and also on crops such as legumes, vegetables, tobacco, and many others, apparently satisfying a wide range of needs under a variety of climatic and economic conditions.

Although peasant farmers and growers in industrialized countries may have identical expectations of a good insecticide, they may place the main emphasis on different aspects of the chemical's performance, depending on their type of application and *level of* sophistication. Equally, a farmer may be using insecticides on different crops with a different objective or standard of pest control in mind. For example, he may want to keep his cotton virtually pest-free, but may tolerate a certain level of infestation and damage on less valuable crops such as sorghum or pigeonpea. SPs have been used successfully under a variety of conditions, but the application strategy may have to be modified to exploit those properties of the products most relevant to the circumstances. The paper will refer particularly to *Heliothis* management problems on

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crops grown by farmers in the tropics and to the SPs permethrin, fenvalerate, cypermethrin, and deltamethrin.

Properties that Influence the Performance of Pyrethroids Against *Heliothis*

Intrinsic Biological Activity

Synthetic pyrethroids used in agriculture are insecticidally more active by at least one order of magnitude than most of the common organophosphates and carbamates, but high activity against insects is combined with low mammalian toxicity. Table 1 compares the activity of some commonly used compounds against *Heliothis virescens*. Younger larvae are generally more susceptible to insecticides and under laboratory conditions the LD_{50} for SPs increases approximately by a factor of 2 per instar. Current products also exhibit a negative temperature-activity relationship, and against *Heliothis virescens* the LD_{50} increased by 1.5 to 2.5 times between a temperature of 7°C and 27°C (Whitney and Wettstein 1979).

Spectrum of Activity and Field Performance

SPs potentially have a broad spectrum of activity, but the biological effect is significantly modified in practice by the rate of application, the application strategy, the behavior of the insects, and, not least, the behavioral modifications induced by the chemicals. With SPs, as with most other insecticides, it is important to draw a distinction between direct insecticidal activity that can be determined in the laboratory and in small plot trials, and performance under practical conditions in the natural environment.

SPs yield exciting results in the laboratory, but much of the success in the field is related not so much to their insecticidal effect as to their overall performance, and particularly their potential to increase yields, an indirect benefit that has only been identified during the large-scale use of these compounds. Some of the mechanisms by which SPs protect the plants and by which yields are increased to a greater extent than can be explained by outstanding pest kill are not well understood at present and offer scope for further investigation. Table 2 summarizes the results of trials conducted during 1978-1979 to determine the performance of Ambush 50 EC (permethrin) in cotton insect control under actual field conditions. Trial plots were selected in 56 locations in five states in India, mainly in irrigated areas, planted with H-4, MCU-5, and Varalaxmi varieties. All trials were nonreplicated, with two plots of 1000 m^2 at each location. In one plot the farmer applied Ambush according to recommendation, on the other plot he used his standard program for comparison. Ambush was applied on threshold, no protocol was fixed for the standard treatment, and cooperator farmers were allowed to exercise their own discretion as to the choice of product, rate, and timing of application.

The results shown in Table 2 demonstrate very conclusively that by applying Ambush only as needed, the number of applications can be significantly reduced, in this case from 12.6 for the best conventional products to 6.9; at the same time, yields can be increased by an average of 36%. Scouting played a crucial part in determining the best timing and the longest possible interval between spray rounds. Irrespective of whether farmers apply sprays on threshold or at fixed intervals, lasting and reliable protection of the crop is a significant advantage, and the relatively long spray intervals associated with SPs is one of their strengths. The pyrethroids used in crop protection are more photostable than many of the common organophosphates and carbamates. They are all lipophilic and hence potentially rainfast. Furthermore, good initial control and, in some cases, a reduction in ovipositing moths allow longer inter-

Table 1. Toxicity of soma organophoaphate and three pyrethroid Insecticides to third-instar larvae of Heliothis virescens by topical application (LDeo ppm).

Organophosphates	
Monocrotophos	5000
Profenophos	500
Parathion-methyl	1250
Synthetic pyrethroids	
Fenvalerate	62.5
Permethrin	62 - 125
Cypermethrin	31

Table 2. Farmer test-use of Ambush In hybrid cottons 1978-79; summary of pooled results (Irrigated cottons: all India).

	Gujarat		Madhya Pradesh		Tamil Nadu		Andhra Pradesh		Karnataka		Average	
Observation/Result	Ambush	Standard	Ambush	Standard	Ambush	Standard	Ambush	Standard	Ambush	Standard	Ambush	Standard
Duration of use (DAS)	63-160	65-165	63-176	63-176	42-142	39-145	49-159	52-160	67-153	57-153	57-160	57-160
No. of days protected	100	100	113	113	100	100	110	106	86	86	103	103
No. of applications	8.1	12.6	6.4	10.0	7.1	11.1	17.4	17.6	5.5	11.5	6.9	12.6
Average application interval (days)	13.8	7.9	17.7	11.3	14.1	9.5	14.9	6.1	15.6	7.5	14.9	8.2
Active ingredient applied (kg/ha)	0.844	23.946	0.760	16.912	0.735	15-709	0.767	38.003	0.704	30.075	0.762	24-929
Cost of insecticides (Rs/ha)[a]												
Total cost	1687.76	2229.74	1519.20	1551.05	1469.57	1936.86	1533.54	1835.57	1407.00	1787.50	1523.41	1878.14
Cost per application	208-36	176.96	237.38	155.11	206.98	174.49	207.24	104.29	255.82	155.43	220.79	149.06
Cost per day protection	16.07	22.30	13.44	13.73	14.70	18.27	13.94	17.00	16.36	20.78	14.79	18.23
Saving in cost of insecticides due to Ambush use (Rs/ha)	541.98	-	31.85	-	467.29	-	302.03	-	380.50	-	354.73	-
Increases in cost of insecticides due to Ambush use (Rs/ha)	-	-	-	-	-	-	-	-	-	-	-	
Yield of seed cotton (kg/ha)	2804.02	2287.06	2857.30	2170.80	3183.88	2183.97	3344.68	2468.93	2893.25	1957.25	3016.63	2214.60
Increase in yield over standard (kg/ha)	516.97	-	686.58	-	994.91	-	875-75	-	936.00	-	802.03	-
Increase in yield over standard (%)	22.60	-	31.62	-	45.45	-	35.47	-	47.82	-	36.22	-

a. Actual price for standard insecticides. For Ambush 50EC an end-user price of Rs.2000/kg ai has been assumed.

vals because of the persistence of effect. However, there seem to be additional reasons for the lasting protection afforded by the SPs. It can be observed that insects that come into contact with residues, even at sublethal concentrations, become hyperactive, behave abnormally, and tend not to remain on treated foliage. Ruscoe (1977) calls this effect "repellent and antifeedant"; Highwood (1979) prefers the term "irritancy." This effect can directly prolong the protection of the crop by preventing newly hatched larvae from feeding, particularly at a time when reduced plant growth or low infestation pressure makes it possible to space sprays further apart. If insects are not knocked down following contact with the spray or the wet deposit, this antifeedant effect prevents virtually all further damage from the time of application. SPs act mainly through contact, and the activity induced in insects that come into contact with the spray deposit may accelerate the poisoning process, much in the same way as it puts mobile parasites and predators at a high risk if ordinary, nonselective contact poisons are used.

In the case of SPs, there is evidence that the repellent effect may play a role in reducing the harm done to winged parasites and pollinators.

Although SPs have a broad spectrum of activity, they have been shown to be more active against *Heliothis* spp than against some of its important predators and parasites, and they seem to compare very favorably in this respect with some of the most commonly used organophosphate and carbamate insecticides. Plapp and Bull (1978) concluded from their studies that of all the insecticides tested, the SPs as a group proved to be most highly selective against the tobacco budworm. Deltamethrin, for example, was 70 times more toxic to *H. virescens* than to *Chrysopa camea* at the LC_{50} level and 200 times as toxic at the LC_{90} level. SPs were also relatively low in toxicity to the parasite *Campoletis sonorensis.* Other researchers (Yehia et al. 1979) found cypermethrin and fenvalerate to be the safest compounds against *Coccinella undecimpunctata* L out of 15 commonly used cotton insecticides. Wilkinson et al. (1979) reported fenvalerate and permethrin to be significantly less toxic to *Apanteles marginiventris,* a parasitoid, and three predators of *Heliothis* spp than the organophosphates sulprophos and profenophos.

All this information shows SPs to be promising insecticides for use in integrated pest management programs. They are of such low toxicity to most predators that at the rates required to control *Heliothis,* harm caused to beneficial insects through a direct toxic effect should be minimal. Against mobile parasites, where the favorable selectivity is

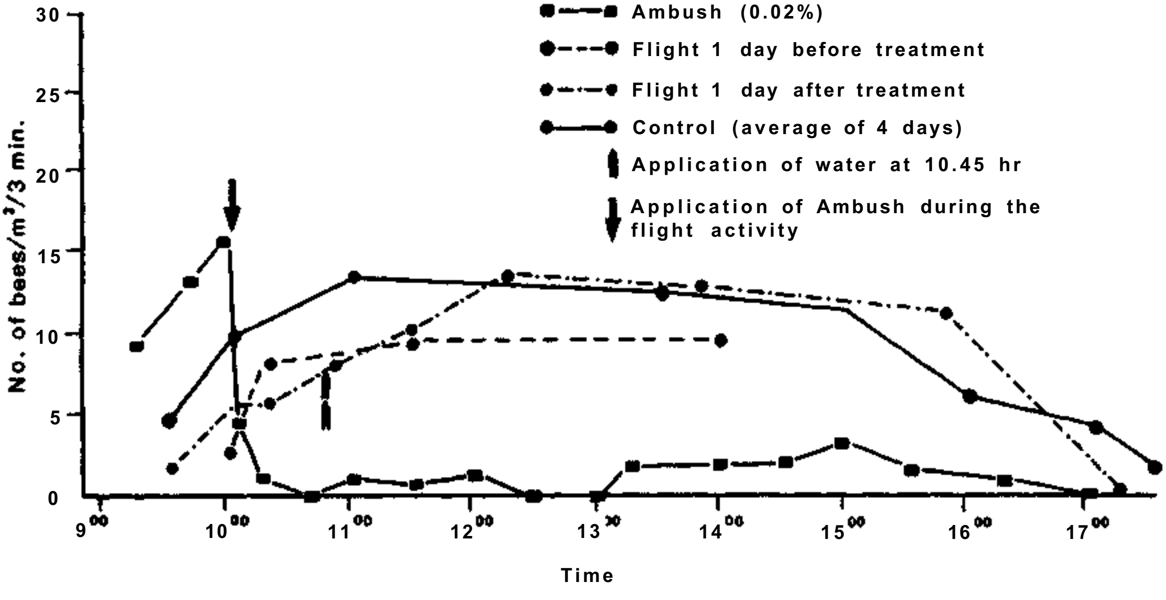

Figure 1. Repellent effect of Ambush compared with flight activity before and after the treatment day and with the average value for 4 days.

slightly less pronounced, the repellent effect can further enhance the safety of SPs. Figure 1 shows the results of detailed work carried out with honeybees in the flight-tent by Gerig (1979). Ambush repelled bees almost completely for several hours, and bees did not visit the treated plants to any appreciable extent during the day of treatment.

Returning to the subject of crop yields, the effective protection provided can in many cases, pass as an explanation for the yield increases obtained. But experience with pyrethroids has also shown that there are often yield increases in conditions where pest control on pyrethroid-treated and conventionally treated areas is very similar. This is one aspect that has not yet been fully elucidated, but the possibility of growth-regulant effects on plants cannot be excluded. It has often been observed that crops treated with pyrethroids, particularly such crops as vegetables and cotton, which receive several sprays, look healthier and lusher and often mature earlier and more uniformly than crops treated with conventional chemicals.

In a plant-growth test on glasshouse-grown tomatoes that were treated five times at 5-day intervals, with three rates of Cymbush 10 EC, Ambush 50 EC, and Docis 2.5 EC, the SP-treated plants were on average 2.1 cm or 15% taller 25 days from the start than the plants sprayed with water.

Table 3 summarizes the results of a trial carried out by Imperial Chemical Industries (ICI) in the USA, in which the damage levels between plots treated with Cymbush at 28 g ai/ha and the standard were comparable, but in which the plots treated with Cymbush yielded 29% more. However, it remains open to discussion whether this and many similar results can be explained by a yield-depressing effect exerted by conventional chemicals.

Use of Synthetic Pyrethroids for Protection Against *Heliothis* Attack

Synthetic pyrethroids are very versatile and can be successfully used under varying conditions. Because of their high insecticidal activity, it is tempting to use them as insecticides have traditionally been used—to eradicate established infestations or as a preventive spray applied more or less according to a schedule, with the objective of keeping the crop pest-free.

Most of the SPs used against *Heliothis* on field crops in the tropics have been used in this way. Experience, particularly in cotton, has shown that SP use follows a certain pattern. During the period following the launch of the first products, farmers often treat them as superior insecticides and apply them only when the infestation is building up and conventional products are no longer giving adequate control. Often they will also use pyrethroids as a component of a tank mixture. As more products enter the market, price competition increases, and farmers recognize their effect on yield and early maturity in addition to their outstanding insecticidal activity, many will use SPs almost exclusively, with generally very satisfactory results.

Unfortunately, the high level of efficacy against *Heliothis,* the reliable performance of the product against this pest, and the relatively low cost of SPs do lead farmers to neglect other aspects of pest management. Whilst application techniques have generally improved in connection with SP use,

Table 3. Control of cotton bollworm *(Heliothis zea*) and tobacco budworm (H. virescens) on cotton with full-season program (7-day schedule), USA.

Treatment	Rate (g ai/ha)	Damaged squares (%)	Lint Yield (kg/ha)
Cypermethrin	28	13	402
Cypermethrin	56	9	609
Methyl-parathion + toxaphene	1120	15	311
Control		25	67

most growers still seem reluctant to use scouting to apply the products as needed on their more valuable crops.

Most prefer to spray when the time seems right or when neighbors begin their treatments. IrradditION, little attention has been paid to the fact that SPs do not control mites, and, depending on the method of application, may not adequately control some of the more hidden sucking insects. In more mature markets such as Thailand, where SPs have been the main insecticides used over several seasons, it has become apparent that SPs will not be a panacea for all types of pest attack, and their indiscriminate use will allow pests that they do not control well to gain in importance. Furthermore, it must be assumed that SPs as a weapon against *Heliothis* will be blunted prematurely if they are used for the control of pests for which they are not particularly suitable.

Considering the savings in chemical and expenditure that farmers could make in return for the little extra time needed to monitor pest infestation levels, it is difficult to understand why reality is still so far removed from the ideal. No doubt a great deal of work has already been done by the agricultural extension services, the scientific community, and commercial companies, and there are isolated signs of farmers adopting more sophisticated pest-control strategies. The large majority of farmers, however, are not yet ready or able to follow pest-control recommendations based on principles of integrated pest management.

Farmers growing cash crops are normally not prepared to take risks and are often willing to take out insurance in the form of early and additional applications of insecticides. From a technical point of view this may seem wasteful, but perhaps from their position it is logical. The farmers' livelihood is at stake, and a lower but secure income may be preferable to a potentially higher reward, with the risk of severe losses from time to time. The farmers' present strategy may be the one best suited to their requirements and capabilities, given the social structure, lack of education, dependence on illiterate laborers, unpredictable weather, inefficient spray equipment, and insecticides that are more effective in preventing *Heliothis* infestation than in cleaning up the crop once the pest is well entrenched. This reality cannot be ignored by a commercial company, and recommendations for the use of SPs have generally taken this situation into account. It is reassuring to know that farmers who are not able to exploit the pest-control potential of SPs to the fullest possible extent may be rewarded with a yield increase.

Obtaining Maximum Benefits from SPs

Suggestions will now be made as to how the maximum benefit can be obtained from the unique properties of the SPs, using the lowest possible amount of active ingredient and with the least impact on the ecosystem.

Given the decreasing susceptibility of older caterpillars, accentuated by usually high ambient temperatures, it is important to apply the SPs early. Not only are young larvae more susceptible, but first and second instars are also more exposed than later instars. On cotton, more than 95% can be found on emerging leaves at the branch tips and small buds (Mabett et al. 1980), and they wander about on the plant a great deal until they find a suitable feeding site (Pearson 1958).

In order to decide whether the infestation by a pest has reached the economic threshold and a spray is required, regular scouting is essential. On crops where *Heliothis or* another lepidopterous pest is the main target, SPs should not be used until these pests have reached the economic threshold, which, of course, will be different for different crops and in different economic situations. On cotton, where early bollworms usually cause little economic damage, it will not normally be necessary to apply the products before the onset of the main flowering phase.

Up to this time it is best to avoid insecticidal treatments or to use soil-applied or selective chemicals, a practice that will help to conserve beneficial insects. They can assist in delaying the onset and reducing the intensity of mid-season *Heliothis* attack.

When economic damage is expected, for example, on cotton from about day 50 onwards, the crop should be scouted at regular intervals (for high-value crops about twice a week). Numbers of black eggs or larvae may be used as the threshold. In areas and on crops where egg parasitism is high and infestaton pressure low or moderate, the number of larvae may give a more reliable indication than the eggs. Eggs, on the other hand, give more advance warning and should be counted if infestation pressure is high and the question is when—rather than whether—to spray.

If infestation is high and the growth of the plants rapid, spray applications should be made at short intervals to protect the new growth, which may otherwise be attacked by larvae repelled from treated older foliage. A low rate/short interval strategy is also preferred to the high rate/longer interval option because it will give better spray distribution and increase the chance of obtaining direct spray impingement on adults, larvae, and eggs.

If the economic threshold is low and the infestation pressure high, as is often the case in cotton, then beneficial insects can play only a small role, certainly once the spray program has started. For these reasons, SPs should not be used to clean up established infestations and in the absence of any other insecticide that is suitable for such a use, it is not advisable to choose an artifically high threshold in the hope that parasites and predators might eventually prevail. The high-threshold option is frequently and quite successfully exercised in China, but the conditions differ from those in most other countries in that the cultivation and the pest-control program for a large area are coordinated centrally, no really effective insecticides are available to date, and manual labor can be used to collect caterpillars in an emergency in order to bring the situation under control.

If infestation pressure from *Heliothis* is continuous and high and the crop has to be sprayed at regular intervals, it is best to use SPs for several sprays in succession and not to alternate with insecticides belonging to another group, unless scouting results indicate an abundance of pests that are not adequately controlled by SPs. This strategy fully exploits the residual properties of the compounds, with the old deposit contributing to the insecticidal level. Furthermore, it is believed that short-term rotation with compounds belonging to different groups has a similar effect as random tank mixtures and could accelerate the selection of strains of insects with broad-based resistance, i.e., a mechanism of simultaneous resistance to insecticides belonging to different groups of chemicals. A third reason for exclusive application of SPs during the main period of fruit formation and growth—on cotton often between about 50 and 110 days after sowing—is that conventional insecticides tend to counteract the SPs' effect on yield.

For crops in which higher economic thresholds are acceptable, a different strategy can be pursued, and integration of SPs and beneficial insects becomes a practical possibility. Ideally, scouting should be used to determine whether and when there is a need for the application of a pyrethroid. When using low rates, which are selectively effective against *Heliothis* but leave predators and parasites largely unharmed, it is important to apply the spray when the pest is still vulnerable. The level of control aimed for should be related to the economic threshold and the lowest possible rate giving the desired level of control should be chosen to avoid unnecessary toxic effects on beneficials, but perhaps more important in the case of SPs, the complete destruction of the prey.

If insecticide application based on the results of regular scouting is not practical in high-value crops such as irrigated cotton, it may seem even less likely that it would be acceptable in less valuable crops. It is true that under normal circumstances sophisticated scouting techniques are not employed, and farmers are unlikely to link infestation levels with the abundance of beneficial insects. There are at least two reasons for which growers follow a more integrated approach to pest management on semi-intensive crops, albeit unconsciously. They are prepared to accept a certain level of infestation and damage before resorting to insecticide application, and secondly—also related to the economics of the crop—they are less likely to overdose in an attempt to eradicate the pests. Although the amount of SPs used on semi-intensive crops for the control of *Heliothis* will be small compared with the programmed use on cotton, the use of additional, nonchemical elements of pest management in these crops and crops not treated with the products at all will be an essential prerequisite for the continual intensive use of SPs on cotton and other crops with low economic thresholds.

Conclusion

In conclusion, two types of use for SPs against *Heliothis* can be distinguished. The products are suitable for multiple application on high-value cash crops such as high-yielding cotton and certain vegetables, on which only a little or no pest damage can be tolerated and where the scope for beneficial insects during the main growing period is very limited. In these crops, SPs, applied either according to need or—more likely in the case of the average grower—at more or less fixed intervals, provide the crop with outstanding protection from *Heliothis* spp attack and encourage early maturity (cotton) and higher yields.

In crops needing less complete protection, as may be the case for rainfed cotton, legumes, sorghum, sunflower, etc., SPs can be used as part of an integrated control program in which their low toxicity to predators and their irritant effect on mobile parasites and pollinators are of major importance.

Acknowledgments

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References

ECN (European Chemical News), 5 Aug 1981:5.

GERIG, L. 1979. The toxicity of synthetic pyrethroids to foraging bees. Swiss Federal Research Institute, Liebefeld, Berne, Switzerland.

HIGHWOOD, D.P. 1979. Some indirect benefits of the use of pyrethroid insecticides. Pages 361 -369 *in* Proceedings, British Crop Protection Conference, Pests and Diseases. Vol. 2. 19-22 Nov 1979, Brighton, UK.

MABETT, T.H., DAREEPAT, P., and NACHAPONG, M. 1980. Behavior studies on *Heliothis armigera* and their application to scouting techniques for cotton in Thailand. Tropical Pest Management 26(3): 268-273.

PEARSON, E.O. 1958. The insect pests of cotton in tropical Africa. Commonwealth Agricultural Bureau, London, UK.

PLAPP, F.W., and BULL, D.L. 1978. Toxicity and selectivity of some insecticides to *Chrysopa carnea* as predator of the Tobacco Budworm. Environmental Entomology 7: 431 -434.

RUSCOE, C.N.E. 1977. The new NRDC pyrethroids as agricultural insecticides. Pesticide Science 8: 236-242.

WHITNEY, W.K., and WETTSTEIN, K. 1979. AC 222, 705, a new pyrethroid insecticide: performance against crop pests. Pages 387-394 *in* Proceedings, British Crop Protection Conference, Pests and Diseases, Vol.2.19-22 Nov. 1979, Brighton, UK.

WILKINSON, J.D., BIEVER, K.O., and IGNOFFO, CM. 1979. Synthetic pyrethroid and organophosphate insecticides against the parasitoid *Apanteles marginiventris* and the predators *Geocoris punctipes, Hippodamia convergens* and *Podisus maculiventris,* Journal of Economic Entomology. 4:473-475.

YEHIA, A.I., EL-SAYED, A.M.K., NEGM, A.A., HUSSEIN, M.H., and EL-SEBAE, A.H. 1979. The relative toxicity of certain insecticides to Spodoptera *littoralis* and *Coccinella undecimpunctata.* International Pest Control July/August: 79-82.

Discussion—Session 4

The very large populations of *Heliothis* larvae on sorghum and the large numbers of eggs on cotton reported by Twine caused some surprise. He explained that a wide array of host crops in that area encourages a large buildup of the local *Heliothis* populations towards the end of the summer season. Although there was an unusually high density of eggs on the cotton, adequate control of this pest was obtained by the application of synthetic pyrethroid sprays.

Dr. Saxena reported that significant phytotonic effects had been recorded when chickpeas were treated with synthetic pyrethroids for *H. armigera* control at Delhi. He asked whether such effects had been recorded elsewhere. He also reported that economic threshold levels for *Heliothis* on chickpea have been determined in India and that similar determinations are now in progress for pigeonpea. Dr. Kohli confirmed that yield effects following synthetic pyrethroid use have been amply documented, but the causes of such effects are not easily identified. He explained that yield differences could be a result of many factors, including phototoxicity of the pesticides used in the check plots and differential control of pests that were not the subject of investigation and so were not recorded. He would welcome an investigation by independent research workers on the effect of synthetic pyrethroids on crop productivity. In response to Dr. Saxena's concern about the toxic residues left on legume and oilseed crops at harvest after treatment with persistent pesticides for the control of *Heliothis* larvae, Dr. Joyce commented that he would much prefer that the target for control measures be the moths and not the larvae. He said that the moths could be killed either by direct contact with very light doses of pyrethroids that would accumulate during their flight from plant to plant, or by stomach poisons used in baits. Changing the target from the larvae to the moths could result in reduced contamination risks.

There was a lively discussion concerning the pest problems in the Sudan Gezira. Dr. Galal Hamid Osman considered that some of the problems had been caused by changing the pre-1969 policy of using pesticides known to be soft to natural enemies, and alternating these to avoid the development of resistance. In the new strategy, two chemicals were used for the control of a single pest—*Heliothis.* This was temporarily successful, but later failed because other pest problems, including whitefly and *Spodoptera littoralis,* developd in the area covered by the new strategy. In reply, Dr. Joyce defended the changed strategy, which involved the use of monocrotophos to kill *Heliothis* moths, their young larvae, and whitefly. He stated that this pesticide had a half-life of 24 hours when applied in the Gezira, and was preferable to persistent pesticides such as DDT, which had been recorded to have led to a doubling of whitefly populations at 30 days after spraying.

The new recommended strategy gave excellent control of *Heliothis* and maintained whitefly at non-damaging levels on cotton for the first 100 to 120 days after planting. It was recommended that spraying should cease after that date, for experiments had shown that elimination of leaf-feeding pests after the cotton was more than 110 days old gave no yield benefit. Also, there was an immigration of beneficial insects into the cotton at this time from groundnut and sorghum that were completing their development, and from weeds in the crops and fallows that were drying up.

Whitefly was not a new problem in the Gezira. Cowland had recorded whitefly problems in 1933-34. In some years whitefly had built up in early-season outbreaks that reduced cotton yields. Late-season reductions of whitefly populations had been caused not by natural enemies but by the collapse of their environment—i.e., the senescence of the leaves on which they fed and this senescence was hastened by jassid attacks. In recent years whitefly has been kept below the level of economic injury by the new strategy during the vegetative stage of the crop. Late-season pesticide use has exacerbated the whitefly problem by reducing jassids and thus delaying leaf senescence. In addition, the policy of watering Acala cotton until picking, and so further delaying leaf senescence, has also increased the whitefly problem. The S. *littoralis* problem appeared to have been associated with the increased areas of groundnut grown in the Gezira in recent years. Dr. Galal Hamid Osman could not accept this view of the events.

Session 5

Host-Plant *Heliothis* Interactions and Resistance Screening

Chairman: W. Reed
Cochairman: A.C. Bartlett

Rapporteurs: P.W. Amin
S.S. Lateef

The Importance of *Heliothis-Crop* Interactions In the Management of the Pest

B.R. Wiseman*

Abstract

The importance and use of the resistant crop cultivar in an integrated pest-management system are reviewed. Today, more than 100 varieties or inbreds, which carry resistance to more than 25 insect species, have been released. Research on plants resistant to insects has been estimated to give about $300 return for each $1 invested. The use of the resistant crop cultivar has been established as a primary method of control of the insect or damage, and as an adjunct to other integrated pest-management components. Examples of Heliothis *-crop interactions in relation to the mechanisms of resistance are illustrated.*

Résumé

Importance des interactions Heliothis *x culture dans la lutte contre le ravageur: L'importance et l'utilisation de cultivars résistants, dans le cadre d'un système de lutte intégrée contre les ravageurs, sont revues. Actuellement, plus de 100 variétés ou consanguins (inbreds) résistants à plus de 25 espèces de ravageurs ont été vulgarisés. La recherche sur la résistance des plantes aux insectes donnerait un rendement de $300 sur chaque $1 investi. L'utilisation de cultivars résistants est considérée comme une méthode fondamentale de lutte contre les insectes ou dommages et un complément aux autres composantes d'un système de lutte intégrée contre les ravageurs. Les exemples d'interactions culture x* Heliothis *cités portent sur les mécanismes de résistance.*

A knowledge of pest-crop interactions in the management of insect pests is of paramount importance. The development and use of a particular cultivar is the base from which all management strategies must arise. If the crop cultivar is susceptible, i.e., one that is readily attacked and damaged by the pest, then efforts must concentrate on certain other control tactics. However, if the crop cultivar is resistant, i.e., it is inherently less damaged or less infested than comparison cultivars (Painter 1951), then the use of the resistant cultivar should become the base of all present components used in the management of the pest.

The Value of Host-Plant Resistance

Holcomb (1970) stated that several United States Department of Agriculture (USDA) officials have referred to the use of crops that are highly resistant or even moderately resistant to insect attack as the most successful and least heralded of all the natural methods of insect control. Luginbill (1969) reported that the most effective and ideal method of combating insects that attack plants was to grow insect-resistant varieties; he further showed the value of research on and development of resistant plants to be about $300 return for each $1 invested. Dahms (1972b) showed that more than 100 varieties or inbreds of crop plants have been released, carrying resistance factors to more than 25 insect species. Today, probably more than 300 cultivars, resistant to more than 40 insect species or biotypes, have been developed. Over 800 literature citations related to plant resistance to *Heliolhis* spp were reported in the recent bibliography published by the soybean scientists Kogan et al. (1978). Of these, 470 were on general plant resistance, 286 were related to resistance in corn, 122 in cotton, 19 in soybeans, 14 in tobacco, 9 in vegetables, and 11 in other crops.

The Uses of Host-Plant Resistance

The use of resistant cultivars usually occurs in one of two ways: (1) as a primary method of control and (2) as an adjunct to other control components. The

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International Crops Research Institute for the Semi-Arid Tropics. 1982. Proceedings of the International Workshop on *Heliothis* Management, 15-20 November 1981, Patancheru, A.P., India.

development and use of the resistant cultivar discourages the release of susceptible ones. Adkisson and Dyck (1980) stated that the integrated system is designed to suppress pest numbers below crop-damaging levels, not to replace chemical pesticides. They further stated that a resistant variety provides a foundation on which to build an integrated control system.

HPR as a Primary Method of Control

Many examples exist where the use of resistant cultivars is the primary method of suppressing insect densities or reducing pest damage. HPR was historically sought in areas and for crops where plant resistance was the only possible plant-protection method (Horber 1972); for example, grape stocks resistant to *Phylloxera* sp were first used in 1870. Wheats resistant to Hessian fly, *Mayetiola destructor* (Say), and wheat stem sawfly, *Cephas cinctus* Norton, are present-day examples; the planting of some 8.6 million hectares of corn hybrids resistant to European corn borer, *Ostrinia nubilalis* (H'ubner), is another example (Schalk and Ratcliffe1976).

The use of resistant cultivars as a primary control measure in historical cases has precluded the use of other control components. The results have been specific, cumulative, and persistent (Painter 1966; Luginbill and Knipling 1969). In certain cases, the insect was eradicated from some localities (Painter 1966). Adkisson and Dyck (1980) stated that reduction in pest numbers achieved through the use of resistant plants is constant, cumulative, and practically without cost to the grower.

HPR as an Adjunct to Other Control Measures

The use of the highly resistant crop cultivar in most cases eliminates the need of most other control components. However, with lesser degrees of resistance, other control components must be used. This system is of great benefit to the grower and may enhance the use of other control components such as insecticides, predators and parasites, pathogens, and cultural methods.

There are no clear examples where resistant crop cultivars that are hosts to *Heliothis* spp have been planted on farms as a primary insect-control measure in suppressing this pest. But several examples exist where research has demonstrated that certain plant characters reduced *Heliothis* spp densities (Lukefahr et al. 1971; Wiseman et al. 1978a). Lukefahr et al. (1971) suggested that the use of glabrous cottons, with the resultant decrease in *Heliothis* oviposition, could delay the need for insecticides and might permit other biological factors to be utilized more effectively.

It is widely accepted that full-season corn hybrids with husks that extend beyond the ear are utilized in the southern USA as a means of limiting corn earworm, *Heliothis zea* (Boddie), losses. Because these corn hybrids show tolerance to the corn earworm rather than resistance, the insect population is not suppressed (Wiseman et al. 1972); in fact, the tolerant corn hybrids could very well be the major contributing factor to the large population buildups in certain areas of the southern U.S. Gross et al. (1976) reported that even whorl-stage corn could be a primary contributor to the early-season buildup of *H. zea.*

The use of resistant cultivars is also compatible with insecticidal control. For many years corn, especially sweet corn, could not be grown economically in the southern USA until moderate corn earworm resistance was introduced into the hybrids (Maxwell 1972). McMillian et al. (1972) and Wiseman et al. (1973) demonstrated the use of a resistant (tolerant) sweet corn hybrid plus insecticide to reduce losses from the earworm (Fig.1). A reduction of about 7.5 kg/ha of insecticides was realized through a reduction in both rate and number of applications (Table 1). The use of sorghum hybrids resistant to greenbug, *Schizaphis graminum* (Rondani) biotype C, permitted the use of extremely low dosage rates of pesticides (Cate et al. 1973). Low pesticide rates also preserved natural biological control agents and prevented resurgence of the greenbug (Teetes 1980).

Refai et al. (1979) reported that *Heliothis armigera* (H'ubner), a polyphagous insect, was thought to have different levels of susceptibility to insecticides as a result of feeding on different host plants. In general, the larvae fed on tomato fruits were the most sensitive to insecticides; those fed on castor bean leaves and cotton bolls were moderately susceptible; and those fed on corn ears showed the least susceptibility to insecticides. Because of this phenomenon of differential susceptibility, it is possible that the use of resistant (antibiosis) varieties within a crop species could render the pest even more susceptible to insecticides. Therefore, it follows that the use of several resistant crop species

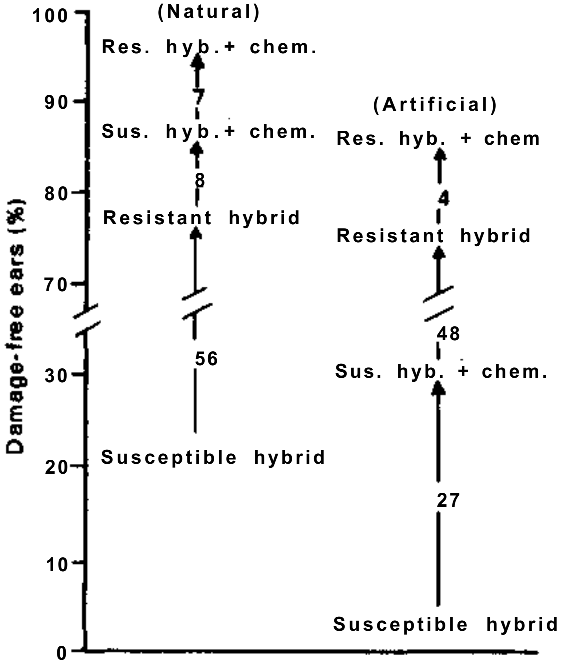

Figure 1. Percentage damage-free ears resulting from combinations of resistant or susceptible sweet corn hybrids with insecticide and natural or artificial infestation of insects 1970. (Source:McMillian et al. 1972.)

Table 1. Percentage earworm damage-free ears of a resistant and susceptible sweet corn hybrid after receiving varying numbers of applications of 1.1 kg/ha of Gardona® WDL4, Tifton, Ga, USA.

No. of applications	Mean % damage-free ears[a] 471-U6 X 81-1 (resistant)	Stowell's Evergreen (susceptible)
7	74.4 a	47.3 c
5	64.5 b	35.0 d
3	60.1 bc	24.2 e
2	52.1 c	23.4 e
1	50.3 c	10.3 f
0	29.7 de	6.6 f

Source : Wiseman et al. (1973).

a. Values followed by the same letter are not significantly different (P=0.05). Percentage based on ratings of 40 ears/ replicate.

on a polyphagous insect such as *Heliothis* spp should result in dramatic suppression of the pest.

In a closely related area of research, the use of chemical plant-growth suppressants in cotton for reducing late-season *Heliothis* spp feeding sites was demonstrated by Thomas et al. (1979). They found in 1978 that larval feeding sites were reduced on an average of 85% and that larval and egg populations were reduced on an average of 64% at five locations. Crop terminators in cotton, such as the plant-growth suppressants, could complement the use of resistant varieties or other control components in eliminating *Heliothis* establishment on late-season foliage and fruit, and consequently reduce contributions to the overwintering populations.

The demonstration of the combination of the resistant cultivar with the use of predator-parasites has been difficult, even though the resistant plants are extremely compatible because resistant cultivars do not greatly affect the natural enemies of the pest species. Wiseman et al. (1976) found that populations of *Orius insidiosus* (Say), a predator on H. *zea* larvae, were higher on the tolerant corn hybrids than on the susceptible hybrids, an indication of the compatibility of the resistance and the predator. Where a high level of resistance significantly reduces the damaging insect population, the effectiveness of the predator or parasite becomes even more difficult to measure, since the host is being quickly reduced, thus preventing parasite buildup. The use of a tolerant or moderately antibiotic cultivar, however, allows full use of the predator-parasite components of an integrated system.

Teetes (1976) and Wiseman and Morrison (1981) indicated that the development of open-headed, partially resistant sorghum hybrids provide a favorable environment for increased predation and parasitism of *H. zea.* The effect of resistance plus biological control is usually not fully appreciated until one observes a compact sorghum head loaded with *H. zea* larvae and accompanying molds.

Since interactions that involve the *Heliothis*-resistant plant and predators or parasites have not been published, the first demonstration of the interactions of greenbug-resistant barley and the parasite *Lysiphlebus testaceipes* (Cresson) on the greenbug (Starks et al. 1972) is shown as an example. They showed that a resistant variety of barley complemented the activity of the parasite in reducing damage to plants and production of greenbugs (Figs. 2 and 3). Starks et al. (1974) later showed the

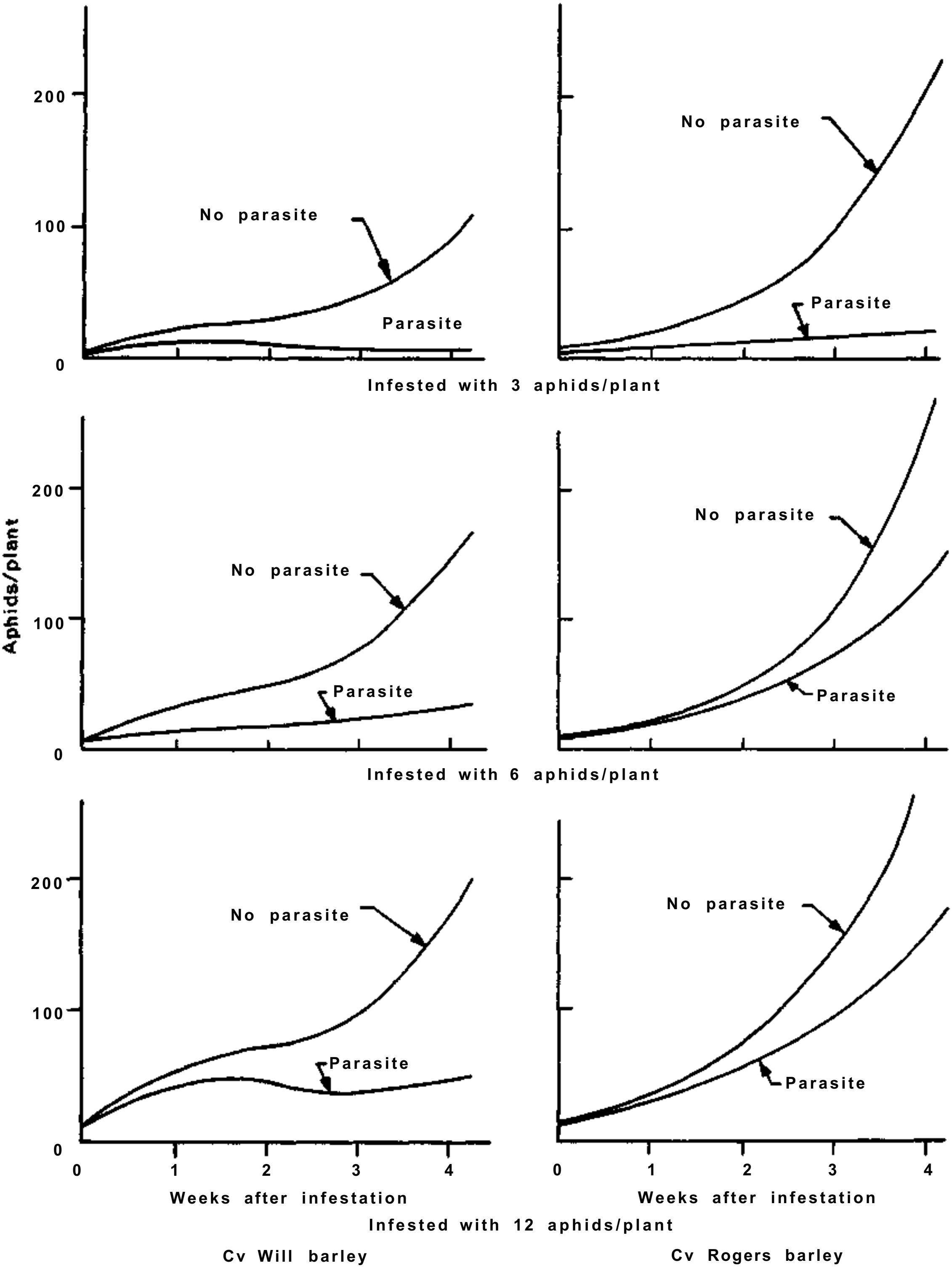

Figure 2. Increase of greenbugs In the absence and presence of one female parasite caged on greenbug-resistant (Will) and susceptible (Rogers) barley; three replications (Source: Starks et al. 1972.)

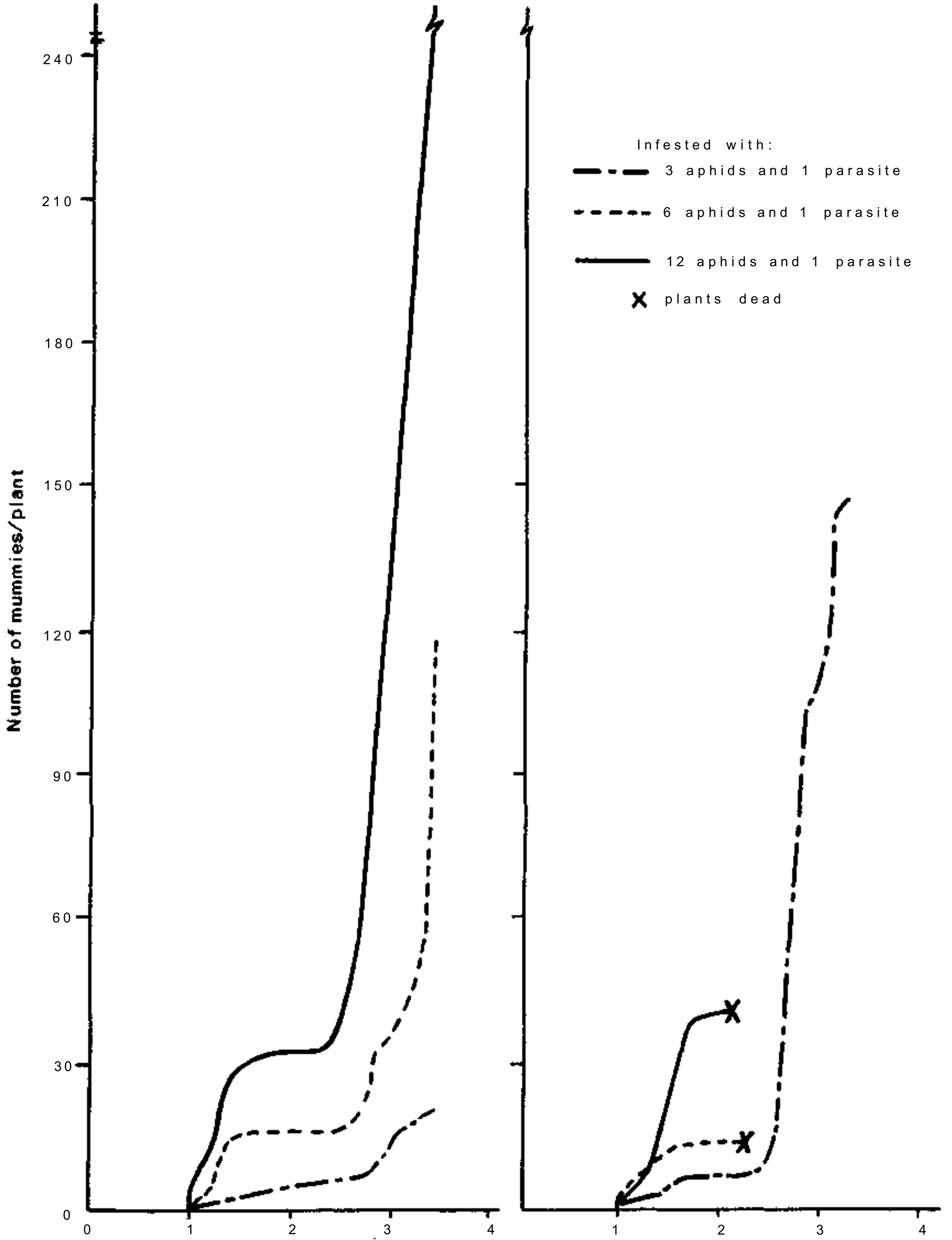

Figure 3. Production of L. testaceipes *mummies on greenbug-resistant (Will) and susceptible (Rogers) barley misted with three populations of greenbugs; three replications (Source: Starks et al. 1972.)*

interactions involving a resistant and susceptible sorghum with the greenbug and the same parasite (Fig. 4). The increase in greenbug abundance was much more pronounced on the susceptible sorghum plus parasites than on the resistant sorghum plus parasites. However, the value of greenbug-tolerant sorghum in combination with natural parasites and predators was reported by Teetes (1976). He reported that the principal mechanism of resistance to the greenbug in the sorghums released by Texas A&M University at that time was tolerance. The economic injury level was raised with little or no disruption of the agroecosystem. This was because the greenbug could attain adequate numbers on these cultivars to maintain beneficial insect populations. Consequently, the beneficials could maintain greenbug density below the economic injury level.

The use of entomopathogenic bacterium, fungus, and virus for control of *H. zea* on soybeans was reported by Ignoffo et al. (1978), where they showed that larval numbers could be reduced by 92 to 100% with a virus, 69 to 96% with a bacterium, and 19 to 77% with a fungus. Mohamed et al. (1978) demonstrated in cage tests the use of *Nomuraea rileyi* (Farl.) Samson on cultivar Dixie Queen sweet

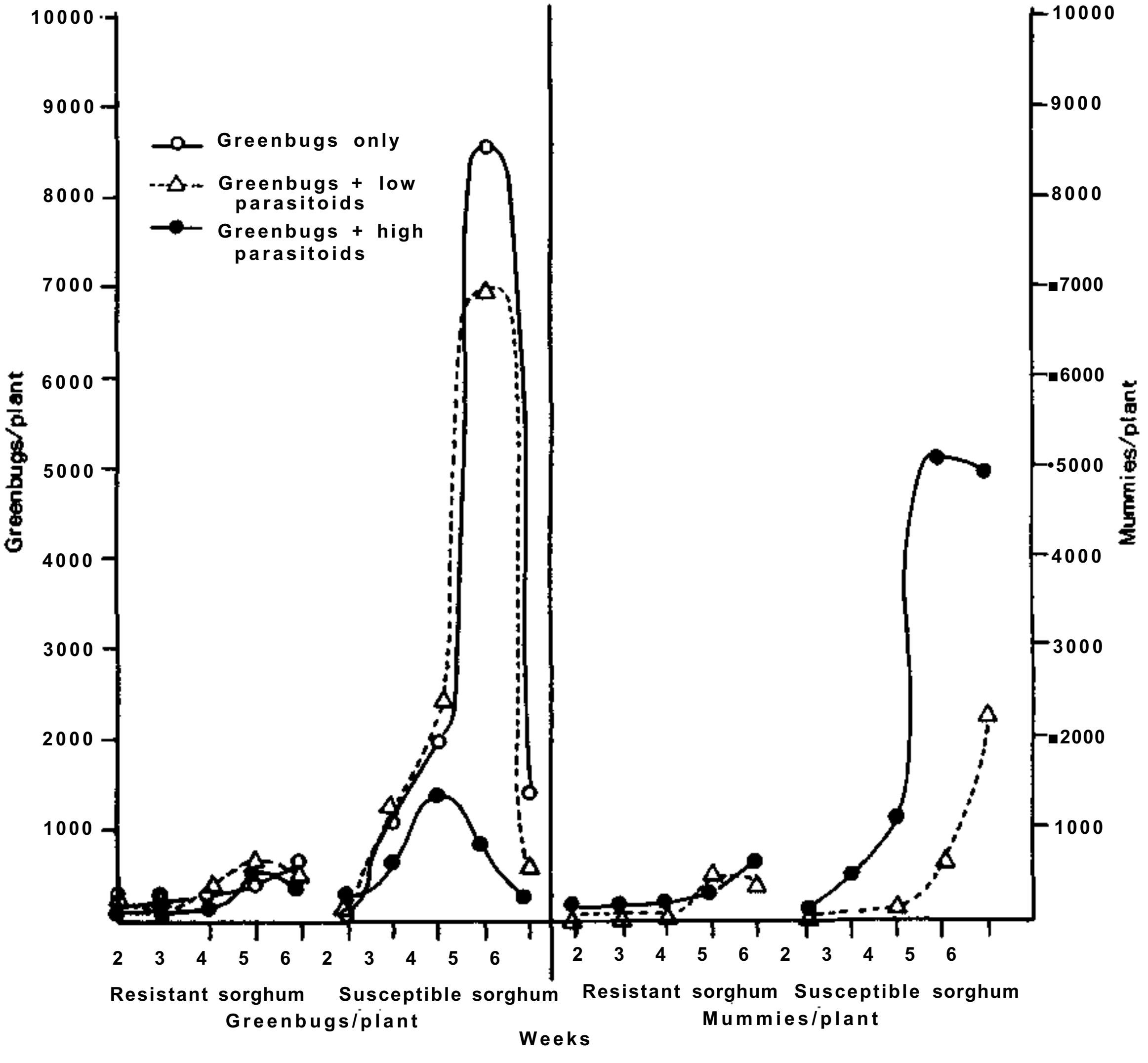

Figure 4. The relationship between various levels of parasitoids and greenbug populations on resistant and susceptible sorghum (Source: Starks et al. 1974.)

corn for control of the corn earworm. Mortality among fourth-instar larvae was 95% in early summer and 88% in mid and late summer. All ears received some damage, but damage *on* the treated ears was significantly lower. The use of resistant varieties in both of these cases would complement the use of insect pathogens, especially when more time is required to attain control of the pest. Tolerant corns should permit the insect to feed longer in the presence of the pathogen, where the antibiotic type of resistance should render the insect more susceptible to the insect pathogens. Fernandez et al. (1969) tested the combinations of resistant cotton (glabrous and nectariless) with a nuclear polyhedral virus against both *H. zea* and *Heliothis virescens* (F.) and found that the control provided was comparable to that obtained with methyl parathion, alone or in combination with ethyl parathion.

The advantage that farmers gain in using cultural control with susceptible varieties would certainly be enhanced when combined with the resistant varieties. The use of early-planted resistant corn hybrids has been recommended for many years in the southern United States as a complementary practice with the resistance to evade damaging corn earworm populations. Adkisson and Dyck (1980) stated that resistant varieties, including those that can be manipulated to evade pest attack, are highly desirable in a cultural control system designed to maintain pest numbers below the economic threshold while preserving the natural enemies. They presented a model to illustrate the impact of a resistant nectariless cotton on a pink bollworm, *Pectinophora gossypiella* (Saunders), population, and then combined this with the early short-season resistant nectariless variety to demonstrate the additional advantages of combining control components such as resistant varieties and cultural control.

Crop-Insect Interactions

Crop-insect interactions may occur at several different levels, i.e., between or among different crop species or between different varieties within a crop species, within a field planted to a resistant variety, and finally at the plant level.

Johnson et al. (1975) reported that many qualitative observations have been made on the interaction of host plants with adult *H. zea.* Host factors included the fitness of the host, variety of the host, number and acreage of the host crops, and the phenological status of the host. Ovipositional response decreased in the following order: corn > tobacco > soybeans > cotton, and preference for corn, soybeans, and cotton was positively correlated with an increase in plant maturity, the peak being at flowering. After flowering, the preference decreases with senescence of the plant. Pretorius (1976) reported somewhat different results with *H. armigera* when he found that, based on net reproductive rates, the best food was cotton buds and leaves, followed by groundnut leaves, sunflower heads, green beans, rose petals, potato leaves, lucerne leaves, grain sorghum panicles, young maize cobs, and tomato leaves. Larvae did not survive on tobacco. Adult production on cotton was about four times as great as on maize. However, Sparks et al. (1971) reported that corn, particularly a multi-eared sweet corn, produced about five times as many corn earworms as cotton.

Some of the basic insect-plant interactions within the crop occur at the plant level. Although many interactions may occur between crops, little research has been initiated in this area on a field basis to demonstrate those insect-crop interactions.The insect and within-crop interactions will be discussed on the basis of the three mechanisms of resistance (Fig. 5).

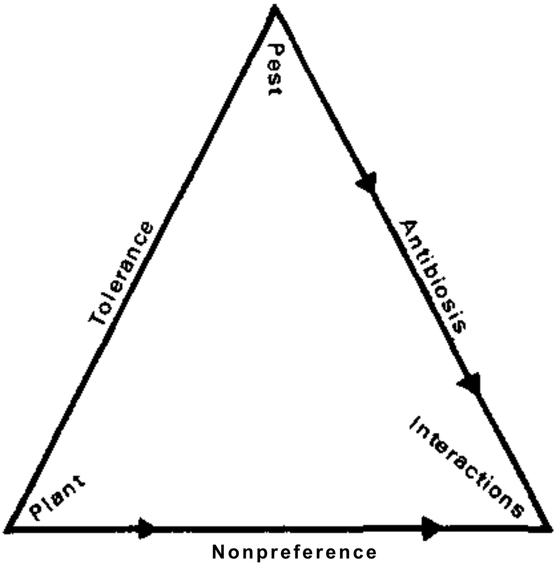

Figure 5. Plant x pest interactions occurring with nonpreference and/or antibiosis mechanisms of resistance.

Tolerance

A crop or plant may be tolerant if it is able to yield well despite infestations that seriously damage susceptible plants (Painter 1968). Interactions between the pest and the resistant variety are not considered to occur, since this phenomenon is entirely a plant response. However, the use of the tolerant variety offers the grower several alternative methods of pest control: (1) pesticides at reduced rates (McMillian et al. 1972; Wiseman et al. 1973); (2) parasites or predators (Starks et al. 1972, 1974); (3) cultural control; and (4) insect pathogens (Fernandez et al. 1969). Therefore, a number of interactions may occur when control components are added to the resistant variety in controlling the pest, especially depending upon whether the variety has low, intermediate, or high tolerance to the insect.

Nonpreference

A crop or variety may be nonpreferred when it possesses plant characters that stimulate insect responses resulting in a particular plant or variety being used less than another for oviposition, for food, for shelter, or for combinations of the three (Painter 1951).

A number of reports exist that deal with nonpreference and *Heliothis* interactions (Fig. 6). Webster (1975) cited a number of papers that reported research on the influence of plant pubescence on *Heliothis-crop* interactions. Lukefahr et al. (1971) showed oviposition suppression of more than 60% on *Heliothis* spp from the use of nonpreferred glabrous cotton strains. Any eggs laid were also easily dislodged; this, plus the nonpreference, was associated with the overall resistance effect. Robinson et al. (1980) reported that significantly fewer *H. virescens* eggs were laid on smooth-leaf cotton than on pubescent cotton, whether or not the tobacco budworm had a choice of hosts. Cosenza and Green (1979) found that the resistance of the fruit of a breeding line of tomato (entry 38) was nonpreference by a 10:1 ratio over Chico III. Leuck et al. (1977) reported that *H. zea* laid significantly fewer eggs (11.8 vs 88.2%) on foliage of a trichomeless near-isogenic Tift 23S (tr tr) pearl millet, *Pennisetum americanum* (L.) Leake, than on pubescent foliage of Tift 23H (Tr Tr) (Fig. 7). Panda and Daugherty (1975) demonstrated that *H. armigera* showed nonpreference of dense pubescent soybean leaves by a ratio of more than 3:1 after 24 h exposure. Wiseman et al. (1976b) first found that Antigua 2D-118 possessed leaf-feeding resistance to *H. zea.* Then Widstrom et al. (1979) showed (Fig. 8) that Antigua 2D-118 had fewer trichomes than Cacahuacintle, a susceptible entry. They also found (Table 2) that about 25% fewer eggs were deposited on Antigua 2D-118 leaves.

Wiseman et al. (1978b) studied some of the corn earworm larvae behavioral movements on susceptible and resistant corn. They found that due to

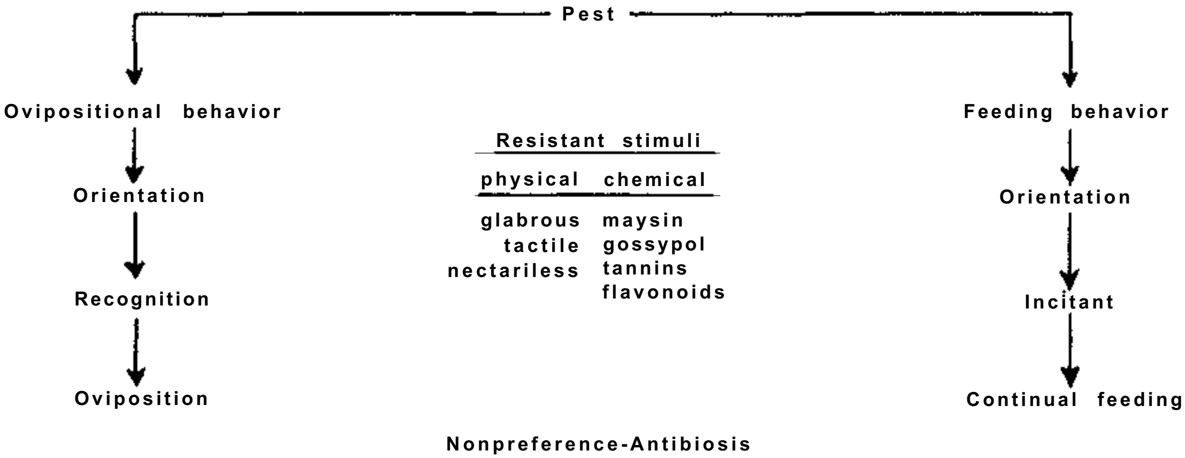

Figure 6. Illustrations of some of the Interactions that occur with nonpreference and antibiosis as mechanisms of resistance.

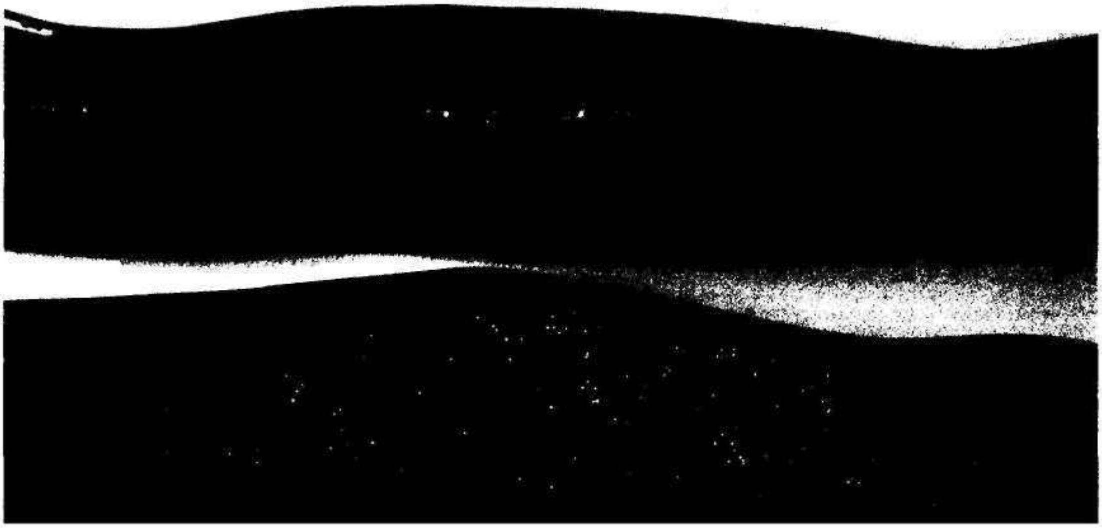

Figure 7. **Heliothis zea** *oviposition on pearl millet; A: 23S (trtr);B:23S(TrTr). (Source: Leuck et al. 1977.)*

a lack of significant thigmotactic stimuli by the susceptible corn, larvae penetrated the corn silks deeper before initial feeding began. Conversely, on the resistant silks, larvae penetrated only slightly into the silk channel before feeding was initiated (Table 3). On the two resistant corns, one tolerant and the other antibiotic, initial movement was similar. However, the tolerant corns possessed a tight silk channel with a large amount of silk that maintained high moisture over the period of larval development. These factors, combined with the absence of antibiotic chemicals, contributed to the fact that the silks were consumed by corn earworms, resulting in little, if any, ear damage (Wiseman et al. 1977).

Other cotton plant morphological characters affect *Heliothis* spp oviposition and eventually are less damaged (Maxwell et al. 1972). In field studies, Lukefahr et al. (1965) found that the absence of extrafloral nectaries on the cotton plant (nectariless) caused as much as a 64% reduction in egg laying by *Heliothis* spp moths. When both glabrous and nectariless characters were combined and evaluated, reductions of up to 80% in eggs of *Heliothis* spp were found in 1969 (Lukefahr et al. 1971).

Antibiosis

A plant or variety may be antibiotic if it either possesses a material injurious to the pest that feeds on it or if the plant part fed on lacks some necessary nutrient (Painter 1968). Antibiosis in plants may be evaluated by several insect responses: (1) death of early instars; (2) decreased larval weights; (3) prolonged life; (4) failure to pupate; and (5) less fecundity.

A number of examples have been cited of antibiosis influencing insect-plant interactions. Panda and Daugherty (1975) reported that resistant soybeans had an antibiotic effect on corn earworm development. When lyophilized green pod material of susceptible and resistant (antibiosis type) soybeans was used in a diet for corn earworm, developmental time of larvae fed on the resistant type was more than twice as long as that of larvae fed on the susceptible type.

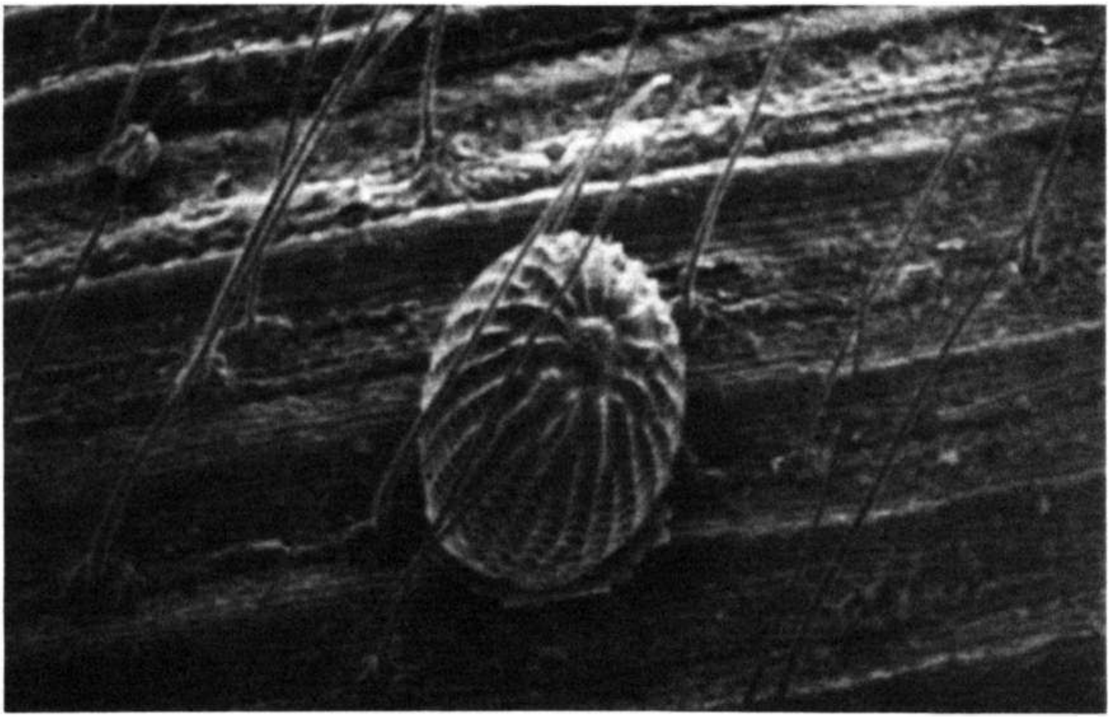

Figure 8. H. zea *egg placement in relation to leaf trichomes. (Source: Widstrom et al. 1979.)*

Table 2. Ovipositional placement and numbers of corn earworm eggs *per* leaf[a] on leaves of two exotic corn selections.

	Selection		
Leaf region	Ant	Cac. C	Mean
Tip	0.77 a	1.00 a	0.88 a
Middle	1.75 b	2.35 b	2.05 b
Base	0.62 a	0.91 a	0.77 a

Source : Widstrom et al. (1979).

a. Means within any column followed by different letters are significantly different at the 1% level of probability.

Lukefahr and Martin (1966) and Shaver and Lukefahr (1969) showed the effects of cotton pigments (gossypol and flavonoid pigments) on the development of *Heliothis* spp. Less than 30% of the larvae of *H. zea* and *H. virescens* reached the pupal stage when the diet contained 0.2% gossypol. Quercetin inhibited the growth of *H. zea* larvae, and killed more than 70% of *H. virescens* larvae.

Kennedy and Yamamoto (1979) using chloroform as a solvent, extracted from the foliage of a wild tomato, *Lycopersicon hirsutum* F. *glabratum,* PI-134417, a concentrate that was toxic to *H. zea* larvae; 2 hours exposure to the extract killed 100% of the larvae. Williams et al. (1980) identified the extract as 2-tridecanone and labeled it as a naturally occurring insecticide. It appears that the 2-tridecanone is the chemical basis of the antibiosis found in this wild tomato. Campbell and Duffy (1979) found that a -tomatine, a resistance chemical found in tomatoes, was toxic to both *H, zea* and to an endoparasite, *Hyposoter exiguae* (Viereck), of *H. zea.* Thus, the potential incompatibility of plant resistance and certain biological controls exists. However, this appears to be only an isolated case of incompatibility.

Recent research on *H. zea* and corn has shown that antibiosis resistance is present in the silks of Zapalote Chico #2451 (Wiseman et al. 1976a, 1977), and that the resistance is high enough to reduce corn earworm numbers by four-fold (Wiseman et al. 1978a). Waiss et al. (1979) discovered a

Table 3. Average location[a] of corn earworm larvae on both resistant (R) and susceptible (S) corns after 3, 6, 9, and 12 days Infestation in 1975, Tifton, Ga, USA.

Corn cultivar	Days after infestation[b]			
	3	6	9	12
Zapalote Chico #2451 (R)	0.83 a	0.83 a	0.99 a	1.29 a
471-U6 X 81-1 (R)	1.03 a	1.21 a	1.67 ab	2.59 b
Dixie 18 (R)	0.93 a	1.17 a	1.73 b	2.13 b
Asgrow A204 (S)	1.24 a	2.43 b	3.27 c	4.13 c
Stowell's Evergreen (S)	1.03 a	3.32 c	5.24 d	5.07 d
Ioana (S)	2.55 b	5.03 d	6.09 e	7.05 e

Source: Wiseman et al. (1978)

a. Location of earworm larvae was based on 0 = no infestation, 1 = larvae in upper 1/3 of silk channel, 2 = larvae in the mid 1/3 of silk channel, 3 = larvae in lower 1/3 of silk channel. 4 = larvae on ear tip feeding on silk, 5 = larvae on ear tip feeding on ear, and 6-n = larval penetration down ear at increments of 1 cm.

b. Means of earworm location within any sample date followed by the same letter are not significantly different at P = 0.05. Means include an average of 10 ears/replication for three separate plantings in 1975.

flavone glycoside, called maysin, in the silks of Z. Chico that retards corn earworm larval growth. When the larvae enter the silks of Z. Chico, they begin to feed near the ear tip; some of the larvae "girdle" the silks, causing the outer silks to drop from the ear, leaving the larvae exposed to the environment. Generally, the silks have deteriorated in quality by this time and the larvae probably crawl out of the ears and die. This condition may be a result of a combination of antibiosis and nonpreference. Laboratory data (unpublished) showed that larvae placed on silks of Z. Chico and in the near vicinity of susceptible silks will migrate to the more acceptable silks. Thus, nonpreference could very well be a factor in the overall resistance of Z. Chico.

Plant Nutrition and Plant Induction

A number of researchers have reported the influence of plant nutrition on insect oviposition and feeding responses. Leuck et al. (1974) stated that micronutrients or trace elements in soils may produce some important ecological and biological effects induced in crop plants and insect populations—effects that are often attributed to such expressions of host-plant resistance as nonpreference, antibiosis, or tolerance. Indeed plant nutrients may influence the search for plants resistant to insects and certainly could have an important effect on management of insect populations.

Jermy et al. (1968) demonstrated that host induction could affect host preference by *H. zea* larvae. They found that the induced preference was specific for the inducing plant and that it was not eliminated by larval molts or subsequent feeding. The implications here are numerous, but in the case of *Heliothis,* the crop on which larvae have developed is not available for the next generation (e.g., corn *or* early-season hosts). Therefore, preference induction would have limited implications for many situations involving *Heliothis.* However, the multihost *Heliothis* could be drastically affected biologically (antibiosis) on one crop and then completely recover during the next generation from the previous effects because it developed on a completely different host. *Heliothis* management then will necessitate plant resistance to be developed in several crop species. On the other hand, Takata (1961) reported that in the cabbage butterfly, *Pieris rapae crucivora* (Boisduval), rearing for successive generations on the same host influenced the ovipositional preference of the adults. Adults that were reared on cabbage for several successive generations tended more and more to avoid cabbage for oviposition. If this situation could be shown for *Heliothis,* then the development of monocultures in certain areas might prove beneficial in

Heliothis ovipositional preference and eventual population reduction.

Conclusions

Several aspects and uses of an insect-resistant variety have been discussed along with the implications of interactions that could occur, especially when nonpreference and antibiosis mechanisms of resistance are present in the crop variety. Dahms (1972a) gave several theoretical examples of effects of resistant plants on a developing aphid population. With an initial infestation of one to two aphids per plant, and assuming no nymphal mortality, an adult reproduction rate of one per day for 20 days, and nymphal maturation in 10 days, twice as many aphids would survive on a susceptible cultivar in comparison to a nonpreferred one after 50 days. Then as one example of many on antibiosis, he showed the effect of nymphal mortality at the end of 50 days. Assuming 10% mortality, the antibiosis would result in ca. 30% fewer insects, a 50% mortality would result in over 90% fewer insects, but it would require in excess of 90% mortality to prevent an insect increase.

Single-factor approaches in the management of *Heliothis* spp are apparently inadequate. However, the wise use of the resistance factors or mechanisms within each crop, coupled with the timely manipulations of other compatible components of integrated pest management should suppress insect density levels below those causing economic injury. The development and use of resistant cultivars will play an important role in the future development of plant protection against *Heliothis* spp, and especially in the implementation of integrated pest management systems.

References

ADKISSON, P.L., and DYCK, V.A. 1980. Resistant varieties in pest management systems. Pages 233-251 *in* Breeding plants resistant to insects, eds. F.G. Maxwell and PR. Jennings, New York, USA: Wiley. 683 pp.

CAMPBELL, B.C., and DUFFEY, S.S. 1979. Tomatine and parasitic wasps: Potential incompatibility of plant antibiosis with biological control. Science 205: 700-702.

CATE, J.R., BOTTRELL, D.G., and TEETES, G.L. 1973. Management of the greenbug on grain sorghums. 1. Testing foliar treatments of insecticides against greenbug and corn leaf aphid. Journal of Economic Entomology 66:945-951.

GOSENZA, G.W., and GREEN, H.B. 1979. Behavior of the tomato fruitworm, *Heliothis* zea (Boddie) on susceptible and resistant lines of processing tomatoes. Hortscience 14:171-173.

DAHMS, R.G. 1972a. The role of host plant resistance in integrated insect control. Pages 152-167 *in* The control of the shoot fly, eds. M.G. Jotwani and W.R. Young. New Delhi, India: Oxford and IBH.

DAHMS, R.G. 1972b. Development of crop resistance to insects. Journal of Environmental Quality V. 28-34.

FERNANDEZ, AT., GRAHAM, H.M., LUKEFAHR, M.J., BULLOCK, H.R., and HERNANDEZ, N.S., Jr. 1969. A field test comparing resistant varieties plus applications of polyhedral virus with insecticides for control of *Heliothis* spp. and other pests. Journal of Economic Entomology 62:173-177.

GROSS, H.R., Jr., WISEMAN, B.R., and McMILLIAN, W.W. 1976. Comparative suitability of sweet corn for establishment by larvae of the corn earworm. Environmental Entomology 5: 955-958.

HOLCOMB, R.W. 1970. Insect control: alternatives to the use of conventional pesticides. Science 168: 456-460.

HORBER, E. 1972. Plant resistance to insects. USDA Agricultural Science Review 10: 1-18.

IGNOFFO, C.M., HOSTETTER, D.L., BIEVER, K.D., GARCIA, C., THOMAS, G.D., DICKERSTON, W.A., and PINNELL, R. 1978. Evaluation of an entomopathogenic bacterium, fungus, and virus for control of *Heliothis zea* on soybeans. Journal of Economic Entomology 71 : 165-168.

JERMY, T., HANSON, F.E., and DETHIER, V.G. 1968. Induction of specific food preferences in lepidopterous larvae. Entomologia Experimental et Applicata 11:211 -230.

JOHNSON, M.W., STINNER, R.E., and RABB, R.L. 1975. Ovipositional response of *Heliothis zea* (Boddie) to its major hosts in North Carolina. Environmental Entomology 4: 291 -297.

KENNEDY, G.G., and YAMAMOTO, R.T. 1979. A toxic factor causing resistance in a wild tomato to the tobacco hornworm and some other insects. Entomologia Experimentalis et Applicata 26: 121-126.

KOGAN, J., SELL, D.K., STINNER, RE., BRADLEY, J.R. Jr., and KOGAN, M. 1978. The literature of arthropods associated with soybeans. V. A bibliography of *Heliothis zea* (Boddie) and *H. virescens* (F.) (Lepidoptera: Noctuidae). International Agriculture Publications INTSOY Series 17, University of Illinois, Urbana, Ill, USA. 242 pp.

LEUCK, D.B., WISEMAN, B.R., and McMILLIAN, W.W. 1974. Nutritional plant sprays: effect on fall armyworm feeding preferences. Journal of Economic Entomology 67: 58-60.

LEUCK, D.B., BURTON, G.W., and WIDSTROM, N.W. 1977. Insect oviposition and foliage feeding resistance in pearl millet. Journal of the Georgia Entomological Society 12: 138-140.

LUGINBILL, P., Jr. 1969. Developing resistant plants—the ideal method of controlling insects. U.S. Department of Agriculture production research report 111, Washington, DC, USA. 14 pp.

LUGINBILL, P., Jr., and KNIPLING, E.F. 1969. Suppression of wheat stem sawfly with resistant wheat. U.S. Department of Agriculture production research report 107, Washington DC, USA. 9 pp.

LUKEFAHR, M.J., HOUGHTALING, J.E., and GRAHAM, H.M. 1971. Suppression of *Heliothis* populations with glabrous cotton strains. Journal of Economic Entomology 64: 486-488.

LUKEFAHR, M.J., and MARTIN, D.F. 1966. Cotton-plant pigments as a source of resistance to the bollworm and *tobacco* budworm. *Journal* of Economic Entomology 59: 176-179.

LUKEFAHR, M.J., MARTIN, D.F., and MEYER, J.R. 1965. Plant resistance to five Lepidoptera attacking cotton Journal of Economic Entomology 58: 516-518.

MAXWELL, F.G. 1972. Host plant resistance to insects—nutritional and pest management relationships. Pages 599-609 *in* Insect and mite nutrition. Amsterdam: North Holland.

MAXWELL, F.G., JENKINS, J.N., and PARROTT, W.L. 1972. Resistance of plants to insects. Advances in Agronomy 24: 187-265.

McMILLIAN, W.W., WISEMAN, B.R., WIDSTROM, N.W., and HARRELL, E.A. 1972. Resistant sweet corn hybrid plus insecticide to reduce losses from corn earworms. Journal of Economic Entomology 65: 229-231.

MOHAMED, A.K.A., BELL, J.V., and SIKOROWSKI, P.P. 1978. Field cage tests with *Nomuraea rileyi* against corn earworm larvae on sweet corn. Journal of Economic Entomology 71: 102-104.

PAINTER, R.H. 1951. Insect resistance in crop plants. New York, USA: Macmillan. 520. pp.

PAINTER, R.H. 1966. Plant resistance as a means of controlling insects and reducing their damage. Pages 138-148 *in* Pest control by chemical, biological, genetic, and physical means—A symposium. USDA-ARS-33-110, U.S. Department of Agriculture, Washington, DC, USA. 214 pp.

PAINTER, R.H. 1968. Crops that resist insects provide a way to increase world food supply. Kansas Agricultural Experiment Station Bulletin 520, Manhattan, Kans, USA. 22 pp.

PANDA, N., and DAUGHERTY, D.M. 1975. Note on the antibiosis factor of resistance to corn earworm in pubescent genotypes of soybean. Indian Journal of Agricultural Sciences 45: 68-72.

PRETORIUS, L.M. 1976. Laboratory studies on the development and reproductive performance of *Heliothis armigera* (Hubn.) on various food plants. Journal of the Entomological Society of South Africa 39: 337-343.

REFAI, A. EL. EL-GUINDY, M.A., and ABDEL-SATTAR, M.M. 1979. Variation in sensitivity to insecticides of *Heliothis armigera* Hbn. fed on different host plants Zeitschrift fur 'Angewandte Entomologie 88: 107-111.

ROBINSON, S.H., WOLFENBARGER, D.A., and DILDAY, R.H. 1980. Antixenosis of smooth leaf cotton to the ovipositional response of tobacco budworm. Crop Science 20: 646-649.

SCHALK, J.M., and RATCLIFFE, R.H. 1976. Evaluation of ARS program on alternative methods of insect control: host plant resistance to insects. Bulletin of the Entomological Society of America 22: 7-10

SHAVER, T.N., and LUKEFAHR, M.J. 1969. Effect of flavonoid pigments and gossypol on growth and development of the bollworm, tobacco budworm and pink bollworm. Journal of Economic Entomology 62; 643-646.

SPARKS, A.N., WISEMAN, B.R., and McMILLIAN, W.W. 1971. Production of corn earworms on several hosts in field cages. Journal of Economic Entomology 64: 540-541.

STARKS, K.J., MUNIAPPAN, R., and EIKENBARY, R,D. 1972. Interaction between plant resistance and parasitism against the greenbug on barley and sorghum. Annals, Entomological Society of America 65: 650-655.

STARKS, K.J., WOOD, E.A. Jr., and BURTON, R.L. 1974. Relationships of plant resistance and *Lysiphlebus testaceipes* to population levels of the greenbug on grain sorghum. Environmental Entomology 3: 950-952.

TAKATA, N. 1961. Studies on the host preference of the common cabbage butterfly, *Pieris rapae crucivora* (Boisduval). XII. Successive rearing of the cabbage butterfly larva with certain host plants and its effect on the oviposition preference of the adult. Japan Journal of Ecology 11: 147-154.

TEETES, G.L. 1976. Integrated control of arthropod pests of sorghum. Pages 24-41 *in* Proceedings, US-USSR Symposium: The integrated control of arthropod, disease and weed pests of cotton, grain sorghum and deciduous fruit. Texas Agricultural Experiment Station miscellaneous publication 1276, College Station, Tex, USA. 216 pp.

TEETES, G.L. 1980. Breeding sorghum resistant to insects. Pages 457-485 *in* Breeding plants resistant to insects, eds. F.G. Maxwell and P.R. Jenning. New York, USA; Wiley. 683 pp.

THOMAS, R.O., CLEVELAND, T.C., and CATHEY, G.W. 1979. Chemical plant growth suppressants for reducing late-season cotton bollworm-budworm feeding sites. Crop Science 19:861-863.

WAISS, A.C., Jr., CHAN, B.G., ELLIGER, C.A., WISEMAN, B.R., McMILLIAN, W.W., WIDSTROM, N.W., ZUBER, M.S., and KEASTER, A.J. 1979. Maysin, a flavone glycoside from corn silks with antibiotic activity toward corn earworm. Journal of Economic Entomology 72:256-258.

WEBSTER, J.A. 1975. Association of plant hairs and insect resistance—an annotated bibliography. U.S. Department of Agriculture miscellaneous publication 1297, Washington DC, USA. 18 pp.

WIDSTROM, N.W., McMILLIAN, W.W., and WISEMAN, B.R. 1979. Ovipositional preference of the corn earworm and the development of trichomes on two exotic corn selections. Environmental Entomology 8:833-839.

WILLIAMS, W.G., KENNEDY, G.G., YAMAMOTO, R.T., THACKER, J.D., and BORDNER, J. 1980. 2-tridecanone: A naturally occurring insecticide from the wild tomato *Lycopersicon hirsutum* F. *glabratum.* Science 207:888-889.

WISEMAN, B.R., and MORRISON, W.P. 1981. Components for management of field corn and grain sorghum insects and mites in the United States. USDA-ARS SR Publication A106.12: ISSN0193-3779, U.S. Department of Agriculture, Washington, DC, USA.

WISEMAN, B.R., McMILLIAN, W.W., and WIDSTROM, N.W. 1972. Tolerance as a mechanism of resistance in corn to the com earworm. Journal of Economic Entomology 65:835-837.

WISEMAN, B.R., HARRELL, E.A., and McMILLIAN, W.W. 1973. Continuation of tests of resistant sweet corn hybrid plus insecticides to reduce losses from corn earworm. Environmental Entomology 2:919-920.

WISEMAN, B.R., McMILLIAN, W.W., and WIDSTROM, N.W. 1976a. Feeding of corn earworm in the laboratory on excised silks of selected corn entries, with notes on Onus *insidiosus.* Florida Entomologist 59-305-308.

WISEMAN, B.R., WIDSTROM, N.W., McMILLIAN, W.W., and PERKINS, W.D. 1976b. Greenhouse evaluations of leaf-feeding resistance in corn to the corn earworm. Journal of the Georgia Entomological Society 11:63-67.

WISEMAN, B.R., WIDSTROM, N.W., and McMILLIAN, W.W. 1977. Ear characteristics and mechanisms of resistance among selected corns to the corn earworm. Florida Entomologist 60:97-103.

WISEMAN, B.R., McMILLIAN, W.W., and WIDSTROM, N.W. 1978a. Potential of resistant com to reduce corn earworm production. Florida Entomologist 61:92.

WISEMAN, B.R., WIDSTROM, N.W., and McMILLIAN, N.W. 1978b. Movement of corn larvae on ears of resistant and susceptible corns. Environmental Entomology 7:777-779.

A Review of the Problems, Progress, and Prospects for Host-Plant Resistance to *Heliothis* Species

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Abstract

The development of insecticidal resistance in the 1960s led to increased support tor host-plant resistance (HPR) projects. As a result, sources of plant resistance in all the major crops were identified. However, identification of resistance factors was based on laboratory studies, and work never progressed to where field suppression of Heliothis *populations was demonstrated. A brief review, with references to the major works and their impact on the field of host-plant resistance, is presented. The prospects for use of host-plant resistance in crops with high production inputs and high fixed costs are not good. The synthetic pyrethroids are highly effective and result in stable yields; their use requires very little management, and in such crops, these chemicals will probably dominate the pest-control strategies. Crops of low cash value or those grown in regions where pesticides are not part of the production system are the ones in which the use of host-plant resistance is thought to have a potential impact.*

Résumé

Revue des problèmes, progrès et perspectives de la résistance de la plante-hôte à Heliothis *spp: Le développement d'une résistance aux insecticides dans la décade 1960 a entraîné un plus vif appui aux projets visant à augmenter la résistance des plantes-hôtes. Aussi, des sources de résistance des plantes ont été identifiées chez toutes les principales cultures. Cependant, l'identification des facteurs de résistance a été basée sur des études en laboratoire et la recherche n'a pas atteint le stade où la réduction des populations d'*Heliothis *fut démontrée sur le terrain. Une brève revue des principales recherches est présentée, avec leur impact dans le domaine de la résistance des plantes-hôtes. Les perspectives d'utilisation de la résistance des plantes-hôtes chez des cultures ayant de forts intrants et des coûts fixes élevés ne sont pas bonnes. Les pyréthrinoides s'avèrent extrêmement efficaces et permettent d'avoir des rendements stables. Leur utilisation requiert fort peu de gestion et pour de telles cultures, ces produits chimiques seront probablement la plus importante composante des stratégies de lutte. Pour les cultures de peu de valeur et celles des régions où les pesticides ne sont pas une composante des systèmes de production, l'utilisation de la résistance de la plante-hôte devrait avoir un impact potentiel.*

The genus *Heliothis* probably contains the most important insect complex in the world trom the standpoint of crop loss. The noctuid pest species of this complex exhibit wide host ranges, high fecundity, and ability to move long distances, thereby spanning several crops and seasons. One or more species can cause economic losses to soybeans, cotton, tobacco, corn, tomato, sorghum, groundnut, and many other plants, both wild and cultivated, on which they are able to reproduce.

As stated by Kogan et al. (1978) the principle of host-plant resistance was first applied against *Heliothis zea* in corn, since this was the major crop affected by *Heliothis* spp in the United States. This work identified several plant characteristics that resulted in partial resistance. However, the efficacy and convenience of insecticides resulted in a de-emphasis of host-plant resistance studies. When control of *H. virescens* became extremely difficult with recommended insecticides in the early 1960s, interest in host-plant resistance was renewed, as it appeared that this may be the only means by which populations could be reduced to subeconomic levels.

The resistance to pesticides in *Heliothis* spp cor-

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International Crops Research Institute tor the Semi-Arid Tropics. 1982. Proceedings of the International Workshop on *Heliothis* Management, 15-20 November 1981, Patancheru, A.P., India.

responded with the awareness of environmental problems associated with high pesticide use, resulting in support for host-plant resistance projects. Reported in this paper are the results achieved against *Heliothis* in some of the major crops attacked by *Heliothis* spp.

Soybeans

Soybeans are grown in several countries; however, the USA and Brazil are the major commercial producers of this crop.

Heliothis zea and *H. virescens* are pests of soybeans, and are commonly referred to as podworms; however, larvae are able to complete development in plants that have not set pods. In these cases, the foliar damage does not appear to result in yield losses, as plants can easily compensate for the damage at this stage.

Cultural practices such as narrow-row planting (75 cm) result in a closed canopy when pods are formed, and *Heliothis* have never been recorded as damaging pods after the canopy has closed (J.R. Bradley personal communication).

However, when plant growth is reduced, due to late planting or drought, *Heliothis* can cause losses. The early instars feed on foliage, the later ones (third instar onwards) on pods.

The economic threshold for *Heliothis* in soybean has been established at 6.5 larvae per meter of row (Mueller and Engroff 1980).

Clark et al. (1972) found that two plant introductions into the USA reduced populations of H. *zea* on soybean. PI-171451 showed reduced oviposition, presumably due to nonpreference; PI-227687 showed the lowest percentage of pod damage-even though oviposition was heavy—probably because of antibiosis.

Beland and Hatchett (1976) reported on feeding trials of *H. zea* developing on leaves of PI-229358, which gave significant reductions in larval growth over the control, cv Davis.

Dreyer et al. (1979) isolated pinitol from the leaves of both PI-229358 and cv Davis, and the authors believed this compound may be involved in resistance to *H. zea* as well as the Mexican bean beetle *(Epilachna varivestis* Mul.). However, other compounds are probably also involved, as the difference between the susceptible standard and resistant line was very small and concentrations required to reduce growth by 50% seem unusually large.

Vegetables

In an excellent review of insect resistance in vegetable and fruit crops (Kennedy 1978), tomato was the only crop mentioned as having any known resistance to *Heliothis.*

Both *H. zea* and *H. virescens* attack tomato and are called tomato fruitworms. The females deposit the eggs on foliage, and the early instars feed on foliage before attacking the fruit. Fery and Cuthbert (1973,1974) found that plant density, vine size, and earliness are all associated with percentage of damaged fruit. When the variability due to these factors was considered, no differences were found when 1030 lines were evaluated. However, the same authors (1975) reported high levels of antibiosis in the wild *Lycopersicon hirsutum,* f. *glabratum.* Intact plants and excised foliage gave similar results. This species was reported to be compatible with cultivated tomatoes, so presumably this source of resistance could be utilized in a host-plant resistance breeding program.

Lange and Bronson (1981) in their review of insect pests on tomato list an economic threshold of 0.25 to 0.50% damaged green fruit for commercial tomato production. If a commercial crop can tolerate so little damage, it seems unlikely that a resistant tomato cultivar can be developed, as near-immunity to insect attack would be required.

Cotton

It has been' estimated that nearly 30% of all pesticides manufactured in the world are used to control *Heliothis* spp on cotton. So successful were chemical pesticides in increasing and stabilizing yields, that for approximately 15 years no other method of controlling cotton insects was given serious consideration. By 1965, high levels of resistance to both the chlorinated hydrocarbons and carbamate insecticides were found (Lowry 1966), and by 1970 *H. virescens* field populations were exhibiting two- to five-fold levels of resistance to methyl parathion (Wolfenbarger et al. 1971). Parallel situations had also occurred in Australia and Central and South America. However, even before 1965, it became obvious that alternative methods of population suppression were necessary, and research into host-plant resistance received support.

An evaluation of several plant characters in cotton showed three that resulted in measurable levels of population suppression.

Morphological Characters

Nectariless

Cotton cultivars have conspicuous nectary glands on the veins and beneath the flowers and bolls; these nectaries secrete copious amounts of sugar, which furnish food for *Heliothis* adults. It has been demonstrated that if adults are unable to obtain food, their longevity and fecundity are reduced by approximately 50% (Lukefahr and Martin 1964). A wild cotton from Hawaii lacks this extrafloral nectary system and this character was transferred into *Gossypium hirsutum* by Meyer and Meyer (1961).

Numerous cage and field tests have been conducted to evaluate this character. In cage tests, where the movement of *Heliothis* can be regulated, the number of eggs and larvae is reduced by approximately 50%. However, in field plots of about 2 ha, there is no measurable reduction in *Heliothis* populations. These differences are probably due to the flight habits of *Heliothis* adults, as feeding can take place at sites widely separated from ovipositional sites. If nectariless cotton was grown over large areas (over 40 ha), reduction may be expected.

Indirectly, the nectariless character does result in *Heliothis* suppression, as it effectively lowers plant bug populations. The chemical control of these early-season bugs eliminates *Heliothis* predators, which then removes some of the constraints on *Heliothis* population (Schuster et al. 1976).

Glabrous

Most commercial varieties of cotton grown in the USA have approximately 2000 trichomes per square inch (about $310/cm^2$) on the terminal leaves, which is the preferred oviposition site of *Heliothis* spp on cotton. If the trichome number is reduced to 200/square inch ($30/cm^2$), at least a 50% reduction in egg and larval populations (Table 1) can be achieved (Lukefahr et al. 1966, 1971, 1975). While the value of this character for *Heliothis* suppression has been demonstrated, it is known to increase susceptibility to plant bugs (Schuster et al. 1976) and leaf-hoppers (Parnell et al. 1949). However, not all glabrous lines show the same degree of susceptibility to these pests, and further research is needed to evaluate additional glabrous sources.

Early

The concept of earliness as a means of escaping *Heliothis* injury was first discussed by Pearson (1958). The value of this characteristic has been demonstrated by Walker and Niles (1971) and by

Table 1. Suppression of Heliothis spp in field tests with glabrous cotton.

		Heliothis/ha	
Year	Cotton type	No. of eggs	No. of larvae
1965	Commercial	43 037	56 078
	Glabrous	23 776	30 430
1966	Commercial	102 539	
	Glabrous	77 108	
1967	Commercial	31 951	5 497
	Glabrous	12 080	3 477
1968	Commercial	41 425	42 905
	Glabrous	16 106	22 953
1969	Commercial	74 487	69 137
	Glabrous	11 772	20 869
Reduction (%)		52	58

Heilman et al. (1977). These early-fruiting types have the ability to set a crop in a shorter period of time than conventional varieties and can also compensate for fruiting forms that are lost due to insect injury. The most successful program in developing these varieties is Texas A & M University's TAMCOT Cotton Program (Bird et al. 1968). Basically, these cottons mature sufficiently early to escape the last, and often most damaging, generation of *Heliothis* attack. The yield is comparable to full-season cultivars.

Plant Chemistry

Gossypol

All cotton species contain a terpenoid aldehyde, gossypol, a compound known to be toxic to warm-blooded animals. A major effort was made to remove gossypol genetically from cotton; however, the gossypol-free cottons that were successfully developed turned out to be very susceptible to *Heliothis* attack.

Most cotton cultivars have a gossypol content of about 0.5% (dry weight) and this level causes no appreciable mortality or growth reduction. However, when this level is increased to 1.2% or above, at least a 50% larval mortality results (Lukefahr et al. 1966). When gossypol is added to larval diets, a much lower concentration is required to achieve this same level of mortality. However, on the plant, the larvae are able to feed selectively on parts that have the lowest gossypol content, such as the pollen, anthers, and stigma.

Heliocides

Beginning in 1976, an effort was made to grow the entire race stock collection of *Gossypium hirsutum* and bioassay plant parts for *Heliothis* resistance. This was essentially achieved, and about 3% of the lines were found to give growth inhibition and/or larval mortality when compared with standard cultivars. Based on gossypol analyses, it was apparent that gossypol was the biologically active agent, but in at least nine lines, other chemical factors were involved. Eventually, five compounds, designated as heliocides, were identified and bioassayed for biological activity against *Heliothis* (Gray et al. 1976; Stipanovic et al. 1977). The nine resistant lines had different combinations and concentrations of the various terpenoids. The assumed advantage to the plant in possessing such an assortment of chemicals would be to marshal a number of toxic agents against one or more insect pests that feed on it. (Table 2 summarizes the ED 50 values of these compounds).

Table 2. ED 50 values of heliothis against Heliothis virescens larvae.

Compound		Mg/g diet
Gossypol		0.8
Hemigossypolone		10.5
Heliocide	H_1	2.5
	H_2	11.2
	H_3	3.9
	H_4	Unstable

Condensed Tannins

Two primitive *G. hirsutum* race stocks, designated as Texas 194 and Texas 254, consistently produced *H. virescens* larvae that were approximately one-half the size of the standard. The antibiotic factor was unrelated to gossypol or the heliocides. Chan et al. (1978) identified the active component of Texas 254 as a condensed tannin. A concentration of 0.2% in larval diet of *H. virescens* suppressed larval growth by 84% (Table 3). Schuster (1980) identified the Heliothis-resistant factor in several lines of cotton as condensed tannins. However, what is not clear is that many of these lines also possessed high levels of terpenoids.

Table 3. Effect of condensed tannin on *H. virescen* larvae.

Tannin in diet (%)	Mean larval weight (mg) after 7 days	
	Test 1	Test 2
0.00	299	266
0.1	260	207
0.2	84	45
0.3	37	20

Maize

The literature appears to be filled with anomalies regarding economic threshold levels as well as sources of resistance in maize.

In South America, particularly Peru, numerous references show that *H. virescens* is a pest of maize, while in other countries of its range, it appears to be an "accidental" pest, as only a small percentage of the entire *Heliothis* collection have been identified as *H. virescens.* In Africa, Europe, Australia, and Asia, *H, armigera* is the recorded pest on maize.

It would appear that in field corn, *Heliothis* results in very small yield losses, as feeding is restricted to the tip of the ear, and damage probably does not exceed 2% of the kernels (Starks et al. 1966). Infestation counts for a 2-year period over five southern U.S. states averaged 83% infested ears, but most damage was indirect, as feeding by *H. zea* permitted entrance of rice weevil and pink scavenger larvae (Starks et al. 1966). The low injury level from *H. zea* is probably associated with the strong cannibalistic habits of the larvae, whereby only one larva per ear matures, regardless of the number of eggs deposited on the silk.

Sweet corn is a high-value cash crop, and because of strong consumer preference, must be nearly worm-free. This condition requires high pesticide usage. Host-plant resistance cannot provide the protection that is demanded for sweet corn where *Heliothis* is an economic problem.

Numerous citations in the literature report on sources of resistance to *H. zea.* Yarnell (1952) and Walter (1957) first reported on lines that possessed resistance to *H. zea,* however, these early studies lacked standards against which comparisons could be made. The investigators reported on a lethal factor in the silk, but this proved to be elusive when later investigators subjected it to rigorous tests (Luckman et al. 1964; Knapp et al. 1967; Starks et al. 1967; Straub and Fairchild 1970). Many of these studies were based on laboratory experiments where freeze-dried silks were incorporated into larval diet. Growth on diets containing both susceptible and resistant silks was very poor.

Another resistant character that appears in the literature is the long and tight husk of maize, which has been reported by numerous investigators as a resistance mechanism. Ditman and Cory (1933) reported that these characters reduced kernel damage because larvae took longer to traverse the silk channels before reaching the kernels. Essentially the same conclusion has been reported by Guthrie and Walter (1961), Zuber et al. (1971), Starks and McMillian (1967), and Wiseman et al. (1970). On the contrary, Del Valle and Miller(1963) found that husk length and tightness were not resistance mechanisms, but only a chance occurrence when related to *Heliothis* resistance.

Luckman et al. (1964) found that silk balling was associated with *H. zea* resistance, as it formed a physical barrier to larval penetration. Zuber et al. (1971) concluded that the longer and tighter silk channels were probably a mechanism of resistance, as more larvae completed development in silk channels before reaching the kernels. Knapp et al. (1965) found a lower concentration of amino acids and reducing sugars in silks of resistant corns than of susceptible ones.

While *Heliothis* spp probably do not cause severe yield losses in maize, the crop serves as the source of infestation for other crops such as cotton, soybeans, and many vegetable crops. Therefore if high levels of resistance did occur in maize, many other crops would benefit.

Ortega et al. (1980) give a comprehensive review of *Heliothis* resistance in maize; however, no information is given on economic thresholds or the value of the resistance sources in lowering field infestations.

Likewise, the review by Maxwell et al. (1972) lists many references relating to *Heliothis* resistance in maize, but no attempt is made to appraise the value of these characters in suppressing populations.

Sorghum and Millet

Sorghums are frequently attacked by *H. zea* but seldom receive insecticidal treatments for its control. It is generally recognized that the loose-headed varieties suffer less damage than those with a compact head.

Burkhardt (1957) found that two to three larvae per head were required to cause economic losses, while Kinzer and Henderson (1968) found that one larva per head reduced yields by approximately 4%.

The only reference found pertaining to *Heliothis* resistance in sorghum was a laboratory study by Oliver and Tipton (1972) who made a diet of mature seed. They noted wide differences between varieties; however, no attempt was made to correlate these studies with field observations.

Millet is also frequently attacked, though *Helio-*

this is not considered a major pest in millet. Burton et al. (1977) found that a trichomeless variety had 75 times fewer eggs than its isogenic hairy counterpart.

Tobacco

Tobacco is a high-value cash crop, and leaf damage lowers the grade and price of the crop.

Several workers have reported on tobacco species or cultivars that exhibit marked differences in response to *H. virescens.* Burk and Stewart (1971) surveyed the different *Nicotiana* species for resistance to *Heliothis* and noted that a cultivar of *N. tabacum* had high levels of resistance to *H. virescens.* Greene and Thurston (1971) noted that H. *virescens* showed a strong preference for tobacco with pubescent leaves over types with smooth leaves. However, Girardean et al. (1973) related *H. virescens* damage of flue-cured tobacco to nicotine content, trichome density, and exudates. They found that the more pubescent lines tended to suffer less larval damage, as the trichomes impeded the movement of the larvae.

Other Legumes

Pigeon pea

Heliothis spp are recognized as major pests of pigeonpea. In the Americas, pigeonpea is grown principally in the Caribbean Islands, where it is an important food source. Cruz (1975) from Puerto Rico reported on some preliminary studies showing that some lines had significantly fewer *Heliothis* eggs deposited while others suffered less damage from larvae.

Davies and Lateef (1978) reported that in India certain pigeonpea lines have shown lower levels of pod damage from *H. armigera,* but no resistant lines have been identified as yet.

Groundnut

In the Americas, *H. zea* can cause economic losses to groundnut. But only one reference to plant resistance could be located. Leuck et al. (1967) evaluated 14 varieties for insect damage using a visual damage score. Ragging, principally due to *H. zea,* ranged from 1.65 to 3.92 on a scale of 1 to 5. Spanish types generally suffered greater damage than runner or Virginia types.

Chickpea

Heliothis spp can be very damaging to the chickpea crop in the Americas as well as in Asia. However, no references noting differences in infestation or studies to identify resistance were found.

Host-Plant Resistance to *Heliothis:* An Appraisal

Problems

Heliothis spp have a wide host range and are multigeneration pests. Therefore a population may build up on one crop and then move to another in large numbers. Since the population increase may not occur within the crop as in monophagous pests, high levels of resistance are required if populations are to be stabilized below the economic threshold level. The probability of finding a single mechanism that will provide this level of suppression is remote, and therefore several characters must be combined. While this is not an unrealistic approach, it does require good methodology in order to recover lines that contain multiple sources of resistance.

Progress

The literature documents that it is possible to locate plant characters that affect *Heliothis* growth and development in the major crops. Admittedly, many of these references are based on laboratory experiments, and field suppression has not been demonstrated, but differences do occur between cultivars and could be exploited. When research programs have received good support, progress has been demonstrated.

Prospects

Progress in host-plant resistance research is a long-term proposition and requires considerable resources. With the limited financial resources available today, many host-plant resistance projects have suffered; unfortunately, funding is available only when a crisis is looming, and with the availability of the synthetic pyrethroids, there is no crisis on the horizon. An effective pesticide makes control of the pests very easy and also insures stability of yields. Very little management is required, and even if the number of applications is excessive, the grower has minimized the risk at very little extra cost. Therefore in crops that have a low damage threshold, or that have a number of different pest species, population suppression will probably rely on conventional pesticides. When pest resistance to the synthetic pyrethroids becomes widespread, the dosages can be markedly increased and still require only relatively small amounts.

However, there are many crops where pesticide use is not part of the production system. These are usually crops that have a low cash value per unit of land or crops grown in regions where growers do not have access to chemicals or the equipment to apply them. It is in these situations that host-plant resistance will have its potential impact.

References

BELAND, G.L., and HATCHETT, J.H. 1976. Expression of antibiosis to the bollworm in two soybean genotypes. Journal of Economic Entomology 6(4):557-560

BIRD, L.S., ED-ZIK, K.M., FREE, E., and ARNOLD, R. 1968. Concepts and procedures for developing cottons with multiple disease resistance. Pages 158-162 *in* Proceedings, Beltwide Cotton Producers Research Conference, Cotton Disease Council 28.

BURK, L.G., and STEWART, P.A. 1971. Survey of resistance among *Nicotiana* spp. to tobacco budworm. Tobacco Science 15:32-34.

BURKHARDT, C.C. 1957. Corn earworm control in grain sorghum. Journal of Economic Entomology 50(4):539-541.

BURTON, G.W., HANNA, WW., JOHNSON, J.C., LEUCK, D.B., MONSON, W.G., POWELL, J.B., WELLS, H.D., and WIDSTROM, N.W. 1977. Pleiotropic effects of trichomeless gene in pearl millet on transpiration, forage quality, and pest resistance. Crop Science 17:613-616.

CHAN, B.G., WAISS, A.C., and LUKEFAHR, M.J. 1978. Condensed tannin, an antibiotic chemical from *Gossypium hirsutum.* Journal of Insect Physiology 24:113-118.

CLARK, W.J., HARRIS, F.A., MAXWELL, F.G., and HARTWIG, E.E. 1972. Resistance of certain soybean cultivars to bean leaf beetle, striped blister beetle, and bollworm. Journal of Economic Entomology 65(6):1669-1672.

CRUZ, C.1975. Observations on pod borer oviposition and infestation of pigeon pea varieties. Journal of the Agricultural University of Puerto Rico 59(1):63-68.

DAVIES, J.C., and LATEEF, S.S. 1978. Recent trends in grain legume pest research in India. Pages 25-31 *in* Pests of grain legumes: ecology and control, eds. S.R. Singh, H.F. van Emden, and T.A. Taylor. London, UK: IITA/Academic Press.

DELVALLE.C.G., and MILLER, J.C. 1963. Influence of husk length and tightness against corn earworm damage in sweet corn. American Society of Horticultural Sciences Proceedings 83:531 -535.

DITMAN, L.P., and CORY, E.N. 1933. Corn earworm studies. Maryland Agricultural Experiment Station Bulletin 348:525-543

DREYER, D.L., BINDER, R.G., CHAN, B.G., WAISS, A.C., HARTWIG, E.E., and BELAND, G.L. 1979. Pinitol, a larval growth inhibitor for *Heliothis zea* in soybeans. Experiment 35:1182-1183.

FERY, R.L., and CUTHBERT, F.P. 1973. Factors affecting evaluation of fruitworm resistance in tomato. Journal of the American Society of Horticultural Science 98(5):457-459.

FERY, R.L., and CUTHBERT, F.P. 1974. Resistance of tomato cultivars to the fruitworm. Horticultural Science 9(5):469-470.

FERY, R.L., and CUTHBERT, F.P. 1975. Antibiosis in *Lycopersicon* to the tomato fruitworm. Journal of the American Society of Horticultural Science 100(3):276-278.

GALLUN, R.L., STARKS, K.J., and GUTHRIE, W.D. 1975. Plant resistance to insects attacking cereals. Annual Review of Entomology 20:337-358.

GIRARDEAN, J.H., GAINES, T.P.and GOLDEN B.A. 1973. Possible causes of differences in tobacco budworm damage to flue-cured tobacco varieties. Journal of Economic Entomology 66(2):470-472.

GRAY, JR., MABRY, T.J., BELL, A.A., STIPANOVIC, R.D., and LUKEFAHR, M.J. 1976. Para Hemigossypolone: a requiterpenoid aldehyde quinone from *Gossypium hirsutum.* 1976 (3):109-110.

GREENE, G.L., and THURSTON, R. 1971. Oppositional performance of *Heliothis virescens* and *Nicotiana* species. Journal of Economic Entomology 64(3): 641 -643.

GUTHRIE, W.D., and WALTER, E.V. 1961. Corn earworm and Egropean corn-borer resistance in sweet corn inbred lines. Journal of Economic Entomology 54(6):1248-1250.

HEILMAN, M.D., LUKEFAHR, M.J., NAMKAN, L.W., and NORMAN, J.W. 1977. Field evaluation of a short season production system in Lower Rio Grande Valley of Texas. Pages 80-82 *in* Proceedings, Beltwide Cotton Producers Research Conference, Dallas, Texas, USA.

KENNEDY, G.G. 1978. Recent advances in insect resistance of vegetables and fruit crops in North America. Bulletin of Entomological Society of America 24:375-384.

KINZER, H.G.,and HENDERSON, C.F. 1968. Damage by the larvae of the corn earworm to grain sorghum. Journal of Economic Entomology 61(2):263-267.

KOGAN, J., SELL, D.K., STINNER, RE., BRADLEY, J.R.,and KOGAN, M. 1978. V. A bibliography of *Heliothis zea* and *H. virescens* (Lepidoptera: Noctuidae). INTSOY Series Number 17; University of Illinois, Urbana, Ill, USA. 242 pp.

KNAPP, J.L., HEDIN, P.A., and DOUGLAS, W.A. 1965. Amino acids and reducing sugars in silks of corn resistant or susceptible to corn earworm. Annals of the Entomological Society of America 58(3):401 -402

KNAPP, J.L., MAXWELL, F.G., and DOUGLAS, W.A. 1967. Possible mechanisms of resistance of dent corn to the corn earworm. Journal of Economic Entomology 60(1):33-35.

LANGE, W.T., and BRONSON, L. 1981. Insect pests of tomato. Annual Review of Entomology 26:345-371.

LEUCK, D.B., HAMMOND, R.O., MORGAN, L.W., and HARVEY, J.E. 1967. Insect preference for peanut varieties. Journal of Economic Entomology 60(6):1546-1549.

LOWRY, W.L. 1966. Bollworm and tobacco budworm resistance to some insecticides in the Lower Rio Grande Valley in 1964. Journal of Economic Entomology 59 (2):479-480.

LUCKMAN, W.H., RHODES, A.M., and WANN, E.V. 1964. Silk balling and other factors associated with resistance to the corn earworm. Journal of Economic Entomology 57(5):778-779.

LUKEFAHR, M.J., BOTTGER, G.T., and MAXWELL, F.G. 1966. Utilization of gossypol as a source of insect resistance. Pages 215-222 *in* Proceedings, Beltwide Cotton Producers' Research Conference, Memphis, Tenn, USA.

LUKEFAHR, M.J., and MARTIN, D.F., 1964. The effects of various larval and adult diets on the fecundity and longevity of the bollworm.tobacco budworm and cotton leafworm. Journal of Economic Entomology 57(2): 233-235.

LUKEFAHR, M.J., COWAN, C.B., PFRIMMER, T.R.,and NOBLE, L.W. 1966. Resistance of experimental cotton strain 1514 to the bollworm and cotton fleahopper. Journal of Economic Entomology 59(2):393-395.

LUKEFAHR, M.J., HOUGHTALING, J.E., and GRAHAM, N.M. 1971. Suppression of *Heliothis* populations with glabrous cotton strains. Journal of Economic Entomology 64(2):486-488.

LUKEFAHR, M.J., HOUGHTALING, J.E.,and CRUMB, D.G. 1975. Suppression of *Heliothis* spp. with cottons containing combinations of resistant characters Journal of Economic Entomology 68(6)743-746.

MAXWELL, F.G., JENKINS, J.N., and PARROT, W.L. 1972. Resistance of plants to insects. Advances in Agronomy 24:187-265.

MEYER, A.J., and MEYER, V.G. 1961. Origin and inheritances of nectariless cotton. Crop Science 1:167-169.

MUELLER, A.J., and ENGROFF, B.W. 1980. Effects of infestation levels of *Heliothis zea* on soybeans. Journal of Economic Entomology 73(2):271-275.

OLIVER, B.F., and TIPTON, K.W. 1972. Effect of diet formulated from sorghum hybrids on weight gain of corn earworm larvae. Journal of Economic Entomology 65(5):1759-1760.

ORTEGA, A., VASAL, S.K., MIHM, J., and HERSHEY, C. 1980. Breeding for insect resistance in maize. *In* Breeding plants resistant to insects, eds F.G. Maxwell and P.R. Jennings. New York, USA: Wiley.

PARNELL, F.R., KING, H.E., and RUSTON, F.F. 1949. Jassid resistance and hairiness of the cotton plant. Bulletin of Entomological Research 39:539-575.

PEARSON, O.E. 1959. The insect pests of cotton in tropical Africa. London and Reading, UK: Eastern Press.

SCHUSTER, M.F., LUKEFAHR, M.J., and MAXWELL, F.M.I 976. Impact of nectariless cotton on plant bugs and natural enemies. Journal of Economic Entomology 69(3):400-402.

SCHUSTER, M.F., 1980. New sources of high tannin resistance to *Heliothis* in upland cotton resulting in feeding deterrance Pages 126-129 *in* Proceedings, Beltwide Cotton Producers' Research Conference, New Orleans, La. USA.

STARKS, K.J., COX, H.C., McMILLIAN, W.W., and BURTON, R.L. 1966. Damage to corn by the pink scavenger caterpillar and its relationship to earworm and rice weevil damage. Journal of Economic Entomology 60(4):920-923.

STRAUB, R.W., and FAIRCHILD, M.L. 1970. Laboratory studies of resistance in corn to the corn earworm. Journal of Economic Entomology 63(6):1901-1903.

STIPANOVIC, R.D., BELL, A.A., O'BRIEN, D.H., and LUKEFAHR, M.J. 1977. Heliocide H2: an insecticidal sesterterpenoid from cotton (*Gossypium*)^2. Tetrahedron Letter 6:567-570.

TURNIPSEED, S.G., and KOGAN, M. 1976. Soybean entomology. Annual Review of Entomology 21:247-282.

WALKER, J.K., Jr., and NILES, G.A. 1971. Population dynamics of the boll weevil and modified cotton types. Texas Agricultural Experiment Station Bulletin 1109, University Station, Tex, USA.

WALTER, E.V. 1957. Corn earworm lethal factor in silks of sweet corn. Journal of Economic Entomology 50(1):105-106.

WISEMAN, B.R., McMILLIAN, W.W., and WIDSTROM.N.W. 1970. Husk and kernel resistance among maize hybrids to an insect complex. Journal of Economic Entomology 63(4): 1260-1262.

WOLFENBARGER, D.A., LUKEFAHR, M.J., and GRAHAM, H.M. 1971. A field population of bollworms resistant to methyl parathion. Journal of Economic Entomology 64(3)755-756.

YARNELL, S.H. 1952. Breeding for resistance to the corn earworm in sweet corn. Proceedings, Association of Southern Agricultural Workers 49:106-107.

ZUBER, M.S., FAIRCH1LD, M.L., KEASTER, A.J., and FERGUSON. V.L. 1971. Evaluation of 10 generations of mass selection for corn earworm resistance. Crop Science 11:16-18

The Potential Role of Natural Product Chemistry Research in *Heliothis* Management

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Abstract

The chemistry and potential applications of *naturally occurring toxicants, repellents, feeding deterrents, growth and mating inhibitors, and sex pheromones lor controlling* Heliothis zea, H. virescens, *and* H. armigera *are reviewed. The sex pheromones of the respective species are useful tor surveying areas of infestation, as mass-trapping agents, and* as *mating suppressants through the contusion technique. The use of various types of traps and pheromone dispensers is compared. Confusion agents such as (Z)-9-tetradecen-l-ol formate are potentially valuable tor the suppression of mating. Feeding deterrents obtained from plants promise to be useful alone as well as in integrated pest-management programs against the pest species* of Heliothis.

Résumé

Rôle potentiel de la recherche sur la chimie de produits naturels dans la lutte contre Heliothis: *La chimie et les applications potentielles de produits naturels—toxiques, répulsifs, produits de dissuasion alimentaire, inhibiteurs de croissance et d'accouplement, phéromones sexuelles—sont revues dans l'optique de la lutte contre* Heliothis zea, H. virescens *et* H. armigera. *Les phéromones sexuelles de ces espèces sont utiles pour la surveillance des aires d'infestation, le piégeage de masse et la suppression de l'accouplement grâce à une technique de confusion. Les utilisations de divers types de pièges et diffuseurs à phéromone sont comparées. Les agents de confusion* [ex. *(Z)-9-tetradecen-1-ol formate*] *peuvent être utiles pour la suppression de l'accouplement. Les produits de dissuasion alimentaire issus des plantes seraient utiles seuls ou dans le cadre de programmes de lutte intégrée contre les espèces nuisibles d'*Heliothis.

In the United States, *Heliothis zea* (Boddie), commonly called the bollworm, corn earworm, or tomato fruitworm, and *H. virescens* (F.), commonly known as the tobacco budworm, are generally referred to as the "bollworm complex." Both species feed on a wide range of host plants, and a free exchange of hosts occurs between cotton and other host plants. *H. armigera* (Hubner), the Old World bollworm, is an important crop pest in many areas of Africa, the Near and Middle East, Asia, and Australia. Although *H. zea* was long believed to be identical with *H. armigera,* the two are now recognized as distinct species (Balachowsky 1972).

Natural substances have proved to be extremely valuable for surveying areas of infestation as- well as in the control of these highly destructive crop pests. These substances are: (1) toxicants and repellents, (2) feeding deterrents, and (3) sex pheromones. I will treat these separately, dealing only with the more recent significant developments now in use or potentially useful.

Toxicants and Repellents

Host-plant resistance has been recognized since the early 1800s. From the standpoint of natural selection in evolution, resistance is a preadaptive characteristic of plants. Before being cultivated by man, plants, coevolving with insects, either intrinsically possessed or have developed means of surviving attack by arthropods.

Normal commercial cottons have 3000 to 5000 trichomes per square inch (465 to 775/cm^2) on the leaves present on the growing points of the plant. Years ago it was suggested that the presence of dark internal glands in cotton *(Gossypium)* plants was associated with resistance to insects, and

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gossypol isolated from these glands was considered to be the main contributing factor against tobacco budworm, *H. virescens* (see Waiss et al. 1977, and Maxwell 1977 for comprehensive reviews of the subject). However, a glandless resistant variety was developed that contains no gossypol, and a condensed tannin (p-hemigossypolone)) was identified as the resistance factor (Gray et al. 1976). Addition of cotton tannin at 0.1 to 0.3% to a synthetic diet markedly reduces the weight of larvae reared on the diet. A number of sesterterpenoids have also been isolated from cotton flowerbuds that are highly toxic to *H. zea* and *H. virescens* (Stipanovic et al. 1977, 1978a, 1978b); they have been designated "heliocides H_1, H_2, H_3, H4," and can be synthesized by a Diels-Alder reaction between hemigossypolone and frans-3 ocimene. It is suggested that plant breeders select for cotton plants with higher pigment content as a mechanism of resistance (Schuster 1979).

In laboratory tests, Ignoffo et al. (1981) showed that incorporation into the diet of either of two varieties of *Bacillus thuringiensis* was lethal to larvae of *H. zea* and *H. virescens.* The LC_{50} values with variety *israelensis* were 19.3 and 27.6 µg/ml, respectively; with variety *kurstaki,* 2.0 and 7.8 µg/ml, respectively.

A toxic factor that kills *H. zea* larvae feeding on wild tomato, *Lycopersicon hirsutum* f. *glabratum* CM. Mull., has recently been identified as 2-tridecanone (Williams et al. 1980). It is also toxic to several other species of insects.

Feeding Deterrents and Growth Inhibitors

Florets of the sunflower, *Helianthus annuus* L., have yielded two diterpene acids, trachyloban-19-oic acid and the biogenetically related (-)-16-kauren-19-oic acid, that drastically reduce larval growth of *H. zea* and *H. virescens* when incorporated in the diet (Elliger et al. 1976).

Severe retardants of larval growth for *H. zea have* been isolated from corn silk; they are the glycosidal flavones maysin (Waiss et al. 1979) and 2^{11}-O-L-rhamnosyl-6-C-(6-deoxyxylo-hexos-4-ulosyl)luteolin(Elliger et al. 1980b). Results obtained by testing a variety of plant flavonoids as retardants of growth and development for *H. zea* are given by Elliger et al. (1980a).

Offering first-instar H. zea larvae a diet containing a chloroform extract of leaves of the chinaberry tree, *Melia azedarach* L, which is native to the United States as well as India, resulted in only slight feeding, gross reduction in growth, and high mortality (McMillian et al. 1969). The results were identical when last-instar larvae of *H. virescens* were offered a diet containing the well-known antifeedant azadirachtin, isolated from the seeds of the Indian neem tree, *Azadirachta indica* A. Juss. (Ruscoe 1972).

Phenylacetaldehyde, a compound found in many plants and available at low cost on the open market, attracts large numbers of adult *H. zea* (mainly females) to field traps (Cantelo and Jacobson 1979). A microencapsulated formulation of phenylacetaldehyde caused a reduction in the number of eggs laid as well as the amount of damage done to cotton plant terminals (Flint et al. 1978). This compound also attracts many other species of lepidopterous insects, especially when used in black-light traps.

Sex Pheromones

Heliothis armigera

The composition of the female sex pheromone appears to vary with the location in which the insects are found. Piccardi et al. (1977) isolated (Z)-11 -hexadecenal from abdominal tips of Sudanese *H. armigera* females, and this compound alone was attractive to males in field traps. However, Dunkelblum et al. (1980a, 1980b) found both (Z)-11-hexadecenal and (Z)-9-hexadecenal, in a ratio of 30:1, in tip extracts of females from Israel, and these did not attract males unless they were combined (Kehat et al. 1980). Working with extracts from the abdominal tips of females reared from pupae in Botswana, Sudan, India, and Malawi, Nesbitt et al. (1979) isolated and identified (Z)-11 -hexadecenal and (Z)-11-hexadecen-1-ol, plus a third component, (Z)-9-hexadecenal, which occurred only in females originating in Malawi. A reexamination of the pheromone components by these investigators (Nesbitt et al. 1980) using ovipositor washes showed that (Z)-11 -hexadecenal and (Z)-9-hexadecenal were consistently present in moths from all of these origins in the ratio of 88.6:2.9.

Field tests conducted in Israel by Kehat et al. (1980) showed that traps baited with (Z)-11-hexadecenal containing 1 to 10% (Z)-9-hexadecenal caught more male moths than traps baited with (Z)-11-hexadecenal alone. Addition of (Z)-11-hexadecen-1-ol reduced the catches.

There is no doubt that the two aldehydes are essential components of the sex pheromone. The mixture of (Z)-11-hexadecenal and (Z)-9-hexadecenal, in the ratio of 97:3, is currently in use in Israel for monitoring *H. armigera* populations (Dunkelblum et al. 1980a).

Heliothis virescens

The sex pheromone produced and released by the adult female was identified by Roelofs et al. (1974) and Tumlinson et al. (1975) as a blend of (Z)-11-hexadecenal and (Z)-9-tetradecenal; it has been named "virelure." The natural ratios of these components were found by Roelofs et al. to be 3:1 in the abdominal tips of females one-half to 4 days old, and by Tumlinson et al. to be about 16:1 in an ether wash of whole females.

In 1980, Klun et al. (1980a) reported that heptane washes of female ovipositors yielded 77 to 91% (Z)-11-hexadecenal, 1 to 3% (Z)-9-tetradecenal, 0.1 to 2.0% (Z)-7-hexadecenal, 0.3 to 2.0% (Z)-9-hexadecenal, 3 to 19% hexadecanal, 1 to 5% (Z)-11-hexadecen-1-ol, and 1 to 3% tetradecanal. In field bioassays, a 152 µg mixture of these seven compounds deployed in an insect trap was five to six times more attractive than virelure alone.

Neither of the two components of virelure alone will attract male moths in the field.

Heliothis zea

Although the presence of a sex attractant in an extract of virgin female abdominal segments was first demonstrated in 1965 by Bergeretal. (1965), it was not until 1970 that two discrete components were isolated by McDonough et al. (1970). However, the latter investigators could obtain only partial identification of these compounds, which they reported to be a 14-carbon straight-chain alcohol and a 14-carbon acetate.

In 1980, Klun et al. (1980a, 1980b, 1980c, 1980d) reported the isolation and identification of the components of the natural pheromonal blend obtained from heptane washes of virgin female ovipositors. The composition consisted of 90 to 95% (Z)-11-hexadecenal, 1 to 2% (Z)-9-hexadecenal, 0.4 to 2.0% (Z)-7-hexadecenal, and 2 to 7% hexadecanal. Binary mixtures containing 115 µg (Z)-11-hexadecenal and 2.25 µg (Z)-9-hexadecenal are quite effective for attracting male moths into baited traps.

Mating Inhibitors

A considerable amount of recent research has demonstrated that pheromonal communication between the sexes of a number of species of Lepidoptera can be effectively disrupted by permeating the air with synthetic compounds identical with or similar to the true pheromones of the target species (see especially Roelofs 1977 and Mitchell 1981).

In field tests conducted in Florida, evaporation of (Z)-11-hexadecenal (a component of *Heliothis* pheromones) reduced the mating of *H. zea* females by 85%. Evaporation of (Z)-9-tetradecenal (a component of the *H. virescens* pheromone) did not affect *H. zea* behavior but did reduce the mating of *H. virescens* females by 95% (Mitchell et al. 1976).

In 1975, (Z)-9-tetradecen-1-ol formate, a compound of nonbiological origin but closely related structurally to (Z)-9-tetradecenal, was found to be an excellent disruptant of pheromonal communication between male and female corn earworms and between male and female tobacco budworms when it was evaporated into the air of infested fields (Mitchell et al. 1975). The use of this compound for this purpose has been patented in the United States (Mitchell et al. 1978). Capture of the moths by pheromone traps in fields in which the formate was released from vials was reduced by more than 95% for both *H. zea* and *H. virescens.* The compound, which is easily prepared, highly stable, and safe for use, was mentioned by Bestmann et al. (1975) as occurring naturally in an extract of female *H. virescens* abdomens, but this claim was later rescinded by these investigators in personal correspondence with me.

Gothilf et al. (1978) reported that (Z)-9-tetradecen-1-ol formate and (Z)-9-tetradecen-1-ol acetate released from virgin female-baited traps in the field were equally effective in inhibiting male capture of *H. armigera.*

Slow release of the formate from laminated Her--- plastic dispensers in a corn field was very effective in reducing mating by *H. zea* in 1977 (Caro et al. 1980). The compound is normally dispensed from microcapsules, plastic laminates, or hollow fibers.

A sensitive method for determining the formate in air was developed by Caro et al. (1979).

Application (Trap Types and Dispensers)

Heliothis armigera

The use of dental roll dispensers impregnated with synthetic pheromone was not as effective as rubber dispensers in plastic pail-type traps in Israel (Gothilf et al. 1979). Rubber dispensers are currently in use in cotton fields throughout Israel for survey purposes (Gothilf et al. 1981), using 2 mg of a 97:3 mixture of (Z)-11-hexadecenal and (Z)-9-hexadecenal plus 0.2 mg of an antioxidant. This mixture is effective from rubber dispensers but not from polyethylene vials (Kehat et al. 1980).

Using traps made of two plastic rectangles joined at each corner by rings, with the inner surface of the bottom rectangle coated with adhesive, a small rubber capsule saturated with (Z)-11-hexadecenal was very effective in capturing male moths in Senegal (Bourdouxhe 1980).

Heliothis virescens

Comparative tests conducted with virelure in unpainted vs. painted paper icecream carton traps showed that fluorescent orange, green, tangerine, and highly reflective white were much superior to unpainted traps. Green appeared to be best for monitoring and mass-trapping (Hendricks et al. 1972).

In the U.S. Virgin Islands, electric grid traps baited with live virgin females captured 101 times more males than did unbaited black-light traps and 9 times more than sticky cardboard traps baited with females (Goodenough and Snow 1973). Placement of the bait inside the grid element was more effective than placement about 15 cm to one side of the element. Saucer-type female-baited traps placed 1.5 m above the ground (just above the top of the cotton vegetation) caught significantly more males than those placed higher or lower (Hendricks and Leal 1973).

Virelure (10 mg) laminated between thin sheets of vinyl polymer plastic attracted males to baited traps for at least 21 days. A mixture of 10 µl of (Z)-11-hexadecenal and 0.5 µl of (Z)-9-tetradecenal was attractive for at least 5 days when incorporated in a 8 x 30 mm cigarette filter encased in a glass shell vial. Cottonseed oil and polyethylene glycol 600 distearate inhibited the excessive vaporization and oxidation of virelure (Hendricks et al. 1977).

Hollingsworth et al. (1978) compared the catches of electric grid traps of several types and nonelectric traps, all of which were baited with virelure. Standard and modified grid traps outperformed miniature grid traps, but a wire mesh cone trap with no bottom was far superior to any of the other nonelectric traps.

Rubber septa baited with virelure caught as many males as did live females when used in cone traps and were effective for 10 weeks. Laminated baits used for comparison were effective for only 3 weeks, with decreasing effectiveness for 2 more weeks (Flint et al. 1979).

Hartstack et al. (1979) reported an efficiency of about 25% for capturing males in a nonelectric cone trap. This trap can be baited with virelure or live females and is portable, inexpensive, and simple to install and operate.

Sparks et al. (1979b) field-tested virelure in cigarette filters and live females in Georgia and Arizona using standard electrocutor grid traps, pie-plate sticky traps, wind-vane traps, and skirted cone-type traps. The grid traps proved to be most efficient and the pie-plate traps were least efficient.

In tests comparing the efficiency of a wind-oriented trap with pie-plate and grid traps, all of which were baited with live females or virelure, the wind-oriented trap was almost as efficient as the grid trap and more efficient than the nonelectric traps (Raulston et al. 1980). This trap was also very efficient for capturing male *H. zea* when it was baited with live *H. zea* females.

Inverted single-cone traps baited with live females captured more males at night during periods of low wind velocity (0-9.6 km/hr) and wind-vane traps captured more males at higher wind velocities (9.6-16 km/hr) (Hendricks et al. 1980).

Heliothis zea

Grid traps baited with a mixture of (Z)-9-hexadecenal were much more efficient for capturing males than a baited wind-vane trap; a baited sticky pie-plate was worst of all (Sparks et al. 1979a).

Grid traps baited with live female *H. subflexa* (Guenee), *H. virescens,* or *H. zea* captured conspecific males with few exceptions. Simultaneous use of *H. subflexa* females with females of either of the other two species resulted in lower catches of males of either species. Exposure of laboratory-reared male *H. virescens* or male *H. subflexa* to virelure in a Plexiglas wind tunnel showed that only *H. virescens* responded (Tingle et al. 1978).

Conclusions

In addition to using the respective sex pheromones of *Heliothis* species for essential monitoring of infested areas, these compounds have been shown to be useful as mass-trapping agents as well as for mating suppression through confusion. The use of rubber dispensers in green traps is recommended, especially with *H. virescens,* for survey, and electric grid traps baited with live females or the sex pheromone appear to be more efficient for mass-trapping than black-light traps. Several types of cone traps, which are portable, lightweight, and inexpensive, are well-suited for use in areas where sources of electric power are not readily available in or near crop sites. Cigarette filters and laminated sheets of vinyl polymer plastic can also be recommended as pheromone dispensers for slow release.

Mating suppression through the use of confusants such as (Z)-9-tetradecen-1 -of formate for air permeation is a potentially valuable development. It has been shown to be very effective with *H. zea* and *H. virescens,* which are serious pests in highly diverse American ecosystems, and should certainly be pursued for the same purpose with *H. armigera.*

A promising ovipositional inhibitor, phenylacetaldehyde, has been shown to be effective for *H. zea* and should be tried for other species of *Heliothis* as a contact spray of dust formulation as well as through slow release.

Broad-spectrum feeding deterrents such as extracts or isolates of chinaberry leaves and neem seeds, as well as the more selective gossypol and cotton heliocides, are potentially useful alone and in programs of integrated pest management of *Heliothis.*

References

BALACHOWSKY, A.S. 1972. Entomologie applique a l'agriculture, vol. 2. Paris: Masson.

BERGER, R.S., McGOUGH, J.M., and MARTIN, D.F. 1965. Sex attractants of *Heliothis zea* and *H. virescens.* Journal of Economic Entomology 58: 1023-1024.

BESTMANN, H.J., STRANSKY, W., VOSTROWSKY, O., and RANGE, P. 1975. Pheromone, VII. Synthese von 1 -substituierten (Z)-9-Alkenen. Chemische Berichte 108: 3582-3595.

BOURDUXHE, L. 1980. Study of changes in *Heliothis armigera* flights with synthetic pheromone traps in Senegal. Tropical Pest Management 26: 107-109.

CANTELO, W.W., and JACOBSON, M. 1979. Phenylacetaldehyde attracts moths to bladder flower and to blacklight traps. Environmental Entomology 8: 444-447.

CARO, J.H., FREEMAN, H.P., and BIERL-LEONHARDT, B.A. 1979. Determination of (Z)-9-tetradecen-1-of formate, a *Heliothis* spp. mating disruptant, in air by electron-capture gas chromatography following photolytic cleanup. Journal of Agricultural and Food Chemistry 27: 1211-1215.

CARO, J.H., GLOTFELTY, D.E., and FREEMAN, H.P. 1980. (Z)-9-Tetradecen-1 -ol formate Distribution and dissipation in the air within a corn crop after emission from a controlled-release formulation. Journal of Chemical Ecology 6: 229-239.

DUNKELBLUM, E., GOTHILF, S., and KEHAT, M. 1980a. Identification of the sex pheromone of the cotton bollworm, *Heliothis armigera,* in Israel. Phytoparasitica 8: 209-211.

DUNKELBLUM, E., GOTHILF, S., and KEHAT, M. 1980b. Identification of sex pheromones from *Heliothis armigera, Spodoptera littoralis* and *Plusia chalcites.* Phyloparasitica 9:77.

ELLIGER. C.A., ZINKEL, D.F., CHAN, B.G., and WAISS, A.C., Jr. 1976. Diterpene acids as larval growth inhibitors. Expenentia 32: 1364-1366.

ELLIGER, C.A., CHAN, B.G., and WAISS, A.C., Jr. 1980a. Flavonoids as larval growth inhibitors. Naturwissenschaften 67: 358-360.

ELLIGER, C.A., CHAN, B.G., WAISS,A.C.,Jr. LUNDIN, R.E., and HADDON, W.F. 1980b. C-Glycosylflavones from *Zea mays* that inhibit insect development. Phytochemistry 19:293-297.

FLINT, H.M., NOBLE. J.M., and SHAW, D. 1978. Phenylacetaldehyde: tests for control of the pink bollworm and observations on other Lepidoptera infesting cotton. Journal of the Georgia Entomological Society 13:284-289.

FLINT, H.M., NOBLE, J.M., SALTER, S.S., and WALTERS, S. 1979. Rubber septa: a long-lasting substrate for (Z)-11 -hexadecenal and (Z)-9-tetradecenal, the primary components of the sex pheromone of the tobacco budworm. Journal of Economic Entomology 72:798-800.

GOODENOUGH, J.L., and SNOW. J.W. 1973. Increased collection of tobacco budworm by electric grid traps as compared with blacklight and sticky traps. Journal of Economic Entomology 66:450-453.

GOTHILF, S., KEHAT, M., JACOBSON, M., and GALUN, R. 1978. Screening pheromone analogues by EAG technique for biological activity on males of *Earias insulana, Helolhis armigera,* and *Spodoptera littoralis.* Environmental Entomology 7:31 -35.

GOTHILF, S., KEHAT, M., DUNKELBLUM, E., and JACOBSON, M. 1979. Efficacy of (Z)-11 -tetradecenal as sex attractants for *Heliothis armigera* on two different dispensers. Journal of Economic Entomology 72:718-720.

GOTHILF, S., KEHAT, M., and DUNKELBLUM, E. 1981. Sex pheromones for monitoring populations of *Heliothis armigera.* Phytoparasitica 9:78-79.

GRAY, J.R., NABRY, T.J., BELL, A.A., STIPANOVIC, R.D., and LUKEFAHR, M.J. 1976. Para-hemigossypolone: a sesquiterpenoid aldehyde quinone from *Gossypium hirsutum.* Journal of the Chemical Society, Chemical Communications 109-110.

HARTSTACK, A.W., WITZ, J.A., and BUCK, D.R. 1979. Moth traps for the tobacco budworm. Journal of Economic Entomology 72:519-522.

HENDRICKS, D.E., HOLLINGSWORTH, J.P., and HARTSTACK, A.W., Jr. 1972. Catch of tobacco budworm moths influenced by color of sex-lure traps. Environmental Entomology 1:48-51.

HENDRICKS, D.E., and LEAL, M.P. 1973. Catch of adult tobacco budworms influenced by height of sex-lure traps. Journal of Economic Entomology 66:1218-1219.

HENDRICKS, D.E., HARTSTACK, A.W., and SHAVER, T.N. 1977. Effect of formulations and dispensers on attractiveness of virelure to the tobacco budworm. Journal of Chemical Ecology 3:497-506.

HENDRICKS, D.E., PEREZ, C.T., and GUERRA, R.J. 1980. Effects of nocturnal wind on performance of two sex pheromone traps for noctuid moths. Environmental Entomology 9:483-485.

HOLLINGSWORTH, J.P., HARTSTACK, A.W., BUCK, D.R., and HENDRICKS, D.E. 1978. Electric and nonelectric moth traps baited with the synthetic sex pheromone of the tobacco budworm. U.S. Department of Agriculture ARS-S-173, Washington, DC, USA.

IGNOFFO, CM., COUCH, T.L., GARCIA, C., and KROHA, M.J. 1981. Relative activity of *Bacillus thuringiensis* var. *kurstaki* and S. *thuringiensis* var. *israelensis* against larvae of *Aedes aegypti, Culex quinquelasciatus, Trichoplusia ni, Heliothis zea,* and *Heliothis virescens.* Journal of Economic Entomology 74:218-222.

KEHAT, M., GOTHILF, S., DUNKELBLUM, E., and GREENBERG, S. 1980. Field evaluation of female sex pheromone components of the cotton bollworm, *Heliothis armigera.* Entomologia Experimentalis et Applicata 27:188-193.

KLUN, J.A., BIERL-LEONHARDT, B.A., PLIMMER, J.R., SPARKS, A.N., PRIMIANI, M., CHAPMAN, O.L., LEPONE, G., and LEE, G.H. 1980a. Sex pheromone chemistry of the female tobacco budworm moth, *Heliothis virescens.* Journal of Chemical Ecology 6:177-183.

KLUN, J.A., PLIMMER, J.R., BIERL-LEONHARDT, B.A., SPARKS, A.N., and CHAPMAN, O.L. 1980b. Trace chemicals, the essence of sexual communication systems in *Heliothis* species. Science 204: 1328-1330.

KLUN, J.A., PLIMMER, J.R., BIERL-LEONHARDT, B.A., SPARKS, A.N., PRIMIANI, M., CHAPMAN, O.L., LEE, G.H., and LEPONE, G. 1980c. Sex pheromone chemistry of female corn earworm moth, *Heliothis zea.* Journal of Chemical Ecology 6:165-175.

KLUN, J.A., PLIMMER, JR., SPARKS, A.N., and BIERL-LEONHARDT, B.A. 1980d. Sex attractant for corn earworm moths. U.S. Patent 4, 216, 202. (5 Aug 1980). 4 pp.

MAXWELL, F.G. 1977. Plant resistance to cotton insects. Bulletin of the Entomological Society of America 23:199-203.

McDONOUGH, L.M., GEORGE, D.A., and LANDIS, B.J. 1970. Partial structure of two sex pheromones of the corn earworm, *Heliothis zea.* Journal of Economic Entomology 63:408-412.

McMILLIAN, W.W., BOWMAN, M.C., BURTON, R.L., STARKS, K.J., and WISEMAN, B.R. 1969. Extract of chinaberry leaf as a feeding deterrent and growth retardant for larvae of the corn earworm and fall armyworm. Journal of Economic Entomology 62:708-710.

MITCHELL, E.R. 1981. Management of insect pests with semiochemicals. New York, USA: Plenum Press.

MITCHELL, E.R., JACOBSON, M., and BAUMHOVER, A.H. 1975. *Heliothis* spp.: disruption of pheromonal communication with (Z) - 9 - tetradecen - 1 - of formate. Environmental Entomology 4:577-579.

MITCHELL, E.R., BAUMHOVER, A.H., and JACOBSON, M. 1976. Reduction of mating potential of male *Heliothis* spp. and *Spodoptera frugiperda* in field plots treated with disruptants. Environmental Entomology 5:484-486.

MITCHELL, E.R., JACOBSON, M., and BAUMHOVER, A.H. 1978. (Z) - 9 - Tetradecen - 1 - ol formate and its use as communication disruptant for *Heliothis.* U.S. Patent 4,083,995 (11 Apr 1978) 4 pp.

NESBITT, B.F., BEEVOR, P.S., HALL, DR., and LESTER, R. 1979. Female sex pheromone components of the cotton bollworm, *Heliothis armigera.* Journal of Insect Physiology 25.535-541.

NESBITT, B.F., BEEVOR, P.S., HALL, D.R., and LESTER, R.1980. (Z) - 9 - hexadecenal: a minor component of the female sex pheromone of *Heliothis armigera* (Hubner) (Lepidoptera, Noctuidae). Entomologia Experimentalis et Applicata 27:306-308.

PICCARDI, P., CAPIZZI, A., CASSANI, G., SPINELLI, P., ARSURA, E., and MASSARDO, P. 1977. A sex pheromone component of the Old World bollworm *Heliothis armigera.* Journal of Insect Physiology 23:1443-1445.

RAULSTON, J.R., SPARKS, A.N., and LINGREN, P.D. 1980. Design and comparative efficiency of a wind-oriented trap for capturing live *Heliothis* spp Journal of Economic Entomology 73:586-589.

ROELOFS, W.L. 1977. An overview—the evolving philosophies and methodologies of pheromone chemistry. Pages 287-297 *in* Chemical control of insect behavior: theory and application, eds. H.H. Shorey and J.J. McKelvey, Jr. New York, USA: Wiley-Interscience

ROELOFS, W.L., HILL, A.S., CARDE, R.T., and BAKER, T.C. 1974. Two sex pheromone components of the tobacco budworm moth, *Heliothis virescens.* Life Science 14:1555-1562.

RUSCOE, C.N.E. 1972. Growth disruption effects of an insect antifeedant. Nature 236: 159-160

SCHUSTER, M.F. 1979. Insect resistance in cotton Pages 101 -112 *in* Biology and breeding for resistance to arthropods and pathogens in agricultural plants, ed. M.K. Harris. Texas Agricultural Experiment Station, College Station, Texas, USA.

SPARKS, A.N., CARPENTER, J.E., KLUN, J.A., and MULLINIX, B.G. 1979a. Field responses of male *Heliothis zea* (Boddie) to pheromonal stimuli and trap design. Journal of the Georgia Entomological Society 14:318-325

SPARKS, A.N., RAULSTON, J.R., LINGREN, P.D., CARPENTER, J.E., KLUN, J.A., and MULLINIX, B.G. 1979b. Field response of male *Heliothis virescens* to pheromonal stimuli and traps Bulletin of the Entomological Society of America 25:268-274.

STIPANOVIC, R.D., BELL, A.A., O'BRIEN, D.H., and LUKEFAHR, M.J. 1977. Heliocide H2: an insecticidal sesterterpenoid from cotton *(Gossypium).* Tetrahedron Letter 6:567-570.

STIPANOVIC, R.D., BELL, A.A., O'BRIEN, D.H., and LUKEFAHR, M.J. 1978a. Heliocide H_1: A new insecticidal C25 terpenoid from cotton *(Gossypium hirsutum).* Journal of Agricultural and Food Chemistry 25:115-118.

STIPANOVIC, R.D., BELL, A.A., O'BRIEN, D.H., and LUKEFAHR, M.J. 1978b. Heliocide H3, an insecticidal terpenoid from *Gossypium hirsutum.* Phytochemistry 17:151-152.

TINGLE, F.C., MITCHELL, E.R., and BAUMHOVER, A.H. 1978. Sex pheromone specificity in *Heliothis.* Journal of Chemical Ecology 4:471 -479.

TUMLINSON, J.H., HENDRICKS, D.E., MITCHELL, E.R., DOOLITTLE, R.E., and BRENNAN, MM. 1975. Isolation, identification, and synthesis of the sex pheromone of the tobacco budworm. Journal of Chemical Ecology 1:203-214.

WAISS, A.C., Jr., CHAN, B.G., and ELLIGER, C.A. 1977. Host plant resistance to insects. Pages 117-121 *in* Host plant resistance to pests, ed. PA Hedin, ACS Symposium Series 62, American Chemical Society, USA.

WAISS, A C , Jr., CHAN, B.G., ELLIGER, C.A., WISEMAN, B.R., McMILLIAN, W.W., WIDSTROM, N.W., 2UBER, M.S., and KEASTER, A.J. 1979. Maysin, a flavone glycoside from corn silks with antibiotic activity toward corn earworm. Journal of Economic Entomology 72:256-258.

WILLIAMS, W.G., KENNEDY, G.G., YAMAMOTO, R.T., THACKER, J.D., and BORDNER, J. 1980. 2-Tridecanone: a naturally occurring insecticide from the wild tomato *Lycopersicon hirsutum* f. *glabratum.* Science 207:888-889.

The Chemist's Role in Host-Plant Resistance Studies

H. Rembold and E. Winter*

Abstract

Semiochemicals have been recognized as important factors in plant-insect interactions. Their terminology is explained. Recent work on crop-plant allomones is reviewed, with particular reference to their inhibitory effect on Heliothis *adults or larvae.*

First data on the chemical composition of exudates collected from chickpea (Cicer arietinum; *and pigeonpea* (Cajanus cajan) *varieties at ICRISAT are presented. In chickpea, the contents of malate—expressed* as *percentage of total dry matter-decrease with increasingly moist conditions, from 100 to less than* 50%. *Intervarietal differences in the capacity of malate excretion under stress conditions can be demonstrated.* Heliothis *damage is high with low malate concentration, and vice versa. A more complicated picture of repelling and attracting compounds is shown in the chemical analysis of pigeonpea exudates. Malate plays a minor role here, whereas various compounds not yet identified show intervarietal differences. Their occurrence and relative proportions under different environmental conditions are discussed.*

Finally, interaction of endogenous plant-specific factors and those originating from the environment and their involvement in host-plant x pest-insect interaction are described.

Résumé

*Rôle du chimiste dans les études sur la résistance de la plante-hôte: Les produits sémiochimiques (semiochemicals) ont été reconnus comme des facteurs importants dans les interactions plante x insecte. Leur terminologie est expliquée. Les études récentes sur les allomones plante-culture sont revues, avec référence particulière à leur effet inhibiteur sur les adultes ou larves d'*Heliothis.

Les premières données obtenues à l'ICRISAT sur la composition chimique des exsudats de variétés de pois chiche (Cicer arietinum) *et de pois d'Angole* (Cajanus cajan) *sont présentées. Chez le pois chiche, la teneur en malate—exprimée comme pourcentage de la matière sèche totale—diminue à mesure que l'humidité augmente, de 100 à moins de 50%. Des différences intervariétales dans la capacité d'excrétion du malate en conditions de stress peuvent être démontrées. Les dommages dus à l'*Heliothis *sont graves lorsque la teneur en malate est faible et vice versa. Chez les pois d'Angole, l'état des composés répulsifs et attractifs est plus compliqué, comme le montre l'analyse de exsudats de cette plante. Le malate ne joue ici qu'un rôle mineur, tandis que divers composés non encore identifiés montrent des différences intervariétales. Leur occurrence et proportions relatives sous différentes conditions environnementales sont discutées. Enfin, l'interaction des facteurs endogènes spécifiques à la plante et ceux originant de l'environnement et leur implication dans l'interaction plante-hôte x insecte-ravageur est décrite.*

The problems of environmental hazards often associated with conventional broad-spectrum insecticides and of an increasing number of insecticide-resistant pests are all too apparent. They have led to a search for more selective and biodegradable insecticides and to studies on host-plant resistance, insect attractants, use of natural enemies, autocidal techniques, and the integration of complementary techniques such as agronomic practices. However, many of these highly attractive approaches have proceeded only slowly or even failed to capitalize on new knowledge. There may be many reasons for this, such as economic constraints—broad-spectrum insecticides can be manufactured in bulk and sold for use against a wide array of pests—or organizational factors. However, our greatest barrier against the practical

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application of semiochemicals (from Greek *semeon,* a mark or signal) in plant protection comes from our ignorance in this no-man's land between basic and applied biology. During a relatively long period of complete reliance on conventional pesticides, the understanding of fundamental processes involved in plant-insect interaction has not been appreciated by the scientist. The translation of biological principles into chemical signals and their incorporation into applied programs therefore often fails in default of biological understanding on the chemist's as well as on the biologist's side. We have yet to recognize that the concept of integrated pest management must incorporate new aspects derived from semiochemicals. The real challenge of the future will be the biochemical understanding of the selection pressure arising from crop monocultures, which finally establishes a few main pests resistant against our traditional insecticide management. One of these pests may become *Heliothis.*

The semiochemicals (Law and Regnier 1971) are subdivided into two major groups, depending on whether the interactions between organisms are intraspecific (pheromones) or interspecific (allelochemicals). In their comprehensive review of semiochemicals and their role in pest control, Nordlund et al. (1981) tabulate the various kinds of chemical-releasing stimuli. Table 1 gives a shortened and simplified definition of this terminology. More familiar are the terms *arrestant, attractant, repellent, stimulant, and deterrent.* The combined use of both terminologies may be recommended, as a kairomone emitted by species A causing reactions in species B with beneficial results for B may be an attractant, arrestant, or stimulant tor species B.

Chemistry of Plant-Insect Interaction

When investigating the significance of semiochemicals in insect-plant interactions, the chemist's view is primarily directed to allelochemicals, i.e., substances interspecific in nature. The other group, the pheromones, has been proven as a potential tool in insect pest management (insect-trapping, c.f. Flint and van den Bosch 1981). How-

Table 1. Chemical-releasing stimuli.

Hormone:	A chemical agent produced by a tissue or endocrine gland. Controls physiological processes within an organism.
Semiochemical:	A chemical involved in the interaction between organisms.
1. *Pheromone:*	A substance externally secreted by an organism causing a specific reaction in a receiving organism of the *same* species.
2. *Allelochemical:*	A substance significant to an organism of a *different* species for reason other than food as such.
a. *Allomone* :	A substance produced by an organism of species A. Received by species B, it causes a reaction in B that is favorable to A, not to B.
b. *Kairomone:*	Similar to allomone, but reaction in B is favorable to B.
c. *Synomone:*	Similar to allomone, but reaction in B is favorable to A and B.
d. *Apneumone:*	A substance emitted by nonliving material, favorable to some species and *detrimental to* others.

Source: Nordlund (1981).

ever, a much more diverse and exciting field has become the study of insect-host-plant interactions.

Schoonhoven (1981) summarizes the present knowledge of the role of chemical mediators between plants and phytophagous insects in five theorems:

1. All plants have allomones that protect them from insects (and other organisms).
2. Some insect species tolerate the presence of allomones from certain plant species.
3. Some insect species exploit these substances and use them as kairomones in the recognition of their host plants.
4. Concomitant with behavioral preferences, physiological adaptations are present, maximizing the insect's nutritional efficiency on specific food plants.
5. Plant-insect relationships evolve continuously, and an apparent status quo exists only at the instant of our observation.

In this paper we will give examples for these five theorems, concentrating on *Heliothis* or lepidopterous species. The following work gives an insight into the chemical interaction of this insect with crop plants.

Bottger et al. (1964) had already found a relationship between gossypol content of cotton plants and their insect resistance. Lukefahr and Martin (1966) extended this work and incorporated the pigments of cotton into artificial diets for *Heliothis zea* and *Heliothis virescens* larvae, of which less than 30% reached the pupal stage when the diet contained 0.2% gossypol. Later, compounds other than gossypol (heliocides) were isolated from cotton and shown as toxic to *Heliothis virescens.* The substances are terpenoids (Stipanovic et al. 1978) or tannins and phenols (Hedin et al. 1980). From corn *{Zea mays)* a flavone-C-glycoside was isolated and proven to inhibit growth and development of *Heliothis zea* (Elliger et al. 1980), and in tomato leaves *(Lycopersicon esculentum)* the phenolic compounds (mainly flavonol glycosides like rutin) excreted by the glandular trichomes were shown to contribute substantially to the growth-inhibiting effect of these leaves on larvae of *Heliothis zea* (Duffey and Isman 1981).

Further plant allomones under investigation are the trypsin inhibitors in legume seeds (e.g., in chickpea, *Cicer arietinum,* Belew et al. 1975) that disturb the insect's digestion, and other allomones such as acetogenins, alkaloids, and aromatics, which are derived from shikimic acid and acetate (cf. Norris and Kogan 1980). Whereas these compounds have a detrimental effect on the insect's growth, others interfere with its endocrine system (precocene from *Ageratum houstonianum,* Bowers et al. 1976; azadirachtin from *Azadirachta indica,* Rembold and Sieber 1981).

In spite of the vast array of allomones present in the plant kingdom, there are insects that tolerate allomones even in plants containing well-known broad-spectrum insecticides, such as *Chrysanthemum, Derris,* and *Nicotiana.* Only a few cases have been analyzed in sufficient detail to elucidate the nature of tolerance. Many chemicals can be broken down by mixed-function oxidases of the insect gut or fat-body (Krieger et al. 1971), or be eliminated by other physiological mechanisms (review: Brattsten 1979). Here, plants and insects wage a continual evolutionary battle, as Schoonhoven (1981) mentioned in his final theorem, and chemists and plant breeders have to keep pace with this evolution.

In conclusion of this brief overview, we should not overlook the fact that plants also emit kairomones beneficial to the insects, mainly in their host-plant recognition. Lepidopterous larvae have a very small number of chemoreceptors, but yield a highly detailed image of the plant's chemical constitution (electrophysiological measurements, Schoonhoven 1969). The recognition of sugars and amino acids was investigated for larvae of *Heliothis zea* by Dethier and Kuch (1971). However, some substances that seem to be allomones may at the same time have a kairomone effect, as was demonstrated by an increased egg-laying of *Heliothis armigera* onto muslin cloth sprayed with malic acid from chickpea exudates compared with water-sprayed muslin (ICRISAT 1978/79).

In this complex and interwoven field of chemical interaction between plants and insects, it is difficult to determine the chemical basis of plant resistance to herbivorous attacks. Comparatively increased resistance of a certain plant species or variety is most certainly based on the special balance of repelling and attracting semiochemicals, their concentration in and on the aerial parts of the plant, the capacity of the plant to produce or excrete these chemicals, and the effect these chemicals have on the key insect pest. Other factors may be of equal importance, such as the life cycle of the plant and insect, insect population density during the life cycle of the plant, morphological defense mechanisms in the plant, nutritional status of the plant, and susceptibility to environmental changes.

The Concept of Concerted Interaction

From observation through many years, a series of chickpea (*Cicer arietinum)* and pigeonpea (Caja*nus cajan)* varieties has been selected at ICRISAT with a comparatively low susceptibility to *Heliothis* attack. These pedigrees offer a promising collection of semiochemicals for the analytical chemist. If should be possible to help the breeder in segregating new resistant varieties by following the presence of chemical signals quantitatively. These data can be collected in the glasshouse and then compared with field data. On this basis, we started a collaborative project with ICRISAT Pulse Entomology and the Max-Planck Institute (MPI), beginning about 1 year ago and financed by Deutsche Gesellschaft fur Technische Zusammenarbeit. This 2-year project has aimed at selection of 10 to 20 varieties with low, moderate, and high borer damage. These varieties are grown under three environmental situations: (1) on dry soil at ICRISAT, (2) on humid soil at ICRISAT, and (3) on humid soil in a glasshouse at MPI, Martinsried. Comparative analysis is made by GC, GC-MS, and HPLC primarily of their respective exudates.

The philosophy behind this initial program is to collect information on the following questions:

1. Are there prominent compounds present in the exudate that can be correlated with pod damage, seasonal differences between flowering and insect population, soil quality, humidity, and photosynthesis?
2. How does each of these varieties respond to stress situations? Is there a collapse in resistance factors? Are some of them more resistant than others? These data could help us to better understand the breakdown of some highly resistant varieties when transferred to other continents or even to other nearer locations.
3. How stable are the chemical characteristics in successive years, and eventually, under different conditions of climate, insect population density, flowering season, etc.?

After a period of 2 years, it should be clear whether such a chemical approach can add important information to the understanding of host-plant resistance to insect pests. If these questions can be positively answered—and the data from our first year's work already indicate that they can—then a second 3-year period of extensive biochemical, entomological, and fiela studies with carefully segregated breeding material will follow.

In principle, our chemical approach to the field of plant-insect relationship differs from those reviewed at the beginning of this paper. We use the concept of a concerted interaction of allelochemicals, which may be attractants and repellents for the larva, oviposition stimulants and deterrents for the adult female, or growth inhibitors for different developmental stages of certain pests. Only the orchestration of these many chemical signals induces the response on the insect's side.

Malate Excretion and *Heliothis* Damage in Chickpea

Both *Cicer arietinum* and *Cajanus cajan have* glands on their whole surface. In chickpea, these glands excrete large amounts of a fluid, visible as droplets all over the plant. Exudation depends on temperature and growth stage and increases towards the reproductive stage (Koundal and Sinha 1981). The exudate can easily be collected with cotton plugs in amounts of milliliters, and we have used this method for a first screening of 12 chickpea varieties that were either grown on dry soil or on a spot near Lake ICRISAT (Table 2). All the samples were extremely acidic, with pH value close to 1.2, which explains the well-known repelling effect of the exudate. The malic acid (malate), contained in concentrations of 10 to 56%, is responsible for the low pH, and the susceptibility to *Heliothis* attack follows these concentrations (Rembold 1981) In other words, borer damage was found low in chickpea varieties that excrete highly concentrated malic acid.

Are there any other compounds contained in the exudates of the 12 chickpea varieties mentioned? Figure 1 gives the malate amounts contained in the dry matter. There are, of course, intervarietal differences; malate is the main component, with about 70 to 100% and there may be other compounds present, which may also function as allelochemicals. However, carefully collected data on pod damage and *Heliothis* population in the test plots are still lacking.

These preliminary data already demonstrate that in exudates collected in the field near the lake, the proportion of malate in the dry matter was generally lower, and *Heliothis* damage was always higher than in the same cultivars on dry soil. These analytical data demonstrate a sensitive reaction of the chickpea's metabolism to its environment. This

Table 2. Borer damage (%) in chickpea samples collected from unsprayed plots: location 1 (BA27) and location 11 (BA24A) at ICRISAT farm, poatralny season, 1980-81.

		Location 1 BA27 (dry)		Location II BA24(A) (Wet)	
Sample No.	Pedigree	Days to 50% flowering	Mean pod damage (%)	Days to 50% flowering	Mean pod damage (%)
1	ICC-506	54	2.0	49	5.5
2	850-3/27	79	8.1		NA
3	Annigeri-1	58	6.3	49	22.6
4	C-235	96	7.6	77	13.0
5	G-130		NA	84	21.7
6	ICC-5716	56	4.8		NA
7	ICC-3999	93	4.6	74	11.9
8	JG-74	58	9.1		NA
9	ICC-5264	103	6.4	77	19.6
10	L-550	86	14.4	63	18.6
11	ICCL-78009		NA	63	18.0
12	ICC-10619		NA	56	4.8

becomes dramatically evident if exudates are analyzed from the same varieties grown in our glasshouse at Martinsried: malate content in the dry matter is generally reduced. However, some of the varieties are more stable in their malate excretion under these conditions than others. The exudates in the dry matter also contain a series of other compounds, some of which may act as attractants and so explain the breakdown of resistance under changing environmental conditions (Rembold 1980). Interestingly enough, in the glasshouse experiment, the exudates show the same intervarietal differences as under moist conditions at ICRISAT. This fact points to a variation of the genetic capability amongst cultivars to produce malate, which needs to be studied in *more* detail.

Composition of Exudates vs *Heliothis* Resistance in Pigeonpea

In contrast to chickpea, the surface in pigeonpea is velvety, but without visible droplets. We therefore collected the exudate by washing the pods with methanol.

In pigeonpea, two main insect pests endanger yields: *Heliothis armigera* and *Melanagromyza obtusa.* Figure 2 shows that the pod damage caused by *H. armigera* is higher than that caused by *M. obtusa* and mainly occurs in the early or mid-flowering cultivars, abating in the late-flowering ones, when *M. obtusa* starts its attack. The cultivars were ordered according to their flowering times to show a possible interrelation of damage rates with insect population densities (data we still have to add to this scheme). Low *Heliothis* damage in late-flowering cultivars may be due to a low insect population, but within the mid-flowering cultivars there are some outstandingly susceptible ones (7 and 14). Gas chromatography of silylated dried samples of pod washings showed that either an extremely high content of total sugars in combination with a moderate amount of an unidentified substance with a retention time of 434 seconds (cultivar 14), *or* low sugar contents with very low amounts of the unidentified substance (cultivar 7), are associated with highly damaged pods. Sugars and other substances seem to counteract by attracting, and repelling, respectively, the insect. Malate seems to play a subordinate role in pigeonpea exudates, as its concentration is rather low.

Not all chemical components can be volatilized for GC analysis; therefore, HPLC was additionally used. One peak of the diverse chromatograms (Fig. 3) showed obvious intervarietal differences (Fig. 2, peak eluting after 474 sec.) that are similar to those of the substance detected by GC analysis. HPLC-isolation and silylation with subsequent GC analy-

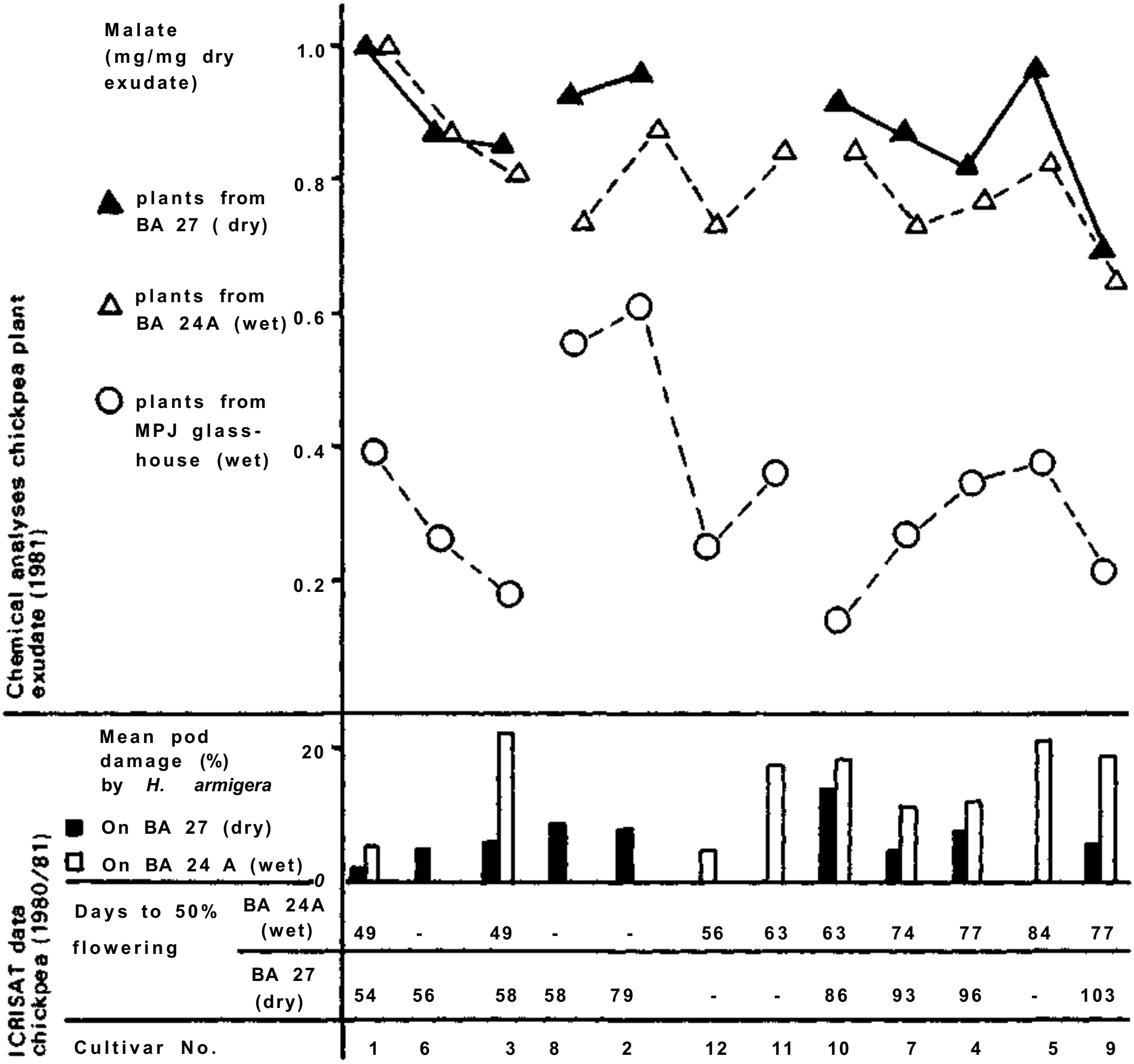

Figure 1. Pod damage and malate contents in the dry exudate of 12 chickpea cultivars (Cicer arietinum) *listed according to days to 50% flowering. Malate contents of the exudates from plants grown at a dry location on ICRISAT fields (▲), under wet soil conditions there (Δ), and from a glasshouse experiment at the Max-Planck Institute, Germany (o). Malate was measured as TMS-derivative by glass capillary (SE 30) G C (Carlo Erba Fractovap with FID) and quantified by means of an integrator (Spectraphysics). For more details see Table 2.*

sis showed that the two substances show similar intervarietal differences but are not identical. So far, two repellent substances have been pointed out but not yet chemically identified or checked for their function as isolated substances in a bio-test. The influence of environmental conditions on the quantity and chemical composition of the pigeonpea exudates is being investigated in a glasshouse experiment at MPI and is currently being examined from wet and dry fields at ICRISAT.

Conclusions

The basic concept of plant-insect interaction through a chemical signal has become more and

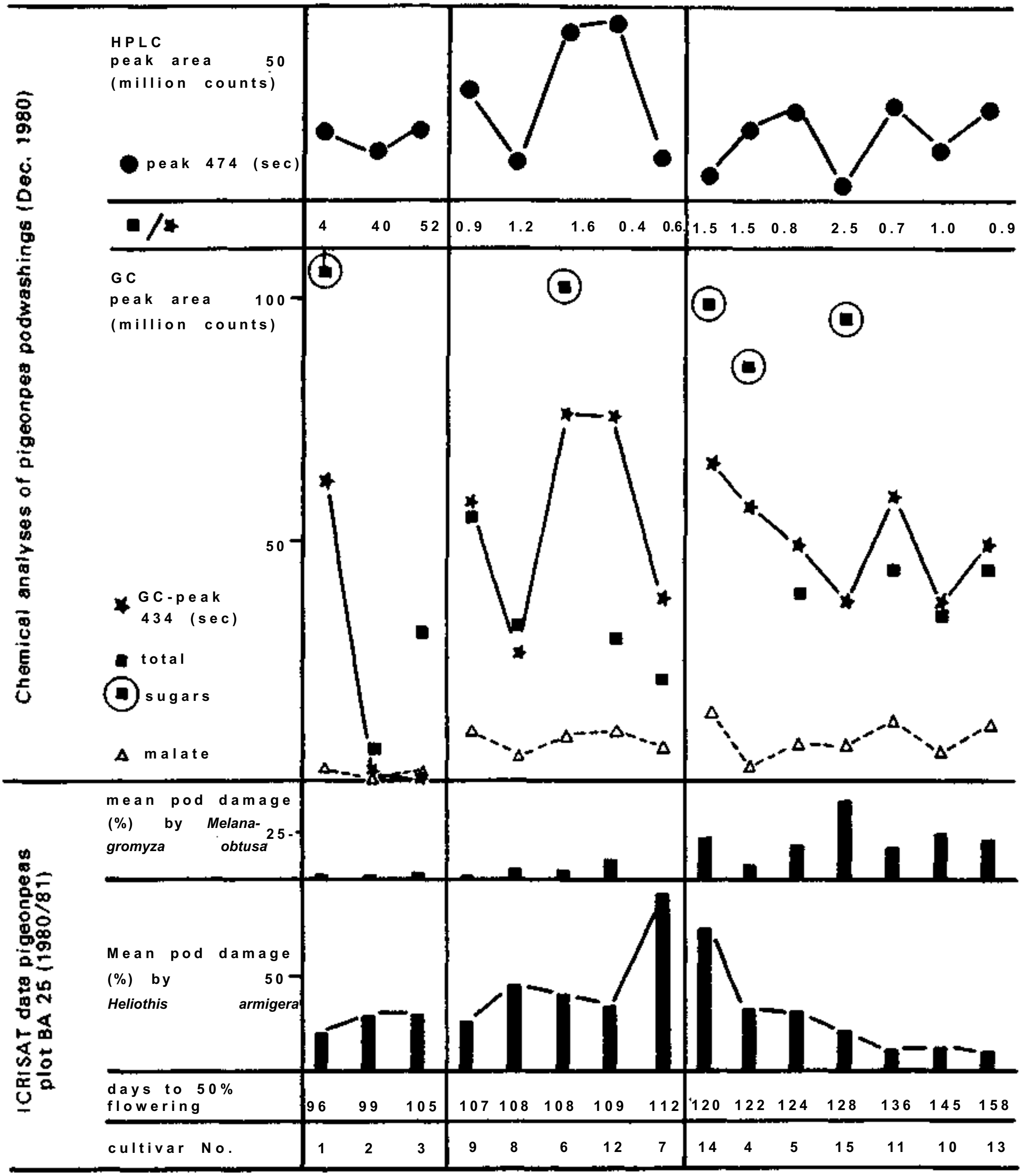

Figure 2. Pod damage and occurrence of various substances in the pod exudates of 15 pigeonpea cultivars 9Cajanus cajan) listed according to days to 50% flowering. For GC, the TMS-derivatives were used. For technical details compare Figure 1; cultivars are listed In Table 3.

Table 3. Percentage pod damage In pigeonpea pod samples collected from unsprayed block (BA25) at ICRISAT farm, rainy season 1980-81.

Sample No.	Pedigree	Days to 50% flowering	Pod damage mean (%)		
			Borer	Podfly	Total
1	PPE-45-E2	96	18.1	2.3	23.9
2	ICP 7203-E1	99	28.2	1.2	29.7
3	7349-1-S4 [redacted]	105	28.2	2.5	31.2
4	7946-E1	122	32.9	5.7	39.1
5	3615-E1	124	30.4	17.4	49.3
6	1691-E1	108	40.1	3.3	45.3
7	7050-EB	112	93.8	0.7	95.0
8	C-11	108	43.9	3.5	51.7
9	Intg-1914-E2	107	25.2	1.9	27.5
10	ICP-7176-18-E2	145	13.0	23.0	45.7
11	8134-1 [redacted]	136	11.2	16.1	37.2
12	810-E1	109	32.5	9.9	43.9
13	6443-EB	158	11.0	20.4	50.4
14	6915-EB	120	76.2	20.2	98.2
15	7337-2-S4 [redacted]	128	18.1	39.4	76.1
16	*Atylosia scarabaeoides*		2.5	0.0	3.4
17	*Atylosia sericea*		1.1	0.0	1.1

more complicated with the detection of a multiplicity of compounds with agonistic or antagonistic effects on the pest insect. As plant protection primarily means dealing with monocultures, one can, at least in principle, understand the immense selection pressure acting on the insect populations. If we want to protect our crops by methods other than toxic chemicals, we need a great deal of information about the host's and the insect's biochemistry, which is not available at present. The concept of semiochemicals will hopefully attract more scientists back to the no-man's land of new approaches to pest control.

This integration of basic research with agricultural problems of crop protection has been started in our collaborative project with ICRISAT, and first-still preliminary—data have been given, which may be summarized as follows. The two pulses under investigation obviously use two different methods for their protection. In chickpea, the excretion of a highly acidic compound in sometimes remarkably high concentrations of more than 50% of the exudate, repels almost every insect. However, *Heliothis* sometimes feeds even on this ideally protected plant. Future studies will have to clarify the presence of other semiochemicals besides the predominant malic acid. Quite another principle is being used by pigeonpea. Here the concept of a concerted action of semiochemicals is extensively used. If compared with pod damage, some compounds are active as allelochemicals, others are inactive. It is obvious from these data that our basic approach of an analytical screening for marker compounds of varieties with different susceptibility has been successful already and will have to be extended in the future. However, it is most important now to correlate these biochemical markers and their quantity with insect behavior and crop-plant metabolism under different environmental conditions. From such studies we will get more information about the extremely complicated orchestration of the genetic, physiological, physical, and chemical factors that continuously influence the insect pest as well as its host. Only such an interdisciplinary endeavor will promote the concept of integrated pest management.

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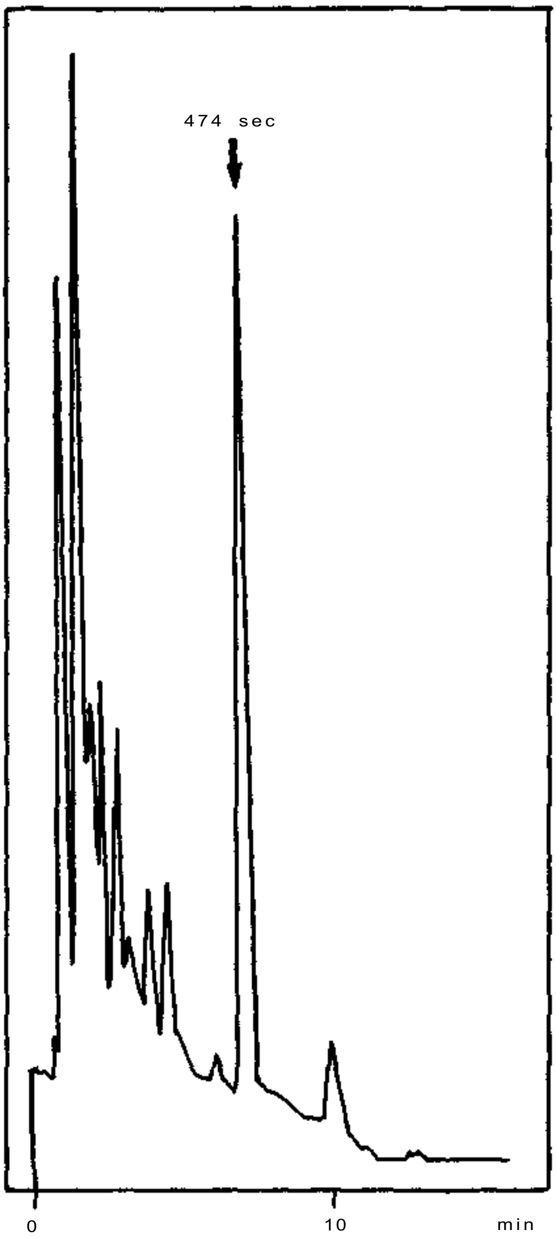

Figure 3. Characteristic HPLC chromatogram of the methanoiic pod washings of Cajanus cajan *plants from ICRISAT field trials. The arrow points to the peak at 474 sec, the substance expressed in Figure 2, upper part, for all varieties. For HPLC Pye Unicam equipment (PU 4010 Pump, LC-UV-Detector, PM 8252 Recorder) was used. Analytical wavelength 215 nm. Column: ODS Hypersil (5 µ), 250 x 5 mm. Eluent: 65% methanol in water.*

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References

BELEW, M., PORATH, J., and SUNDBERT, J. 1975. The trypsin and chymotrypsin inhibitors in chick peas (Cicer *arietinum* L.). European Journal of Biochemistry 60: 247-258.

BOTTGER, G.T., SHEEHAN, E.T., and LUKEFAHR, M.J. 1964. Relation of gossypol content of cotton plants to insect resistance. Journal of Economic Entomology 57(2):283-85.

BOWERS, W.S., OHTA, T., CLEERE, J.S., and MARSELLA, P.A. 1976. Discovery of insect anti-juvenile hormones in plants. Science 193: 542-547.

BRATTSTEN, L.B. 1979. Biochemical defense mechanisms in herbivores against plant allelochemics. Pages 190-270 *in* Herbivores: their interaction with secondary plant metabolites, eds. G.A. Rosenthal and D.H. Janzen. New York, USA: Academic Press.

DETHIER. V.G., and KUCH, J.H. 1971. Electrophysiological studies of gustation in lepidopterous larvae. I. Comparative sensitivity to sugars, amino acids and glycosides. Zeitschrift fur vergleich ende Physiologie 72: 343-363.

DUFFEY, S.S., and ISMAN, M.B. 1981. Inhibition of insect larval growth by phenolics in glandular trichomes of tomato leaves. Experientia 37: 574-576.

ELLIGER, C.A., CHAN, B.G., WAISS, A.C., Jr., LUDIN, R.E., and HADDON, W.F. 1980. C-glycosylflavones from *lea mays* that inhibit insect development. Phytochemistry 19: 293-297.

FLINT, M.L., and VAN DEN BOSCH, R. 1981. Introduction to integrated pest management. New York, USA: Plenum Press.

HEDIN, P.A., COLLUM, D.H., WHITE, W.H., PARROTT, W.L., LANE, H.C., and JENKINS, J.N. 1980. The chemical basis for resistance in cotton to Heli*othis* insects. Pages 1071 -1086 *in* Scientific Papers of the Institute of Organic and Physical Chemistry of Wroclaw *Technical University* No.22, eds. F. Sehnal, A. *Zabza, J.J.* Menn and B. Cymborrowsky. Wroclaw Technical University Press, Wroclaw, Poland.

ICRISAT. 1979. Pulse Entomology (chickpea) Departmental Progress Report-4, Patancheru, A.P., India. Mimeographed.

KOUNDAL, K.K., and SINHA, S.K. 1981. Malic acid exudation and photosynthetic characteristics in *Cicer arietinum.* Phytochemistry 20(6):1251-1252.

KRIEGER, R.I., FEENY, *P.P.,* and WILKINSON, C.F. 1971. Detoxication enzymes in the guts of caterpillars: an evolutionary answer to plant defenses? Science 172: 579-581.

LAW, J.H., and REGNIER, F.E. 1971. Pheromones. Annual Review of Biochemistry 40: 533-548.

LUKEFAHR, M.J., and MARTIN, D.F. 1966. Cotton-plant pigments as a source of resistance to the bollworm and tobacco budworm. Journal of Economic Entomology 59(1):176-179.

NORDLUND, D.A., JONES, R.L., and LEWIS, W.J. (eds.) 1981. Semiochemicals: their role in pest control. New York, USA: Wiley.

NORDLUND, D.A. 1981. Semiochemicals: a review of the terminology. Pages 13-28 *in* Semiochemicals, their role in pest control, eds. D.A. Nordlund, R.L. Jones, and W.J. Lewis. New York, USA: Wiley.

NORRIS, D.M., and KOGAN, M. 1980. Biochemical and morphological bases of resistance. Pages 23-61 *in* Breeding plants resistant to insects, eds. F.G. Maxwell and PR. Jennings. New York, USA: Wiley.

REMBOLD, H. 1980. Chemical aspects of plant resistance against insects. Transactions Bose Research Institute 43: 53-63.

REMBOLD, H. 1981. Malic acid in chickpea exudate—a marker for *Heliothis* resistance. International Chickpea Newsletter 4: 18-19.

REMBOLD, H., and SIEBER, K.P. 1981. Inhibition of oogenesis and ovarian ecdysteroid synthesis by azadirachtin in *Locusta migratoria migralorioides* (R.+ F). Zeitschrift fur Naturforschung 36: 466-469.

SCHOONHOVEN, L.M. 1969. Gustation and food-plant selection in some, lepidopterous larvae. Entomologia Experimentalis et Applicata 12: 555-564.

SCHOONHOVEN, L.M. 1981. Chemical mediators between plants and phytophagous insects. Pages 31 -50 *in* Semiochemicals, their role in pest control, eds. D.A. Nordlund, R.L. Jones, and W.J. Lewis. New York, USA: Wiley.

STIPANOVIC, R.D., BELL, A.A., O'BRIEN, D.H., and LUKEFAHR, M.J. 1978. Heliocide H; A new insecticidal C25 terpenoid from cotton (*Gossypium hirsutum).* Journal of Agricultural and Food Chemistry 26(1):115-118.

Progress in Research on Chemical Aspects of Host-Plant Resistance to *Heliothis* zea in Corn, Soybean, and Tomato

A.C. Waiss, Jr., R.G. Binder, B.G. Chan, C.A. Elliger and D.L. Dreyer*

Abstract

Inhibitors of Heliothis zea *larval growth have been isolated from corn, soybean, and tomato plants, and have been identified. Isolation procedures, biological activities, and significance of these compounds in plant resistance to* H. zea *are discussed.*

Résumé

Aspects chimiques de la résistance de la plante-hôte à Heliothis zea *chez le maïs, le soja et la tomate: Des inhibiteurs de croissance de la larve d'*Heliothis zea *ont été isolés à partir de plants de maïs, de soja et de tomate et identifiés. Les procédures d'isolation, les activités biologiques et le rôle de ces composés dans la résistance de la plante à* H. zea *sont discutés.*

For several years, our research group in California has tried to determine phytochemical bases tor the resistance to insect pests shown by some economically important host plants. We hope to become able to use specific analyses of plant chemicals to recognize plants that have good likelihood of showing resistance and thereby help plant breeders and entomologists select more efficiently for insect-resistant plant varieties.

This paper reports some of the work done and progress made in isolating and identifying growth inhibitors of *Heliothis zea* larvae from corn, soybean, and tomato and to discuss the roles of these compounds in plant protection. I shall omit our contributions to the understanding of cotton-H. *zea* interactions because this work is well documented elsewhere (Chan et al. 1978a, 1978b; Elliger et al. 1978; Waiss et al. 1981a, 1981b).

H. zea Larval Growth Inhibitors in Corn

The resistance of certain corn varieties to attack by corn earworm has been ascribed both to chemical and morphological factors. These factors, with perhaps varying degrees of effectiveness, might operate separately or possibly synergistically.

The presence in corn silk of a factor lethal to corn earworm larvae was reported by Walter (1957) and confirmed by Wann and Hills (1966). However, no work relating chemical composition of corn silk to biological activity was reported until recently, when—with the cooperation of scientists at the Small Grain Insect Laboratory, Tifton, Georgia, and the University of Missouri, Columbia, Missouri—we isolated a novel compound from the methanolic extract of silk of a resistant line (var. Zapalote Chico), chemically characterized this compound, maysin, and showed that it was an effective larval growth inhibitor for *H. zea* (Waiss et al. 1979). Growth of corn earworm larvae fed 0.15% (w/w) maysin in a synthetic diet for 12 days was only 50% as much as for larvae fed control diet. In addition to maysin, the 3'-methyl ether and 3'-de-oxy derivatives of maysin were also isolated from Zapalote Chico silk (Elliger et al. 1980a). These compounds occur at lower concentrations than maysin and are less active against *H. zea.*

Maysin has an absorption maximum at 352 nm in the ultraviolet spectrum. Therefore, comparison of relative absorptivities of corn-silk extracts at this wavelength has been used as a measure of relative and maximum maysin content in corn silk.

In 1980, nine corn genotypes planted at five locations (Tifton, Georgia; Geneva, New York; Columbia, Missouri; Union City, Tennessee; and

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Oahu, Hawaii) were evaluated for relative maysin content of their silk. Initial results indicate that there is little correlation between the amount of maysin in the silk and the location of the planting, regardless of differences in climate and daylength. What may be especially interesting and important is that maysin content varies greatly (up to 20-fold) within a corn line and that crosses between corn varieties produce F_1 offspring with higher maysin levels in their silk than is found in the silk of either parent. We therefore hope that the use of a recurrent selection technique in breeding could be used to increase maysin content and thereby increase resistance to corn earworm.

Data from the interregional experiment also indicate that the amount of maysin in corn silk diminishes as much as 80% in the 20 days after anthesis (pollination). We hypothesize that changes in the silk after pollination allow reaction of polyphenol oxidase with the polyphenolic maysin to give polymeric compounds. These polymeric compounds, similar to condensed tannin (Chan et al. 1978b), also inhibit growth of corn earworm larvae; thus simply determining maysin content would not give an adequate estimation of the antibiotic potential of the corn silk. Currently, efforts in our laboratory are directed toward developing an improved analysis for total phenolic compounds in corn silk. Subsequently, observations of corn-earworm damage will be compared with content of phenolic compounds in the silk.

Antibiotic Constituents of Soybean

In a comparison of experimental and commercial cultivars of soybean, Clark et al. (1972) found several cultivars that exhibited significantly greater resistance to the bollworm than did the commercial cultivars. Among larvae fed on the plant introductions, mortality was higher, weight gains were reduced, and time to pupation was longer than in larvae fed on commercial cultivars (Hatchett et al. 1976). In larvae fed PI-229358 leaves, mortality occurred predominantly in the later instars and appeared to be due to difficulties in molting (Beland and Hatchett 1976). Differences in mortality were attributed to differences in the age of leaves fed and to stage of plant growth (Beland and Hatchett 1976; McWilliams and Beland 1977).

In one study, two insect-resistant and two susceptible soybean cultivars were analyzed at different growth stages for their contents of total nitrogen, carbohydrates, organic acids, and sterols (Tester 1977). The resistant cultivars had lower nitrogen content, a larger amount of soluble carbohydrates, and at flowering and pod-filling, a greater amount of sterols. Recently, Grunwald and Kogan (1981) determined the sterol composition of insect-susceptible and -resistant soybean varieties and lines and concluded that resistance to insect attack is not due to a sterol imbalance or unusual sterol makeup of the soybean leaf. Analyses of benzoic and cinnamic acid derivatives from injured and noninjured leaves of a resistant and a susceptible cultivar (Hardin 1979) showed differences in amounts from these tissues. However, even the highest concentration found seems, based on our bioassays with these compounds (Chan, unpublished), to be too low to be effective in antibiosis to *H. zea.*

To bioassay soybean phytochemicals, we incorporate leaf extracts or fractions thereof in an artificial diet for the bollworm (Chan et al. 1978c). When extracts of dry leaves are obtained by successive extraction with heptane, ethyl acetate, acetone, methanol, and water and put into the bollworm diet in amounts essentially equivalent to amounts obtainable from fresh leaves, larvae fed a diet containing the heptane, ethyl acetate, or acetone extracts weigh modestly more at 12 days old than do control larvae. However, they weigh substantially less when fed diet containing the methanol or water extracts, being generally 40 to 75% the size of control larvae. If fed combined methanol and water extracts, larvae at 12 days are about one-third the size of control larvae.

From the methanol extract, we have isolated a compound that seems to be largely responsible for the weight-gain reduction activity of this extract. This compound is pinitol, a monomethyl ether of chiro-inositol, also found in soybean leaves in smaller amounts. With 0.7% pinitol in their diet, 12-day-old larvae were 50% the size of control larvae (Dreyer et al. 1979). What is the role of pinitol in soybean host-plant resistance? This is difficult to answer. Content of pinitol in soybean leaves is variable, depending on cultivar, stage of development, age of leaf on the plant, and even time of day (Dougherty 1976; Binder unpublished). Indeed, pinitol has been identified as a feeding stimulant for another lepidopteran, the yellow butterfly (Numata et al. 1978)!

We are trying to identify compounds in the water extract that restrict larval growth but do not have a specific identification yet.

Feeding larvae the methanol and water extracts lengthens the time to pupation, but the majority do successfully pupate and emerge. An interestingly different situation prevailed for larvae fed the heptane extract of PI-229358 soybean leaves. Throughout their development they were as large as controls or larger, yet the majority was unable to pupate successfully. Mean day of death was 20.8, whereas mean day of pupation was 17.3 for control larvae. Overall mortality was about 85%. Larvae fed a combination of all extracts experience both delayed pupation and high mortality.

Clearly, feeding of leaf extracts evinces much of the antibiotic activity that is given by feeding of leaves and thus offers us encouragement in our search for phytochemicals responsible tor host-plant resistance.

H. zea Larval Growth Inhibitors in Tomato

The presence of chemical factors in tomato leaves antibiotic to *H. zea* was reported by Fery and Cuthbert in 1975. Later, Cosenza and Green (1979) gave evidence for both nonpreference and antibiosis to account for reduced damage in certain tomato lines. Recently, Williams et al. (1980) discovered 2-tridecanone in the wild tomato Lycoper*sicon hirsutum* f. *glabratum,* described it as a natural pesticide, and suggested improving the insect resistance of domestic tomatoes by breeding with the wild variety.

In our laboratory, we found that not one compound but rather a group of diverse compounds is responsible for the reduction of *H. zea* damage to tomato plants (Elliger et al. 1981). These compounds are tomatine, a glycoalkaloid that is feeding deterrent to the potato beetle and other insect pests of potato; rutin; chlorogenic acid; and caffeyl esters of glucaric acid. The effectiveness of rutin in retarding the growth of *Heliothis* species has been reported (Lukefahr and Martin 1966; Chan et al. 1978a) and the presence of rutin in the glandular trichomes of tomato plants has been suggested as a factor in the inhibition of larval growth on tomato plants (Duffey and Isman 1981).

References

BELAND, G.L., and HATCHETT, J.H. 1976. Expression of antibiosis to the bollworm in two soybean genotypes. Journal of Economic Entomology 69:557-560.

CHAN, B.G., WAISS, A.C., Jr., BINDER, R.G., and ELLIGER, C.A. 1978a. Inhibition of Lepidopterous larval growth by cotton contituents. Entomologia Experimentalis et Appllcata 24:94-100.

CHAN, B.G., WAISS, A.C., Jr., and LUKEFAHR, M.J. 1978b. Condensed tannin, an antibiotic chemical from Gossypium *hirsutum.* Journal of Insect Physiology 24:113-118.

CHAN, B.G., WAISS, A C, Jr., STANLEY, W.L., and GOODBAN, A.E. 1978c. A rapid diet preparation method for antibiotic phytochemical bioassay. Journal of Economic Entomology 71:366-368.

CLARK, W.J., HARRIS, F.A., MAXWELL, F.S., and HARTWIG, E.E. 1972. Resistance of certain soybean cultivars to bean leaf beetle, striped blister beetle and bollworm. Journal of Economic Entomology 65:1669-1672.

COSENZA, G.W., and GREEN, H.B. 1979. Behavior of the tomato fruitworm, *Heliothis zea* (Boddie), on susceptible and resistant lines of processing tomatoes. Horticultural Science 14:171-173.

DOUGHERTY, D.E. 1976. Pinitol and other soluble carbohydrates in soybean as factors in facultative parasite nutrition. Ph.D. thesis, University of Georgia, Ga, USA.

DREYER, D.L., BINDER, R.G., CHAN, B.G., WAISS, A.C., Jr., HARTWIG, E.E., and BELAND, G.L. 1979. Pinitol, a larval growth inhibitor for *Heliothis zea* in soybean. Experientia 35:1182-1183.

DUFFEY, S.S., and ISMAN, M.B. 1981. Inhibition of insect larval growth by phenolics in glandular trichomes of tomato leaves. Experientia 37-574-576.

ELLIGER, C.A., CHAN, B.G., and WAISS, A.C. Jr., 1978. Relative toxicity of minor cotton terpenoids compared to gossypol. Journal of Economic Entomology 71:161-164.

ELLIGER, C.A., CHAN, B.G., WAISS, A.C. Jr., LUNDIN, R.E., and HADDON, W.F. 1980a. C-Glycoflavones from *Zea mays* that inhibit insect development. Phytochemistry 19:293-297.

ELLIGER, C.A., CHAN, B.G., and WAISS, A.C. Jr., 1980b. Flavonoids as larval growth inhibitors: structural factors governing toxicity. Naturwissenschaften 67:338-339.

ELLIGER, C.A., WONG, Y., CHAN, B.G., and WAISS, A.C., Jr., 1981. Growth inhibitors in tomato *(Lycopersicon)* to tomato fruitworm *{Heliothis zea*). Journal of Environmental Ecology (in press).

FERY, R.L., and CUTHBERT, F.P. 1975. Antibiosis in *Lycopersicon* to tomato fruitworm *(Heliothis zea).* Journal of the American Society of Horticulture 100:276-278.

GRUNWALD, C., and KOGAN, M. 1981. Sterols of soybeans differing in insect resistance and maturity group. Phytochemistry 20:765-768.

HARDIN, J.M.T. 1979. Phenolic acids of soybeans resistant and nonresistant to leaf feeding larvae. M.S. thesis, University of Arkansas, Fayetteville, Ark, USA.

HATCHETT, J.H., BELAND, G.L., and HARTWIG, E.E. 1976. Leaf-feeding resistance to bollworm and tobacco budworm in three soybean plant introductions. Crop Science 16.277-280.

LUKEFAHR, M.J., and MARTIN, D.F. 1966. Cotton plant pigments as a source of resistance to the bollworm and tobacco budworm. Journal of Economic Entomology 59:176-179.

McWILLIAMS, J.M., and BELAND, G.L. 1977. Bollworm: effect of soybean leaf age and pod maturity on development in the laboratory. Annals of the Entomological Society of America 70:214-216.

NUMATA, A., HOKIMOTO, K., SHIMADA, A., YAMAGUCHI, H., and TAKAISHI, K. 1978. Feeding stimulants for the larvae of the yellow butterfly, *Eurema hecabe mandarina* (Lepidoptera: Pieridae). Applied Entomology and Zoology 13(2):133-135.

TESTER, C.T. 1977. Constituents of soybean cultivars differing in insect resistance. Phytochemistry 16:1899-1901.

WAISS, A.C., Jr., CHAN, B.G., ELLIGER, C.A., WISEMAN, B.R., McMILLIAN, W.W., WIDSTROM, N.W., ZUBER, M.S., and KEASTER, A.J. 1979. Maysin, a flavone glycoside from corn silks with antibiotic activity. Journal of Economic Entomology 72:256-258.

WAISS, A.C., Jr., CHAN, B.G., ELLIGER, C.A., and BINDER, R.G. 1981a. Biological active cotton constituents and their significance in HPR. Pages 61 -63 *in* Proceedings, Beltwide Cotton Improvement Research Conference, 5-10 Jan 1981, New Orleans, La, USA.

WAISS, A.C., Jr., CHAN, B.G., ELLIGER, C.A., DREYER, D.L., BINDER, R.G., and GUELDNER, R.C. 1981b. Insect growth inhibitors in crop plants. Bulletin of the Entomological Society of America. (In press.)

WALTER, E.V. 1957. Corn earworm lethal factor in silk of sweet corn. Journal of Economic Entomology 50:105-106.

WANN, E.V., and HILLS, W.A. 1966. Earworm resistance in sweet corn at two stages of ear development. American Society of Horticultural Science 89: 491 -496.

WILLIAMS, W.G., KENNEDY, G.G., YAMAMOTO, R.T., THACKER, J.D., and BORDNER, J. 1980. 2-Tridecanone: A naturally occurring insecticide from the wild tomato *Lycopersicon hirsutum* f. *glabratum.* Science 207:888-889.

Techniques for Efficient Mass Rearing and Infestation in Screening for Host-Plant Resistance to Corn Earworm, *Heliothis zea*

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Abstract

This paper presents the experience accumulated and techniques developed at CIMMYT (Centro Internacional de Mejoramiento de Maiz Y Trigo) in Mexico and other locations where Heliothis *species are being mass reared. Emphasized are techniques tor efficient rearing—establishment of the insect colony, the rearing facility, diet—and artificial infestation in screening and improving host-plant resistance to* H. zea *in maize. These techniques show promise of being adaptable to other pest species, crop species, and screening /breeding initiatives in other parts of the world. Finally, methods of efficient field infestation and rating scales used to evaluate ultimate damage and genotype resistance reactions are described.*

Résumé

Techniques efficaces d'élevage de masse et d'infestation lors du criblage pour la résistance de la plante-hôte à Heliothis zea: *Cette communication décrit l'expérience acquise et les techniques mises au point au CIMMYT (Centro Internacional de Mejoramiento de Maiz y Trigo), au Mexique, et sur d'autres sites où les espèces d'*Heliothis *sont élevées massivement. L'accent est mis sur des techniques d'élevage efficaces — établissement des colonies d'insectes, installations d'élevage, régime alimentaire — et l'infestation artificielle lors du criblage et l'amélioration de la résistance de la plante-hôte à* H. zea *chez le maïs. Ces techniques semblent bien adaptées à d'autres espèces de ravageurs, espèces de cultures et projets de criblage/amélioration dans d'autres parties du monde. Enfin, des méthodes d'infestation efficaces sur le terrain et des échelles d'évaluation servant à mesurer la perte finale et les réactions de résistance des génotypes sont décrites.*

The practice of growing varieties, lines, or hybrids resistant to attack by insects, and their subsequent effectiveness in reducing pest populations and corresponding crop losses, is well documented for several agricultural crops and pest species.

The development of many of these resistant cultivars has resulted from or been facilitated by (1) many years of study of the insect pests, (2) the development of techniques to mass rear the insects, artificially infest, and screen the germplasm of the crop species (or their wild relatives) for resistance, and (3) the successful application of appropriate breeding procedures for improvement of the resistance characteristic over succeeding cycles or generations of population improvement (Guthrie 1974, 1980).

The basic components necessary to identify or develop germplasm with resistance, or with higher levels of resistance than cultivars now utilized, include:

1. A colony of the insect species that exhibits the vigor and vitality of the damaging pest population within the geographical area that is affected.
2. The capability to efficiently mass culture the pest species, including: rearing facility; trained personnel; natural, meridic, or defined diets; and rearing procedures and containers.
3. Germplasm resources that are representative of the genetic variation within the crop and/or its closely related species.

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4. Methods of uniform artificial infestation.
5. Methods of assessing resultant damage, or absence thereof, to the plants subjected to deliberate infestation (rating scales to determine classes or categories of resistance or susceptibility).
6. Screening, to determine whether adequate levels of resistance exist within suitable agronomic types (equivalent or better than currently grown cultivars), and an effective selection/breeding scheme established to improve either the resistance levels or the agronomic characteristics of the "improved" materials.

This paper will present the experience accumulated and techniques developed at CIMMYT over the past 6 years for efficient mass rearing and infestation in screening and improving host-plant resistance to the corn earworm, *Heliothis zea* (Boddie), in maize. (Fig. 1 a shows the species, of *Heliothis* occurring in Mexico.) The techniques described show promise of being adaptable to other pest species, crop species, and screening/breeding initiatives in other parts of the world.

These techniques include the establishment of the insect colony and basic requirements for efficient mass rearing. The latter focuses on the rearing facility, diet, and rearing containers, and on the rearing procedures for the various life stages of *Heliothis zea.*

The paper goes on to explain a method of efficient field infestation and concludes with a description of the rating scales used to evaluate resultant damage, which aids in the identification of resistant genotypes.

Establishment of the Insect Colony

Guidelines established and recommended by some entomologists who have developed crop cultivars with resistance (Guthrie 1980), and proven by experience under CIMMYT conditions, are followed to maintain a healthy, vigorous *H. zea* colony.

As there is only one crop and infestation cycle per year in the tropical highlands of Mexico, the earworm colony is replaced, or rejuvenated, by using: (1) progeny of larvae collected from a late-planted trap crop of sweet corn (Fig. 1b), or (2) progeny of adults captured in a light trap in spring at the beginning of the rainy season (Fig. 1c). The colony is replaced or genetically mixed with wild stock at least every ten generations.

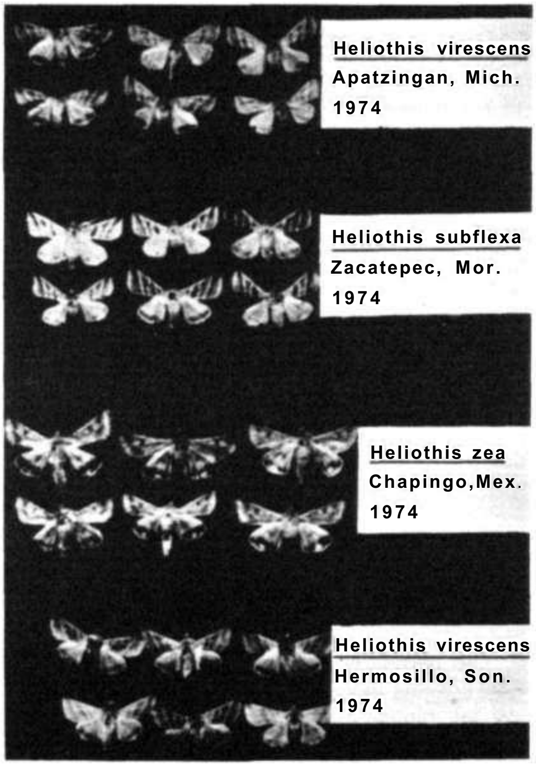

Figure 1a. Species of Heliothis *occurring in Mexico.*

Figure 1b. Collecting H. zea *larvae in late-planted sweet corn trap crop for establishing the laboratory colony.*

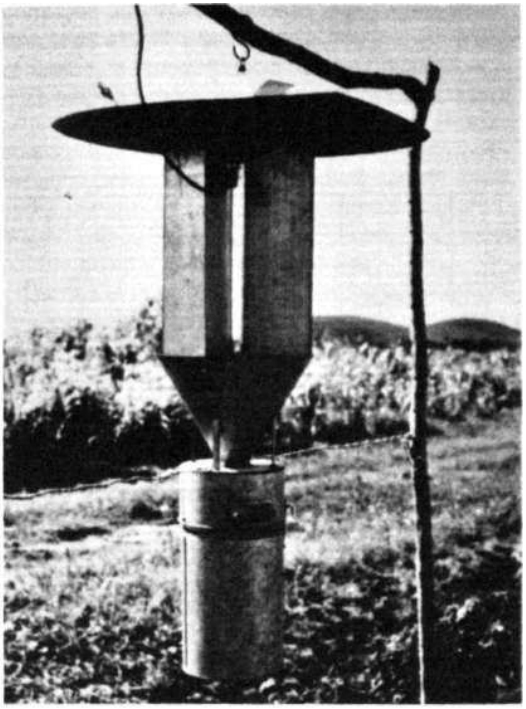

Figure 1c. Light trap for collecting **H. zea** *adults for laboratory colony establishment or renovation.*

Efficient Mass Rearing of the Insects

The basic requirements for successful insect colonization and rearing were listed by Needham et al. (1937) and include: (1)food, (2) protection from enemies, (3) a suitable physical environment, and (4) conditions suitable for reproduction

The components necessary in an efficient mass-rearing operation include (1) the physical facility (2) diet(s), (3) rearing containers, (4) rearing procedures, or management of the various life stages of the insect, and (5) qualified trained personnel.

Rearing Facilities

In many countries, physical facilities may consist simply of a room or two, a few boxes and cages, electrical power, and perhaps some means of temperature and humidity control. Some of the most developed countries have insect "factories." Leppla and Ashley (1978) have compiled a valuable reference on the types of physical facilities that are at present being used for insect rearing—from small chambers to grand-scale, semiautomated production. Anyone contemplating starting or expanding rearing programs should consult this reference for ideas that may apply to their particular conditions.

The physical facility should be simple, practical, and functional. Entomologists with experience in rearing the insect or species desired or contemplated should be involved in the design or modification of the facility as applicable to their situation. If the entomologist has not had a great deal of experience in mass rearing the species of concern, he should visit one or more facilities where the species are being successfully reared. In most cases, he will get new ideas; he should, however, be aware that everything he observes may not be appropriate for his conditions, and that he may need to modify or adapt existing techniques to his own circumstances.

The rearing facility that serves the CIMMYT maize program is a simple, inexpensive structure that satisfies the most basic requirements for insect rearing. It has been modified as necessary, and this process is expected to continue. Most of the changes made since its establishment have been to improve general sanitation and storage facilities, and to make it more independent of the other facilities.

In our experience, where we are producing four or five species twice a year for field infestation at appropriate plant-growth stages over 2-month-long periods, insect rearing is a 7-day-a-week job. Therefore, the laboratory must be independent of other units, which operate only five or six days per week. This includes separate facilities for electrical power, refrigeration, water, storage space, and general supplies.

One essential component in the CIMMYT facility, which many rearing facilities do not have, is a small workshop, with the necessary tools and materials for basic maintenance and for the construction of rearing dishes, cages, or any unexpected necessities. I am convinced that this small workshop has considerably improved the efficiency of our operation.

Diet

Singh (1977) lists seven meridic diets that have been used successfully for rearing *H. armigera*

(Hubner), and 16 diets that have been used for either *H. virescens* (Fabricius) or *H. zea* (Boddie), or both. The adults of these *Heliothis* species are illustrated in Figure 1 a.

The diet register used at CIMMYT for preparing corn earworm diet is presented in Figure 2a. Use of the checklist-register is recommended in order to avoid errors in diet preparation, and for use as a

Supplier	ICN Pharm.	Bio-Serv.	Lot. No.	Ingredient	Amount to make 10 kg diet	Day, Month Year													
1				Water	8 ltd														
2				Agar	100 g														
3				Soybean meal	500 g														
4				Ground opaque maize	960 g														
5				Brewer's or Turula yeast	400 g														
6				Wheat germ	40 g														
7				Sorbic acid	20 g														
8				Choline chloride	20 g														
9				Ascorbic acid	40 g														
10				Methyl p-Hydroxybenoate	25 g														
11				Salt mixture W	70 g														
12				Vitamin mixture	150 ml														
13				Formaldehyde	25 ml														
14				Aureomycin	50 g														
15				Streptomycin	1 unit														
16				Maize tassel powder (autoclaved)	200 g														
17				Other ingredients if used															
18																			

Figure 2a. Diet preparation register tor corn earworm, **Heliothis zea.**

record to identify material lots that may coincide with problems encountered in rearing. The only item unique to this diet is dried, sterilized, maize tassel powder, added at the rate of 20 g/kg of diet. (The tassel is collected and processed prior to pollen shed.) In tests under our conditions, we obtained better larval establishment, shorter larval period, larger pupae, and better oviposition from insects reared on diet with tassel powder than without the powder on the standard diet.

Guthrie et al. (1969) found that *Ostrinia nubilalis* larvae could survive to pupal stage on only maize pollen, indicating that it is a nutritious food source. Our trials at CIMMYT indicate that it acts as a feeding stimulant and/or makes the diet more palatable. We have been using it in our diets for rearing five lepidopterous species, with consistently good results for the past 4 years. At CIMMYT, where the crop is continually undergoing improvement, the tassel powder is a low-cost diet ingredient.

Prepared commercial diets for rearing *Heliothis* spp are now available from several sources in the USA. Our experience with them, however, has shown that we need to add a few ingredients, mainly supplemental vitamins and microbial inhibitors, to use them successfully in our rearing facility. They have the advantage of saving time and effort in preparation, while providing the necessary quality assurance. They are somewhat more costly than other alternative diets, but as long as the cost: benefit ratio is acceptable, we continue to use them.

Walker et al. (1966) list criteria for diet suitability: (1) high larval survival, (2) vigorous adults with high reproductive capacity, (3) normal rate of larval development, (4) low-cost ingredients, (5) easy preparation from readily available ingredients of uniform quality, and (6) good keeping quality. No single diet, however, will measure up to all these criteria for mass rearing a given species under all conditions or at all locations. However, after testing several diets that have been used successfully by other scientists, and after experimenting with various concentrations of ingredients, it is possible to develop a suitable diet for a particular location and its conditions.

New information on diets, diet ingredients, suppliers, and rearing techniques is available in the *FRASS Newsletter* (Anonymous 1981), published biannually by the Insect Rearing Group, which is composed of 575 scientists involved in rearing insects in 27 countries. It is provided free of charge to interested scientists and is a valuable reference.

Rearing Containers

Containers suitable for rearing *Heliothis* spp cover a wide range: individual glass or plastic vials or cups (Sparks and Harrell 1976), Hexcel units (Roberson and Noble 1968; Raulston and Lingren 1969), polystyrene light-diffusion cell blocks (Raulston and Lingren 1972), and cell webs processed and infested by a modified Inline form-fill-seal machine (Sparks and Harrell 1976).

Any of these may be utilized efficiently in a mass-rearing program, Choice may be dictated by the size of the rearing operation, cost and amount of labor available, and supply, availability, and durability of a given container. The ultimate and most efficient system would appear to be the Inline form-fill-seal machine and system (Sparks and Harrell 1976). However, at CIMMYT and many other locations in the world, it is probably not the best choice, because of the cost of the initial unit and subsequent materials, and the problems likely to be encountered in operation and maintenance. In fact, because of high costs associated with such production, a study was done to see if *H. zea* could be produced more economically on maize plants in field cages (Sparks et al. 1971).

At CIMMYT, we have adapted the system used by Raulston and Lingren (1972) to meet our needs (Figs. 2b, 2c, 3a, 3b). The cell grids are made from polystyrene light-diffusion louvers available in Mexico, the boxes are made locally from 3 and 6 mm Plexiglas, the cap for the unit is a layer of paper toweling, a 50-mesh bronze screen, and a sheet of the polystyrene grid, held in place by inexpensive

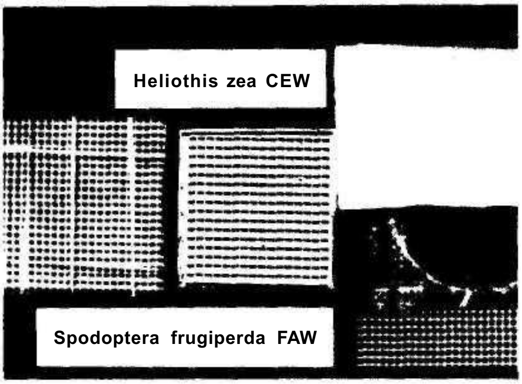

Figure 2b. Simple, locally made container for rearing **H. zea.**

Figure 2c. A mixture of sterilized corncob grits and first-instar* H. zea *larvae is applied to the rearing container until there are approximately five larvae per cell in the grid.

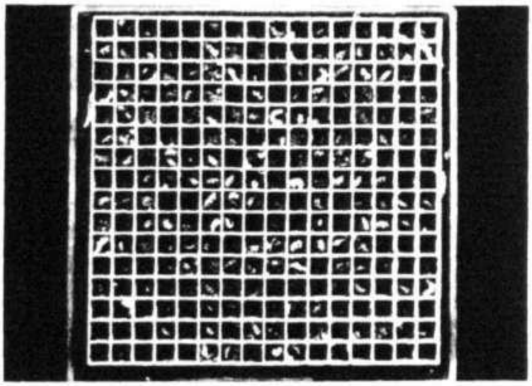

Figure 3a. Rearing container with mature larvae. As* H. zea *are cannibalistic, only one larva survives per cell to population.

large rubber bands. To minimize problems with microbial contamination, the units are sterilized by soaking them in 10% sodium hypochlorite solution, and the boxes and grid blocks are surface-treated by spraying with a 5% sorbic acid/5% methyl paraben alcohol solution. This treatment does not affect insect growth and aids in confining any chance contamination to a few cells within the box.

Hot diet is poured into the dishes, and the grids forced into the diet manually. To further reduce microbial contamination, the unit is exposed to UV radiation prior to infesting.

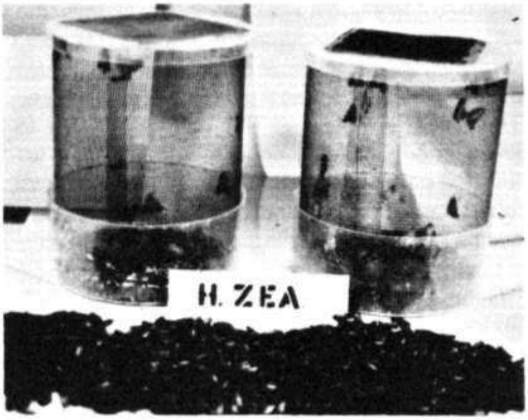

Figure 3b. Pupae are manually removed from larval rearing containers and placed in simple screen cages for adult emergence.

Rearing Procedures and Colony Handling

Adult Stage

When we first began rearing *H. zea* at CIMMYT in 1975, we frequently lost our colonies because of sterility. Callahan (1962) reported that a major problem in rearing *H. zea* was unpredictable mating in the laboratory; consequently, he obtained a higher incidence of mating using large cages containing host plants, with controlled temperature and humidity, and a 10% honey solution for adult nutrition.

Since 1977, we have used a similar mating cage (Fig. 3c) with continued success. It consists of a 0.5 x 0.5 x 1.0 m Plexiglas cage with screen on two sides for the moths to hang and rest easily. A pot containing several whorl-stage maize plants is placed within the cage. A dish containing cotton moistened with a 10% sugar solution is also provided. Moths are left in the cage for 48 hours before they are transferred to oviposition cages.

Oviposition cages used at CIMMYT consist of a simple wire-frame support and a bag of nylon mesh (Bridal Illusion) material (Fig. 4a). We find this system superior to cotton cheese cloth placed over paper icecream cartons (Burton 1969; Raulston and Lingren 1972), or on the front or sides of other style cages (Callahan 1962; Knott et al. 1966). Its advantages include ease in changing oviposition substrate without adults escaping, ease in cleaning, maximum oviposition surface area; there is

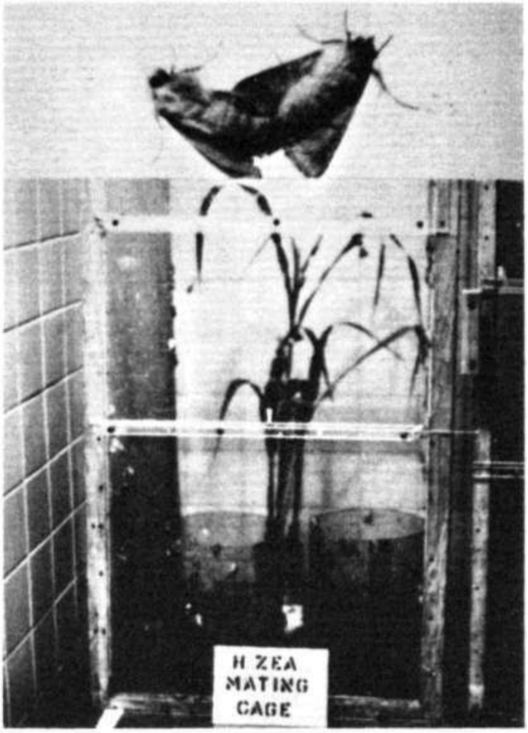

Figure 3c. Pupal containers are placed inside a 0.5 x 0.5 x 1/m mating cage, with potted maize plants and 10% sugar solution for adult food. Adults are transferred to oviposition cages every 24-48 hours.

also no need for cage liners and no problem with hatching larvae, since the entire cage walls are replaced daily.

Changing the cage (Fig. 4b) is accomplished by simply placing a new bag over the mouth of the egg-laden one. As the egg-laden one is pulled off, the new one is pulled over the frame. A small plastic box, with cotton moistened with a 10% sugar solution, is placed inside for food.

Egg Stage

Egg-laden bags are placed in a small, inexpensive portable washing machine and agitated for 2 to 3 minutes in a 0.2% sodium hypochlorite solution. Egg-laden water is then decanted onto a fine mesh screen, the eggs are immersed in a 10% sodium thiosulfate solution, and then rinsed with water. (See Figs. 4c-5c). Eggs are then washed onto a paper towel, the excess moisture is removed, and the eggs are placed inside plastic dishes for incubation.

Once larvae have hatched (0-8 hours old), they can be stored in a refrigerator (at 10°C) for up to 5 days, or used immediately to reinfest diet or plants in the field.

Larval Stage

At CIMMYT, newly hatched larvae (<12 hours old) are used for infesting diet to maintain the laboratory colony.

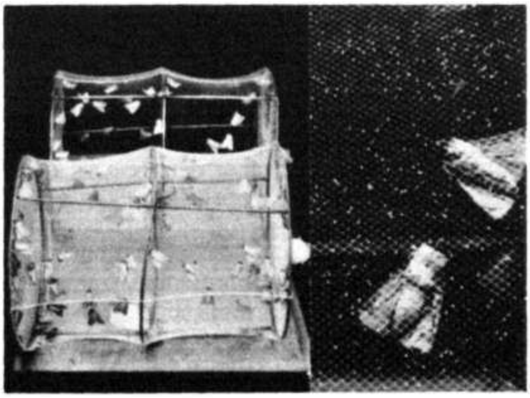

Figure 4a. Oviposition cages consist of a simple wire frame support and a bag made of nylon mesh (bridal illusion). Females oviposit and attach single eggs to the mesh.

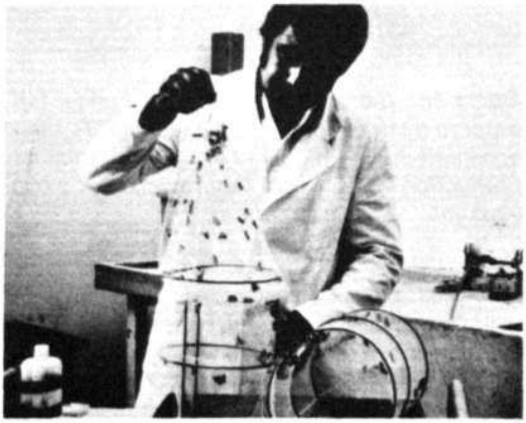

Figure 4b. Cages are changed daily by placing a clean nylon bag over the mouth of the egg-laden one.

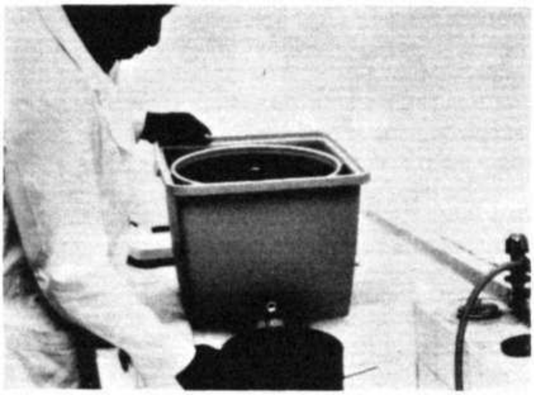

Figure 4c. Egg-laden bags are agitated for 2 minutes in a small portable washing machine containing a 0.2% solution of sodium hypochlorite to loosen the eggs from the mesh. Then the egg-bearing water is decanted on to a fine mesh screen.

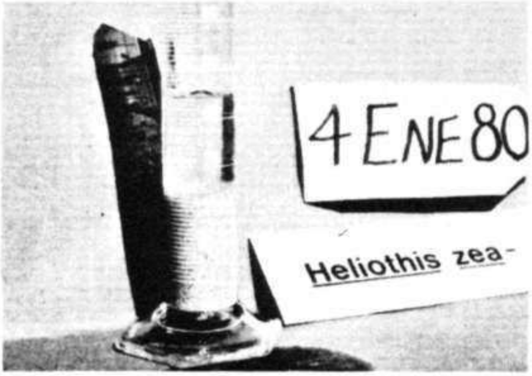

Figure 5a. The eggs are then rinsed under tap water to wash off the sodium hypochlorite, then decanted into a graduated cylinder to estimate production. There are approximately 2 000 eggs/ml.

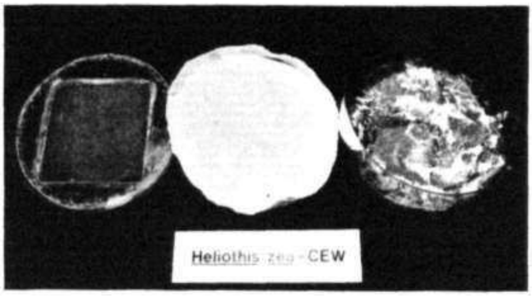

Figure 5b. Eggs are decanted onto paper towelling and placed in box for incubation. They hatch in 2 days at 30°C and 95% RH.

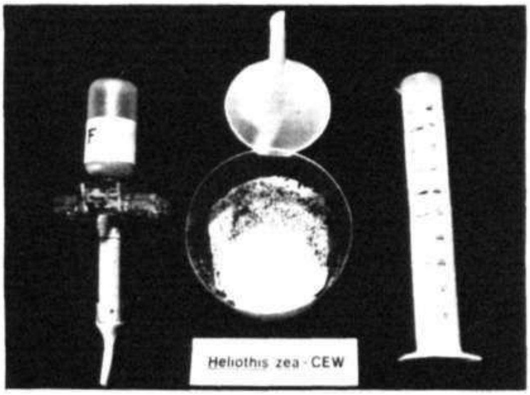

Figure 5c. Newly-hatched larvae are mixed with corn cob grits for field infestation.

Infestation of the rearing boxes is accomplished easily and rapidly: 100-200 cc of sterilized corncob grits are placed in the dish containing larvae; this is rotated gently to mix uniformly. The mixture is transferred to a simple shaker jar and shaken over the boxes containing diet and cell grid unit until there are 2 to 5 larvae per cell (Fig. 2c). After capping, the rearing boxes are moved to shelves in rearing rooms at 70 to 80% RH and temperatures ranging from 20 to 32°C, depending on how quickly the next generation is needed.

Depending on temperature, larvae mature and begin pupating in 18 to 30 days. The developmental stage can be easily checked through the clear Plexiglas box, which is not opened until pupal stage. Only one larva per cell survives to pupate (Fig. 3a). Other rearing programs (Raulston and Lingren 1972; Burton 1969; Sparks and Harrell 1976) use eggs for infesting diet and rearing containers because they are more appropriate to their systems.

Pupal Stage

Many rearing operations, particularly those where much or all of the procedure is mechanized, have developed various machines for pupal extraction

Figure 6a. Plants with fully emerged, fresh silks to be infested are tagged with date of infestation for later identification. This is done prior to infestation to avoid dislodging the larval grits mixture.

Figure 6b. About 10 larvae are applied per plant. Within minutes, they move into the silk mass and begin attacking the developing maize ear.

(Raulston and Lingren 1972; Sparks and Harrell 1976; Harrell et al. 1968, 1974).

At CIMMYT, by modifying the polystyrene cell units into a split unit (three layers glued and one layer below), we eliminated the need for any special machine for pupal collection, as nearly all pupae are found below the surface of the diet in our boxes. The split cell unit, when removed, splits the diet layer and pupation cell so that the pupae can be gently dumped from the dish. If desired, the few remaining pupae that pupated above the diet plug can be removed by hand or simply discarded.

Pupae are placed one layer deep in boxes or dishes of various sizes, depending on quantities, and provided with a screen for newly emerged adults to hang and spread their wings (Fig. 3b). These containers are then put inside the mating cages when the first adults have emerged (Fig. 3c).

Efficient Field Infestations

Infestations with *Heliothis* spp have been done with both eggs and larvae (newly hatched, second instar, and third instar). Manual infestation (using a camel's-hair brush) with newly hatched larvae was made over 40 years ago (Blanchard et al. 1942), and found to be an effective method (Josephson et al. 1966), but very inefficient because of the time and labor involved.

More efficient methods in use today include: (1) infesting with eggs suspended in a 0.2% agar solution, applied to the plants in controlled amounts (hypodermic syringes or pressure applicators) or uncontrolled amounts (squeeze bottles) (Wiseman et al. 1974); (2) infesting with uniform numbers of newly hatched larvae, using the Bazooka applicator. The second technique was developed by Mihm and colleagues at CIMMYT in 1976 (CIMMYT 1977). The technique and its advantages for use with several lepidopterous species were described in detail by Ortega et al. 1980. Infestation of maize with *H. zea* larvae is illustrated in Figures 6a and 6b.

Larval infestation is more efficient than other means, because it is more rapid, uses less insects per plant, and is more effective (fewer plants escape) than other techniques. To my knowledge, the Bazooka, in original or modified versions (Wiseman et al. 1980), has been used efficiently and effectively for field infestation with at least 11 species of lepidopterous insect larvae *(Diatraea saccharalis, D. grandiosella, D. lineolata, Ostrinia nubilalis, Chilo partellus, Sesamia cretica, S, calamistis. Busseola fusca, Heliothis zea, H. virescens,* and *Spodoptera frugiperda)* and one leafhopper *(Dalbulus maidis)* in three crop species—corn, sorghum, and cotton. To use the technique in cotton, the plants were simply sprayed first with water (Hall et al. 1980). If done after rain or heavy dew, infestations in cotton would be even more efficient, as spraying the plants would then be unnecessary.

For infesting corn or sorghum in the whorl stages, the larval-corncob grits mixture is simply dispensed into the whorl. For infesting developing maize ears, the mixture is dispensed onto the fresh silks. For infesting sorghum near flowering stage, the mixture is dispensed onto the panicle. Care must be taken not to disturb the plant for a few minutes after infestation, however, so that the larvae have time to attach themselves.

If corncob grits are not readily available, other materials may be used in preparing the larval mixture. To my knowledge, corn meal (Hall et al. 1980), millet seed (personal communication), and sorghum meal have been used successfully. Other materials will probably be reported as they are tried.

Damage Evaluation

Rating scales are generally used to quantify the resistance (or susceptibility) (Fig. 7a) of the plant(s) after infestation in the field or greenhouse.

For corn earworm damage in whorl-stage corn, a scale similar to the one devised by Wiseman et al. (1976) is generally used. It is a 0 to 10 scale, where 0 is no damage and 10 is a completely destroyed plant. For damage to ears, the revised centimeter scale (Figs. 7b, 7c) developed by Widstrom (1967) is recommended as the most effective in indicating plants with heritable resistance.

Conclusion

The CIMMYT techniques and experience described in this paper for efficient mass rearing and infestation show promise *of* adaptability to other

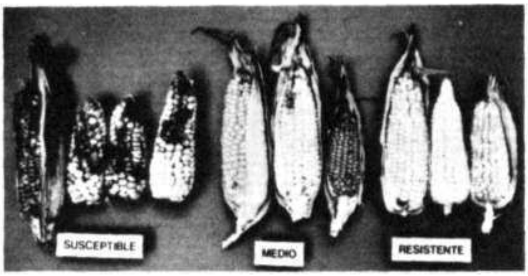

Figure 7a. After deliberate infestation, plants may be categorized as susceptible, intermediate, or resistant.

REVISED CENTIMETER SCALE FOR CLASSIFYING CORN EARWORM DAMAGE TO MAIZE. (Widstrom 1967)

CATEGORY	VALUE	DESCRIPTION
RESISTANT	0	No damage
	1	Damage to silks only
	2	Feeding to 1 cm beyond the *ear* tip
INTERMEDIATE	3 ...	Value increases by 1 for each additional centimeter of feeding beyond the tip of the ear
SUSCEPTIBLE	. . N	

Figure 7b. Use of the revised centimeter scale helps classify more exactly the plant reaction in screening and selecting in variable or segregating maize genotypes.

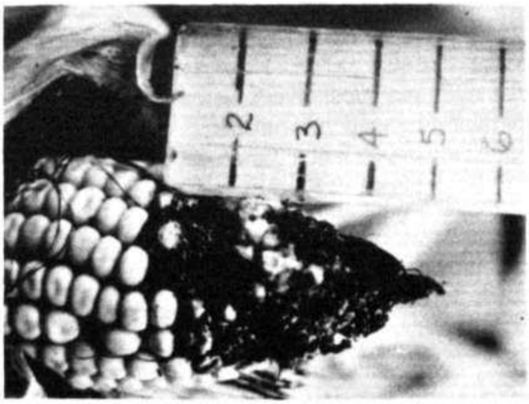

Figure 7c. This ear shows an intermediate to susceptible reaction.

pest and crop species and to screening and breeding initiatives in other parts of the world. The final objective in the application of these techniques to any program of efficient mass rearing and infestation is to identify resistant genotypes for immediate use or for use in a breeding program. Varieties with improved resistance can serve as one of the major components in the effort to manage the *Heliothis* spp pest populations.

References

ANONYMOUS. 1981. The Frass Newsletter. Insect Rearing Group (of the Society of America). Membership list address: R. Wheeler, Chevron Chemical Corp., 940 Hensley St.. Richmond. Calif, 94804, USA.

BLANCHARD, R.A., SATTERTHWAIT, A.F., and SNELLING, R.O. 1942. Manual infestation of corn strains as a method of determining differential earworm damage. Journal of Economic Entomology 35.508-511.

BURTON, R.L. 1969. Mass rearing the corn earworm in the laboratory. U.S. Department of Agriculture, Agricultural Research Service Publication 33-134, Washington DC, USA. 8 pp.

CALLAHAN, P.S. 1962. Techniques for rearing the corn earworm, *Heliothis zea.* Journal of Economic Entomology 55:453-457.

CIMMYT (Centro Internacional de Mejoramiento de Maiz y Trigo). 1977. CIMMYT Review 1977. El Batan, Mexico, 99 pp.

GUTHRIE, W.D. 1974. Techniques, accomplishments and future potential of breeding for resistance to European corn borer in corn. Pages 359-380 *in* Proceedings, Summer Institute on Biological Control of Plant Insects and Diseases eds K.G. Maxwell and FA. Harris. University of Mississippi press, Jackson, Miss, USA.

GUTHRIE, W.D. 1980. Breeding for resistance to insects in corn. Page 290 *in* Biology and breeding for resistance to arthropods and pathogens in agricultural plants, ed. M.K. Harris. Proceedings, International Short Course in Host-Plant Resistance, Texas, A & M University, College Station, Texas, USA. 605 pp.

GUTHRIE, W.D., HUGGANS, J.L., and CHATTERJI, S.M. 1969. Influence of corn pollen on the survival and development of second-brood larvae of the European corn borer. Iowa State Journal of Science 44:185-192.

HALL, P.K., PARROT, W.L., JENNINGS, J.N., and McCARTY, J.C. 1980. Use of tobaco budworm eggs and larvae for establishing field infestations on cotton. Journal of Economic Entomology 73:393-395.

HARRELL, E.A., BURTON, R.L., HARE, W.W., and **SPARKS, A.N. 1968.** Collecting corn earworm pupae from rearing containers. U.S. Department of Agriculture, Publication 42-160, Washington DC, USA.

HARRELL, E.A., SPARKS, A.N., and PERKINS, W.D. 1974. Machine for collecting corn earworm pupae. U.S. Department of Agriculture, Agricultural Research Service Publication 5-43. 4 pp.

JOSEPHSON, L.M., BENNETT, S.E., and BURGES, E.E. 1966. Methods of artificially infesting corn with the corn earworm and factors influencing resistance. Journal of Economic Entomology 59:322-1234.

KNOTT, CM., LAWSON, F.R., and HOBGOOD, J.M. 1966. Oviposition cage for the tobacco budworm and the corn earworm. Journal of Economic Entomology 59:1290.

LEPPLA, N.C., and ASHLEY, T.R. (eds). 1978. Facilities for insect research and production. U.S. Department of Agriculture SEA Technical Bulletin 1576, Washington, DC, USA.

LEPPLA, N.C., CARLYLE, S.L., GREEN, C.W., and PONS, W.J. 1978. Custom insect-rearing facility. Pages 66-70 in Facilities tor insect research and production, eds N.C. Leppla and T.R. Ashley. U.S. Department of Agriculture—SEA Technical Bulletin 1576. 86 pp.

NEEDHAM, J.G, GALTSOFF, P.S., LUTZ, F.W., and WELCH, P.S. (eds.). 1937. Culture methods for invertebrate animals. Comstock, NY. Reprinted 1959. New York, USA: Dover Publications.

ORTEGA, A., VASAL, S.K., MIHM, J., and HERSHEY, C. 1980. Breeding for insect resistance in maize. Pages 371 -419, *in* Breeding plants resistant to insects (eds. F.G. Maxwell and PR. Jennings). New York. USA: John Wiley.

RAULSTON, J.R., and LINGREN, P.D. 1969. A technique for rearing larvae of the bollworm and tobacco budworm in large numbers. Journal of Economic Entomology 62:959-961.

RAULSTON, J.R., and LINGREN, P.D. 1979. Methods of large-scale rearing of the tobacco budworm. U.S. Department of Agriculture. Production Research Report No. 145, Washington, DC, USA 10 pp.

ROBERTSON,J.L.,and NOBLE, L.W. 1968. Rearing of tobacco budworm in honey comb-like cells. Journal of Economic Entomology 61:331 -332.

SINGH, P. 1971. Artificial diets for insects, mites and spiders. New York, USA: Plenum. 594 pp.

SPARKS, A.N., and HARRELL, E.A. 1976. Corn earworm rearing mechanization. U.S. Department of Agriculture, Agricultural Research Service Technical Bulletin 1554.11 pp.

SPARKS, A.N., WISEMAN, B.R., and McMILLIAN, W.W. 1971. Production of corn earworms on several hosts in field cages. Journal of Economic Entomology 64:540-541.

WALKER, D.W., ALEMANY, A., QUINTANA, V., PADOVANI, F., and KAGEN, K.S. 1966. Improved xenic diets for rearing the sugarcane borer in Puerto Rico. Journal of Economic Entomology 59(1):1 -4.

WIDSTROM, N.W. 1967. An evaluation of methods for measuring corn earworm injury. Journal of Economic Entomology 60:791 -794.

WISEMAN, B.R., WIDSTROM,N.W., and McMILLIAN, W.W. 1974. Methods of application and numbers of eggs of the corn earworm required to infest ears of corn artificially. Journal of Economic Entomology 67:74-76.

WISEMAN, B.R., WIDSTROM, N.W., McMILLIAN, W.W., and PERKINS, W.D. 1976. Greenhouse evaluations of leaf-feeding resistance in corn to corn earworm (Lep. Noct). Journal of the Georgia Entomological Society 11:63-67.

WISEMAN, B.R., DAVIS, F.M., and CAMPBELL, J.E. 1980. Mechanical infestation device used in fall armyworm plant resistance programs. Florida Entomologist 63(4):425-432.

Screening Groundnut for *Heliothis* Resistance

W.V. Campbell, J.C. Wynne, and H.T. Stalker*

Abstract

Plant introductions, commercial cultivars, and groundnut breeding lines were screened in the field for resistance to Heliothis zea, *using naturally occurring populations of the pest. Plant introductions from South America were generally susceptible. PI-269062 from China exhibited resistance to* H. zea. *NC-6 (NC-343 x Va-61 R), which was developed tor resistance to the southern corn rootworm, was cross-resistant to* H. zea. *The sister lines, NC-GP 343 and NC-AC 342 were also resistant.*

Some wild species of groundnut in the sections Arachis, Erectoides, Rhizomatosae, Ambinervosae, Caulorhizae, Extranervosae *and* Triseminalae *exhibited high resistance, and some approached immunity to* H. zea.

Nonpreference and antibiosis were identified as mechanisms of resistance. Larval weight was reduced three- to five-fold on resistant cultivated groundnuts and 700% *mortality resulted when larvae were fed some wild species.*

The low to moderate level of resistance present in the cultivated groundnut is of economic importance in a pest-management program. Generally the resistant cultivars and breeding lines will maintain H. zea *below the damage threshold.*

Résumé

Criblage de l'arachide pour la résistance à Heliothis: *Des introductions, cultivars commerciaux et lignées de sélection d'arachide ont été criblés sur le terrain pour la résistance à* Heliothis zea, *en utilisant des populations qu'on retrouve naturellement. Les introductions provenant de l'Amérique du Sud se sont avérées généralement sensibles. La PI-269062, de Chine, s'est montrée résistante à* H. zea. *La NC-6 (NC-343 x Va-61R), améliorée pour la résistance à* Diabrotica undecimpunctata, *était également résistante à* H. zea. *Les lignées soeurs, NC-GP 343 et NC-AC 342, ont aussi été résistantes.*

Certaines espèces sauvages d'arachide des sections Arachis, Erectoides, Rhizomatosae, Ambinervosae, Caulorhizae, Extranervosae, Triseminales *ont eu une forte résistance et certaines avaient presque une immunité contre* H. zea.

Une non préférence et antibiose ont été identifiées comme mécanismes de résistance. Le poids des larves a été réduit de 3 à 5 fois sur les arachides cultivées résistantes et il y a eu un taux de mortalité de 100% quand les larves se sont nourries de certaines espèces sauvages. Le niveau de résistance, de faible à moyen, présent chez l'arachide cultivée a une importance économique dans le cadre d'un programme de lutte contre les ravageurs. En général, les cultivars résistants et les lignées de sélection contiendront H. zea *sous un seuil de nuisibilité.*

Groundnut *(Arachis hypogaea* L.) is attacked by a complex of insects and mites. Among these pests the corn earworm *Heliothis zea* (Boddie) has recently become an economic pest. Prior to 1977, *H. zea* damage to groundnut was subeconomic in North Carolina, but recently 50% or higher defoliation has been observed.

Defoliation from *H. zea* occurs principally during August (90 to 130 days postplant). Larval feeding coincides with the period of principal fruit production. Defoliation during this critical period of growth has the greatest effect on reducing yield (Campbell, unpublished).

Pesticides applied in North Carolina during August to control *H. zea* often result in adverse interactions that induce spider-mite outbreaks. Any pesticide that does not have miticidal properties may cause an increase in the population of the two-spotted spider mite, *Tetranychus urticae,*

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Journal Series Paper 8079, North Carolina Agricultural Research Service. Raleigh, NC, USA.

International Crops Research Institute for the Semi-Arid Tropics. 1982. Proceedings of the International Workshop on *Heliothis* Management 15-20 November 1981, Patancheru, A.P., India

Table 1. Rasistance of groundnut plant Introductions to Haliothis zea, North Carolina, USA, 1977.

Cultivar or plant introduction	Location	Average defoliation (%)
Florigiant		12.5
NC2		10.0
NC5		9.0
NC6		6.0
NC-GP 343		11.0
NC-15729		10.0
NC-10272		7.5
NC-15745		8.5
NC-10247		9.0
PI-261959 Violaceo I	Paraguay	24.0
PI-261924 Negro I	Argentina	10.0
PI-261931 Palido I	Paraguay	18.0
PI-261940 Colorado 1	Paraguay	13.5
PI-261965 Violaceo I	Paraguay	12.5
PI-261929 Negro I	Argentina	24.0
PI-261938 Colorado I	Paraguay	21.5
PI-261968 Violaceo I	Paraguay	17.5
PI-261951 Colorado I	Paraguay	16.0
PI-261935 Palido I	Paraguay	11.5
PI-275696 Palido II	Goias, Brazil	13.5
PI-262052 Colorado I	Sao Paulo, Brazil	24.0
PI-269062	China	4.5
PI-268768 Super Khandeish	from Jozi collection, Sudan	14.0
PI-268740 B727 (sequential)	Rhodesia	16.5
PI-270804 Nalal ex-NC-46	Rhodesia	18.5
PI-271023 Spanish (alternate)	Rhodesia	18.5
PI-270901 Manyuna (alternate)	Rhodesia	14.0
PI-275691 Manyuna (alternate) II	Goias, Brazil	15.0
PI-275728 S.L. Jater II	Goias, Brazil	13.5
PI-270853 Ndala Bunch	Rhodesia	16.5
PI-275742 S.S. 16	Minas Gerais, Brazil	22.5
PI-262042 Palido I	Sao Paulo, Brazil	21.0
PI-270764 Short Valencia ex EC I	Rhodesia	15.0
PI-275753		21.0
PI-275735 S.S. 181 II	Minas Gerais, Brazil	15.0
PI-270803 Pink ex BC 259	Rhodesia	18.5
PI-275719 II	Minas Gerais, Brazil	15.0
PI-262095 Colorado IV	Bolivia	19.0
PI-275700 II	Minas Gerais, Brazil	16.5
PI-262031 Colorado I	Sao Paulo, Brazil	18.0
PI-271014 Valencia Rouge de	Rhodesia	16.5
PI-270773 White Manyuna Cordoba	Rhodesia	16.0
PI-269006 S-726 (alternate runner)	Rhodesia	11.5
PI-262060 Colorado I	Sao Paulo	16.0
PI-262069 Palido I	Sao Paulo	19.0
PI-275687 II	Minas Gerais, Brazil	14.5
PI-274267		13.5
PI-262080 Colorado I	Mato Grosso, Brazil	19.0
PI-269049 Ndoba NCR-2	Rhodesia (alternate runner)	15.0
PI-270792 Brown ex-BC 253	Rhodesia	18.0
LSD (0.05)		7.3

Koch, on groundnut in North Carolina (Campbell 1978).

An ideal solution to the control of *H. zea* would be the development of groundnut cultivars with resistance to *H. zea.* Such resistance has been reported for several other crops, including sweet corn (Brett 1958), field corn (Douglas and Eckhardt 1957; McMillian and Wiseman 1972), soybeans (Clark et al. 1972), and cotton (Lukefahr et al. 1965). Numerous other references of *Heliothis* resistance in crop plants are found in the comprehensive review by Maxwell et al. (1972).

However, information on resistance of groundnut to *H. zea* is limited. Leuck et al. (1967) reported that Spanish cultivars were more susceptible than Virginia cultivars. Cvs Florigiant and Virginia Bunch had the lowest damage, but differences in *H. zea* damage were not significant among the Virginia types.

Field Screening Groundnut for *H. zea* Resistance

Evaluation of germplasm was not initiated in North Carolina until 1977, because of the low *H. zea* populations prior to this time. Groundnut was planted in single, 10-m rows and replicated three times. Corn is rotated with groundnut, and approximately 40% of the area where the experiment was conducted was planted in corn each year. This provided a local population of *H. zea* emerging from corn. No effort has been made to supplement naturally occuring field populations of *H. zea.*

Egg laying occurs over a period of 3 to 5 weeks, generally starting in early August (90 days postplant). Where *H. zea* damage is low, groundnut lines may be evaluated by counting the number of damaged leaves, but where damage is high, this is not possible. In such cases, determining defoliation is a better method of rating lines suffering extensive damage. In North Carolina, defoliation is rated on a 0 to 100% scale, but alternative damage-rating scales of 0 to 9 or 0 to 5 may be used where the numbers progressively represent light, moderate, heavy, severe, and total defoliation. Generally, plots are visually rated for percent defoliation in early September and after peak *H. zea* damage. It is important to observe the entire row, because of variation in damage within the row.

In 1977 a group of plant introductions were compared with four North Carolina cultivars and five potato leafhopper resistant accessions for *H. zea* damage (Table 1). PI-269062 exhibited the lowest defoliation; the next lowest being NC-6, a North Carolina cultivar selected from the cross of NC-GP 343 and Va-61 R that has multiple insect resistance (Campbell and Wynne 1980). All but five plant introductions exhibited significantly higher H. *zea* damage than NC-6.

Groundnut breeding lines, including selections from crosses involving NC-6, which is moderately resistant to *H. zea* (Campbell and Wynne 1979), showed significant differences in damage from *H. zea.* NC-6 and NC-GP 343, the insect-resistant parent of NC-6, had less defoliation than Florigiant. Breeding lines that showed less than 8% defoliation included 17168 x NC-6, NC-6 x 17164, 17168 x 15753, and 15753 x 17163 (Table 2). Resistance in most of these breeding lines resulted from the use of NC-GP 343 or NC-AC 342 as parents.

When tested in advanced generations, NC-6, NC-Ac 342, and NC-GP 343 (insect-resistant sister lines) and crosses containing NC-Ac 342 and NC-GP 343 generally exhibited less *H. zea* defoliation than the susceptible Florigiant check (Table 3). The lowest damage was in a selection from the cross of NC-GP 343 x Florigiant.

An additional evaluation of cultivars and selected breeding lines for *H. zea* resistance in 1977 and 1978 showed the following cultivars had less defoliation than Florigiant: NC-6, NC-Fla 14, Va-72R, NC-5, Florunner, and Early Bunch. A breeding line selected from the cross of Florigiant and a Valencia PI received the highest damage (Table 4).

H. zea population pressure was highest in 1980. Under high populations of *H. zea,* NC-6, the resistant sister lines NC-Ac 342 and NC-GP 343, crosses containing these lines, and Early Bunch sustained less defoliation than Florigiant. NC-6 had 6.7% defoliation and Early Bunch, 12%, while Florigiant had 46.7% defoliation (Table 5).

Breeding lines that have been tested for a number of years and lines that are agronomically promising for release were evaluated in an experiment called Advanced Test. Using NC-6 as the standard resistant line and Florigiant as the standard susceptible line, only 8 entries among the 48 tested showed defoliation equal to or less than NC-6. Among the entries with low damage from *H. zea were* NC-6, NC-17404, NC-GP 343 x Florigiant, (NC-GP 343 x NC-5) x UF 70115, GK-3 x UF-70115, and PI-138870 x NC-5 (Table 6).

NC-6 (multiple insect-resistant cultivar) was crossed with NC-3033 (*Cylindrocladium* black rot

Table 2. Resistance of F_8 groundnut lines to Heliothis *Mm,* North Carolina, USA, 1977.

Breeding line or cultivar[a]	Average defoliation (%)
NC-Ac 17168 x NC-6	6.5
NC-Ac 17168 x NC-6	10.0
NC-Ac 17166 x NC-Ac 15753	11.0
NC-6 x NC-Ac 17164	12.0
NC-6 x NC-Ac 17164	7.0
NC-Ac 17163 x NC-Ac 17168	17.5
Florigiant	13.5
NC-Ac 17163 x NC-Ac 17166	14.5
NC-Ac 17163 x NC-6	11.0
NC-Ac 17163 x NC-6	11.5
NC-Ac 17168 x NC-Ac 15753	14.0
NC-Ac 17168 x NC-Ac 15753	7.0
NC-Ac 17168 x NC-Ac 17166	8.0
NC-Ac 17164 x NC-Ac 17163	11.0
NC-Ac 17164 x NC-Ac 17163	16.0
NC-Ac 15753 x NC-Ac 17163	6.5
NC-Ac 15753 x NC-Ac 17163	7.5
NC-Ac 15753 x NC-Ac 17163	18.0
NC-Ac 15753 x NC-Ac 17164	13.5
NC-Ac 15753 x NC-Ac 17164	12.5
NC-Ac 15753 x NC-Ac 17164	16.0
NC-6	5.0
Florigiant	16.0
NC-GP 343	9.0
LSD (0.05)	5.5

a. Pedigree of NC Accessions as follows:
Ac-15753 = selection from CVShulamit.
Ac-17163 = NC-5 x Florigiant.
Ac-17164 = Florigiant x Fla-393-
Ac-17166 = Florigiant x Ac-342.
Ac-17168 = NC-5 x Ac-342.

Table 3. Resistance of F_{12} groundnut Unas to Heliothis zea, North Carolina, USA, 1978.

Breeding line or cultivar[a]	Average defoliation (%)
NC-GP 343 x Florigiant	1.7
NC-GP 343 x Florigiant	6.0
Florigiant x NC-Ac 342	4.3
NC-Ac 301 x NC-5	7.0
NC-GP 343 x NC-5	3.0
NC-GP 343 x Florigiant	12.3
NC-GP 343 x NC-2	6.3'
Florigiant x NC-Ac 342	8.0
NC-Ac 301 x Va-61R	7.3
NC-Ac 301 x NC-2	4.7
Florigiant x NC-Ac 301	10.7
NC 5 x NC-Ac 342	4.0
NC-GP 343 x NC-5	5.0
NC-GP 343 x Florigiant	18.7
NC-Ac 301 x NC-5	7.0
NC-Ac 301 x NC-2	7.7
NC-Ac 302 x Florigiant	6.3
NC-GP 343 x NC-5	3.0
NC-Ac 302 x Florigiant	13.7
NC-Ac 302 x NC-2	6.3
Florigiant x NC-Ac 301	15.7
Florigiant x NC-Ac 301	4.3
Florigiant x NC-Ac 301	11.0
NC-Ac 301 x NC-5	10.0
NC-Ac 342	3.7
NC-GP 343	3.7
NC-6	2.3
Florigiant	14.3
LSD (0.05)	4.9

a. NC-GP 343, NC-Ac 342, NC-Ac 301, and NC-Ac 302 are sister lines selected from the cross of NC-Bunch x PI-121067.

resistant) and screened for insect resistance. All of the NC-6 x NC-3033 lines selected for insect resistance exhibited damage in the range of the NC-6 parent (Table 7). These data indicate that *H. zea* resistance is heritable. Furthermore the breeding lines gave similar reactions in 1979 and 1980.

Effect of Planting Date

Three planting dates were employed to determine if date of planting influenced the susceptibility/resistance of the two contrasting cultivars, Florigiant and NC-6. Plots were eight rows wide (1-m row spacing) and approximately 50 m long, with three replications.

Early-planted (May 7) groundnut had less *H. zea* damage than late planted (May 23 and June 3), regardless of the cultivar tested. A May 23 planting had the highest foliage damage, suggesting optimum synchronization of groundnut development with the moth flight. Florigiant was more susceptible over a wider range of planting dates than NC-6 (Table 8). Douglas (1954) and Luckman (1956)

Table 4. Resistance of groundnut cultivars and breeding lines to Heliothis zea, North Carolina, USA.

Breeding line or cultivar	Average defoliation (%)	
	1977	1978
NC-2	18.0	7.3
NC-4	14.0	1.7
NC-5	13.3	3.3
NC-6	7.3	1.0
NC-17	10.7	4.7
NC-Fla 14	7.7	NR
Va-72R	12.7	4.0
Avoca-11	15.0	5.7
Shulamit	13.0	NR
GK-3	10.0	8.0
Early Bunch	4.7	NR
Florunner	8.3	3.3
NC-GP 343	NR	4.0
NC-3033	24.0	10.7
NC-6333 x NC-5	18.7	NR
NC-3033 x NC-2	18.3	NR
NC-5 x NC-7484	11.7	NR
NC-5 x Fla-393	9.0	6.3
Florigiant x Florunner	22.3	8.3
Florigiant x Valencia[a]	24.0	14.3
Florigiant	19.3	12.3
LSD (0.05)	5.5	5.9

a. PI-337396. NR = not recorded

found early-planted corn also had less damage from *H. zea,* and Stinner et al. (1976) reported early-planted soybeans escaped *H. zea* damage.

Field Screening Wild Species

Greenhouse-grown seedlings of wild *Arachis* species were transplanted in the field in single-row, six-plant plots. Three commercial cultivars were used as standards to compare the reaction of *Arachis* collections to *H. zea.*

Among the wild species, there is evidence of high resistance to *H.* zea that approaches immunity (Table 9). There was more damage to the wild species in 1981 than in 1979 or 1980; however, damage was still considerably less than that for the domestic cultivars.

Table 5. Resistance of groundnut to Heliothis zea. North Carolina, USA, 1980.

Breeding line or cultivar	Average defoliation (%)
NC-2	24.3
NC-5	27.0
Florigiant	46.7
NC-7	21.7
NC-6	6.7
Early Bunch	12.0
NC-3033	25.0
NC-GP 343	14.0
Florunner	17.0
NC-Ac 342	6.0
Florigiant x Spanhoma	48.3
NC-GP 343 x Florigiant	11.3
Florigiant x NC-Ac 342	13.3
NC-GP 343 x NC-5	11.7
Florigiant x NC-Ac 301	10.7
NC-5 x NC-Ac 342	9.0
NC-GP 343 x NC 5	8.0
NC-GP 343 x Florigiant	34.3
NC-Ac 301 x NC-5	16.0
NC-Ac 301 x NC-5	17.3
NC-GP 343 x NC-5	9.3
NC-Ac 302 x Florigiant	29.0
Florigiant x NC-Ac 301	30.0
NC-Ac 17168 x NC 6	30.0
NC-Ac 17163 x NC-Ac 17166	33.3
NC-Ac 17163 x NC 6	12.3
NC-Ac 17164 x NC-Ac 17163	31.7
NC-Ac 15753 x NC-Ac 17163	53.3
NC-Ac 15753 x NC-Ac 17164	65.0
NC-Ac 15753 x NC-Ac 17164	26.7
NC-Ac 15753 x NC-Ac 17163	26.7
LSD (0.05)	12.2

Laboratory Screening Groundnut for *H. zea* Resistance

The mechanisms of plant resistance to insects were placed in three categories by Painter (1951): nonpreference, antibiosis, and tolerance. We utilized these categories to study the mechanism of resistance to *H. zea* in groundnut.

Table 6. Resistance of groundnut to Heliothis zea, North Carolina, USA, 1981.

Breeding line or cultivar	Avg. % defoliation
Florigiant	16.7
NC-6	7.7
NC-7	12.3
NC-18222	10.0
NC-18224	11.3
NC-18225	12.7
NC-17921	16.3
NC-17922	12.7
NC-17976	11.7
NC-17404	7.0
NC-77-2	11.7
NC-77-6	21.7
NC-77-7	14.0
NC-17941	17.7
NC-3139	12.3
Va-71-347	14.0
NC-Ac 3139 x Florigiant	17.3
NC-3033 x NC-2	11.3
NC-GP 343 x Florigiant	7.3
Florigiant x NC-Ac 342	9.0
NC-GP 343 x NC-5	11.0
Florigiant x NC-Ac 301	14.7
NC 5 x NC-Ac 342	11.7
NC-GP 343 x NC-5	16.0
NC-GP 343 x Florigiant	10.7
NC-Ac 301 x NC-5	14.7
NC-Ac 301 x NC-5	12.3
NC-GP 343 x NC-5	9.7
NC-Ac 302 x Florigiant	17.7
Florigiant x NC-Ac 301	19.0
NC-Ac 17163 x NC-Ac 17166	15.3
NC-Ac 17164 x NC-Ac 17163	13.0
NC-Ac 15753 x NC-Ac 17163	14.7
NC-Ac 15753 x NC-Ac 17164	9.7
NC-Ac 15753 x NC-Ac 17164	16.0
NC-Ac 15753 x NC-Ac 17163	15.0
(NC x Fla 393) x PI-138870	13.0
(NC-GP 343 x Va-61R) x (B_2 x NC-4)	9.0
(NC-GP 343 x NC-5) x UF-70115	10.0
(NC-GP 343 x NC-5) x UF-70115	6.0
(NC 5 x Florigiant) x (NC-5 x Fla-393)	14.0
UF-73307 x UF-73307	10.7
GK-3 x (Florigiant x NC-Ac 342)	9.0
GK-3 x UF-70115	10.0
GK-3 x UF-70115	3.3
GK-3 x UF-70115	5.3
(B_2 x NC-5) x Florigiant	16.3
(B_2 x NC 5) x Florigiant	16.0
PI-152122 x Frost resistant	12.3
PI-138870 x NC-5	15.0
PI-138870 x NC-5	7.3
PI-138870 x (B, x NC-4)	8.3
(Florigiant x NC-5) x (Florigiant x Valencia)	12.3
LSD (0.05)	6.7

Table 7. Resistance of NC-6 x NC-3033 groundnut lines to Heliothis zea, North Carolina, USA.

Breeding line or cultivar	Average defoliation (%) 1979	1980
NC-6 x NC-3033	1.3	16.0
	2.7	17.7
	2.3	20.0
	1.3	14.0
	2.0	15.0
	2.7	14.3
	3.0	23.3
	1.7	22.7
	2.7	15.7
	3.0	22.0
	3.0	16.0
Florigiant	7.3	50.0
NC-6	1.3	19.3
NC-2	9.0	32.3
NC-3033	NR	28.3
NC-7	NR	36.0
LSD (0.05)	2.2	7.3

NR = Not recorded.

Table 8. Effect of planting data and cultivar on *Heliothis* zea damage to groundnut, North Carolina, USA, 1980.

Date of planting and cultivar	Average foliage damage (%)
May 7	
NC-6	6.7
Florigiant	14.0
May 23	
NC-6	15.0
Florigiant	41.0
June 3	
NC-6	6.3
Florigiant	27.7
LSD (0.05)	6.3

Nonpreference

Heliothis zea larvae normally do not have a choice of host plants. In these tests, larvae were provided a

Table 9. Reaction of *Arachis* collections to Heliothis zea in field tests, at Lewiston, NC, USA.

Section	No. of genotypes	No. of damaged leaves (avg. and range) 1979[a]	1980	1981	Mean no. of leaves damaged 1979-1981
Arachis	11	1.82 (0.4-5.0)	2.13 (1.0-4.3)	4.57 (1.0-6.3)	2.84
Erectoides	6	1.50 (1.0-2.5)	1.55 (2.0-5.7)	3.78 (2.0-5.7)	2.28
Rhizomatosae	21	1.60 (0-5.5)	0.80 (0-1.7)	12.05 (3.3-35.7)	4.81
Ambinervosae	1	0.5	0.3	0.7	0.5
Caulorhizae	1	0.0	0.0	2.0	0.67
Extranervosae	1	2.5	1.3	3.3	2.37
Triseminalae	1	1.0	0.7	NR	0.85
Cultivated checks:					
Florigiant		13.5	40.0	60.0	37.83
NC-2		14.0	26.0	51.7	30.57
NC-6		4.5	10.0	30.0	14.83

a. Means are average of two replicates for 1979 and three replicates for 1980 and 1981.
NR = not recorded.

choice of three cultivars to determine larval preference. An excised leaf from each of three cultivars was placed in a petri dish with moist filter paper. Nine 4-day-old larvae were released in the center of each dish. Damage was determined 4 days after larval release.

The larvae preferred NC-2 and Florigiant to NC-6 for feeding (Table 10). NC-6 received only half the damage of NC-2 and Florigiant.

Table 10. Preference of *Heliothis* zee larvae for groundnut cultivars, laboratory test, 1979.

Cultivar	Average foliage damage[a] (%)
NC-6	20.8
NC-2	44.0
Florigiant	44.5
LSD (0.05)	5.4

a. Each replicate infested with nine 4-day-old larvae that fed for 4 days.

Antibiosis

The same three cultivars were tested for antibiosis, or the adverse effect of the plant on the normal metabolism of the insect. The experiment was conducted in an insect-rearing room, with plastic jelly cups (4-cm diameter and 4,5 cm deep) for cages. A single 4-day-old, diet-reared larva was placed in each cup with sufficient excised groundnut leaflets for 1 day's food. Food was changed daily, and larvae were weighed when 10 days old.

In Test 1 larvae reared on NC-2 and Florigiant weighed approximately three times more than larvae reared on NC-6. In Test 2 larvae weighed three times and five times more when reared on NC-2 and Florigiant, respectively, than when reared on NC-6 (Table 11).

In another test, NC-6 and one of the insect- and disease-resistant breeding lines, NC-6 x 3033, were compared for effect of resistance on the development of the insect. NC-6 and NC-6 x 3033 (selected line) did not differ from each other in their effect on larval weight gain, days to pupation, or emergence date; however, larvae reared on these two lines weighed less, pupated later, and emerged later than those reared on NC-2 and Florigiant (Table 12). Beland and Hatchett (1976) reported *H. zea* pupated 3 to 5 days earlier on susceptible soybean lines than on the resistant soybean introduction PI-229358. On groundnut *H. zea* pupated 3 days earlier on Florigiant and NC-2 (susceptible) than on NC-6 (resistant).

Laboratory Screening Wild Species

Field-grown Plants

Leaves were collected from selected field-grown wild species to compare their relative resistance when *H.zea* did not have a choice of oviposition substrates. Excised leaves were placed in plastic bags and transported from the field to the laboratory in a cooler filled with ice.

Leaflets were placed in plastic jelly cups (4 x 4.5 cm) and one 4-day-old larva was placed in each cup. The cups were observed daily, and food was replaced as it was consumed, but there was always excess foliage in the cup. Larvae were weighed when they were 11 days old, and mortality recorded.

Heliothis larvae did not survive on leaves of groundnut species from sections *Ambinervosae, Extranervosae* and *Erectoides.* When larvae were fed groundnuts from the section *Rhizomatosae,* weight gain was low, and mortality averaged 80%. Groundnuts in the section *Arachis,* more closely related to cultivated groundnuts than species of other groups, caused moderate reduction in weight gain, and larval mortality averaged 57.5%. Larvae fed leaves of cultivated groundnut did not differ from each other in weight gain or mortality, but they had only 20% mortality and their weights were two to three times more than the average weight of the larvae that survived for 11 days on the wild species (Table 13).

Table 11. Antibiosis as a mechanism of resistance In groundnut cv NC-6 to Heliothis zea, North Carolina, USA, 1979.

Cultivar	Average wt of larvae (mg) Test 1[a]	Test 2[b]
NC-6	19.2	10.4
NC-2	53.4	34.7
Florigiant	66.3	55.0
LSD (0.05)	20.8	14.3

a. Mean is an average for five 10-day-old larvae.

b. Mean is an average for eight 10-day-old larvae.

Greenhouse-grown Plants

Excised leaves from wild species were compared with cultivated groundnut for effect on *H. zea* development and survival. Leaves were placed in plastic cups (4 x 4.5 cm) and a single 4-day-old larva was placed in each cup. The experiment was replicated six times and when the larvae were 10 days old, they were weighed and mortality was recorded.

Larvae did not survive on leaves of *A. batizocoi* Krap. et Greg. (Coll. GKP-9484 of section *Arachis)* or on *A.* sp. GK-10596C of section *Rhizomatosae.* There was some larval mortality on all wild species but there was no mortality on NC-2 or NC-6. Larvae reared on the wild species weighed less than those reared on the NC-2 susceptible standard (Table 14).

Table 12. Effect of groundnut cultivar on Heliothis zea development, laboratory teat, North Carolina, USA, 1981.

Cultivar	Average wt of 11-day-old larvae (mg)	Days to pupation	Date of emergence
NC-6	10,0	29.2	2 April
NC-6 x 3033	11.1	29.0	4 April
NC-2	33.2	25.5	31 March
Florigiant	36.5	25.8	31 March
LSD (0.05)	13.2	2.2	2.3[a]

a. Days

Table 13. Laboratory evaluation of Heliothis zea feeding and survival on field-grown Arachis collections.

Section	No. of genotypes	Average and range of larval weight gain (mg)	Average and range of mortality (%)
Arachis	8	68 (20-150)	57.7 (40-80)
Erectoides	6	0	100
Rhizomatosae	3	37 ((0-60)	80 (60-100)
Ambinervosae	1	0	100
Extranervosae	1	0	100
Cultivated checks			
Florigiant		100	20
NC-2		130	20
NC-6		110	20

Table 14. Differences *among* wild species of groundnut grown in the greenhouse on *Heliothis* zea development, North Carolina, USA.

Arachis Species	Collection	Section	Average wt of 10-day-old larvae (mg)	Average mortality (%)
A. hypogaea	NC-2	*Arachis*	29.5	0
A. hypogaea	NC-6	*Arachis*	16.9	0
A. monticola	K-7264	*Arachis*	11.7	16.7
A. sp	GKP-9645	*Rhizomatosae*	4.9	50.0
A. sp	Manfredi #5	*Arachis*	3.8	83.3
A. sp	GKP-9649	*Rhizomatosae*	3.4	66.6
A. batizocoi	GKP-9484	*Arachis*	NR	100
A. sp	GK-10596C	*Rhizomatosae*	NR	100
LSD (0.05)			17.4	

NR = not recorded.

Conclusion

There is evidence of moderate resistance to *H. zea* among cultivated groundnuts. Resistance in NC-GP 343 and NC-Ac 342 is heritable. The wild species of *Arachis* exhibited a high level of resistance to *H. zea,* some approaching immunity.

Antibiosis appears to be a major mechanism of resistance to *H. zea* in groundnut; however, ovipositional nonpreference has not been tested.

While the level of resistance to *H. zea* among cultivated peanuts is low to moderate, it is of economic importance in a pest-management approach. Defoliation among resistant groundnut lines was usually below the damage threshold; therefore insecticide applications would not be required for *Heliothis* control on resistant groundnuts, and pesticide-induced mite outbreaks can be avoided.

References

BELAND, G.L., and HATCHETT, J.H. 1976. Expression of antibiosis to the bollworm in two soybean genotypes. Journal of Ecoomic Entomology 69:557-560.

BRETT, C.H. 1958. Resistant corn to control corn earworm. North Carolina Research and Farming 16:6.

CAMPBELL, W.V. 1978. Effect of pesticide interactions on the two-spotted spider mite on peanuts. Peanut Science 5:83-86.

CAMPBELL, W.V., and WYNNE, J.C. 1979. Resistance of NC-6 peanut cultivar to *Heliothis zea.* Proceedings, American Peanut Research and Education Society 11:63.

CAMPBELL, W.V., and WYNNE, J.C. 1980. Resistance of groundnuts to insects and mites. Pages 149-157 *in* Proceedings, International Workshop on Groundnuts. ICRISAT, 13-17 Oct 1979, Patancheru, A.P., India.

CLARK, W.J., HARRIS, F.A., MAXWELL, F.G., and HARTWIG, E.E. 1972. Resistance of certain soybean cultivars to bean leaf beetle and bollworm. Journal of Economic Entomology 65:1669-1672.

DOUGLAS, W.A. 1954. Effect of planting date on corn earworm damage to dent corn. Journal of Economic Entomology 47:1158.

DOUGLAS, W.A., and ECKHARDT, R.C. 1957. Dent corn inbreds and hybrids resistant to the corn earworm in the south. U.S. Department of Agriculture, technical bulletin 1160, Washington DC, USA. 13pp.

LEUCK, D.B., HAMMONS, R.O., MORGAN, L.W., and HARVEY, J.E. 1967. Insect preference for peanut varieties. Journal of Economic Entomology 60:1546-1549.

LUCKMAN, W.H. 1956. Observations on the European corn borer and the corn earworm infesting early season plantings of Country Gentleman sweet corn. Journal of Economic Entomology 49:877

LUKEFAHR, M.J., MARTIN, D.F., and MEYER, J.R. 1965. Plant resistance to five Lepidoptera attacking cotton. Journal of Economic Entomology 58:516-518.

MAXWELL, F.G., JENKINS, J.N., and PARROTT, W.L. 1972. Host plant resistance to insects. Advances in Agronomy 24:187-265.

McMILLIAN, W.W., and WISEMAN, B.R. 1972. Host plant resistance: A twentieth century look at the relationship between *Zea mays* L. and *Heliothis zea* (Boddie). Florida Agricultural Experimental Station monograph series 2, Fla, USA. 131 pp.

PAINTER, R.H. 1951. Insect resistance in crop plants. New York, USA: Macmillan. 520 pp.

STINNER, R.E., RABB, R.L., and BRADLEY, J.R. 1976. Natural factors operating in the population dynamics of *Heliothis zea* in North Carolina. Pages 622-642 *in* Proceedings. 15th International Congress of Entomology, Washingon, DC, USA.

Screening Legumes for Resistance to *Heliothis*

D.J. Rogers*

Abstract

Resistance or differential susceptibility to Heliothis *species—H.* armigera, *H.* punctigera, H. virescens, *and* H. *zea-has been demonstrated in* Arachis hypogaea, Cajanus cajan, Cicer arietinum, Glycine max, Lablab purpureus, Medicago sativa, *and* Phaseolus vulgaris. *Knowledge of* Heliothis *biology on the host and of the relationship of the pest infestation to host-plant phenology is essential to the development of realistic and effective methods of screening for* Heliothis *resistance. In general,* Heliothis *infestation of legumes occurs during the flowering period, with larvae feeding on young leaves for a short time before completing development on the flowers and pods. Therefore techniques based on pod feeding are more appropriate, in most cases, than those based solely on leaf feeding. While germplasm collections and segregating populations are being screened for* Heliothis *resistance, knowledge of optional screening techniques would increase progress in the development of* Heliothis-*resistant legume cultivars.*

Résumé

*Criblage de légumineuses pour la résistance à l'*Heliothis: *Une résistance ou sensibilité différentielle aux espèces d'*Heliothis--H. armigera, H. punctigera, H. virescens *et* H. zea*—a été démontrée chez* Arachis hypogaea, Cajanus cajan, Cicer arietinum, Glycine max, Lablab purpureus, Medicago sativa *et* Phaseolus vulgaris. *Une connaissance de la biologie de l'*Heliothis *sur l'hôte et de la relation entre l'infestation du ravageur et la phénologie de la plante-hôte est essentielle au développement de techniques de criblage réalistes et efficaces pour la résistance à l'*Heliothis. *Généralement, l'infestation des légumineuses par l'*Heliothis *a lieu durant la floraison, lorsque les larves se nourrissent des jeunes feuilles pendant une courte période avant d'achever leur développement sur les fleurs et les gousses. Aussi, les techniques basées sur l'alimentation des gousses sont généralement plus appropriées que celles basées sur l'alimentation des feuilles. Les collections des ressources génétiques et les populations en ségrégation étant criblées pour la résistance à l'*Heliothis, *la connaissance de techniques optionnelles de criblage favoriserait le progrès vers le développement de cultivars de légumineuses résistants à l'*Heliothis.

The earliest published records of resistance or differential susceptibility to *Heliothis* within legume species were for chickpea *(Cicer arietinum)* and hyacinth bean *(Lablab purpureus)* (Parsons et al 1938; Parsons and Marshall 1939). They reported that *H. armigera* larvae bred on a purple-flowered chickpea cultivar produced small pupae and adults with reduced fecundity, while those bred on a white-flowered cultivar produced normal-sized individuals with normal fecundity. They also noted that three strains of hyacinth bean differed in the level of *H. armigera* oviposition during the preflowering period. No further cases of host-plant resistance to *Heliothis* in legumes appeared in the literature until 1967 (Leuck et al. 1967). Since then the literature on *Heliothis* resistance in legumes has expanded rapidly. The legumes in which host-plant resistance to *Heliothis* has been reported are *Arachis hypogaea* (groundnut), *Cajanus cajan* (pigeonpea) *Cicer arietinum* (chickpea) *Glycine max* (soybean), *Lablab purpureus* (hyacinth bean), *Medicago sativa* (lucerne), and *Phaseolus vulgaris* (common bean). The *Heliothis* species for which host-plant resistance in legumes is known are *H. armigera* (Hubner), *H. punctigera* (Wallengren), H. *virescens* (F), and *H. zea* (Boddie).

General Principles of Screening Plants for Resistance to Insects

Reviews have been published by Ortman and Peters (1980), Dahms (1972), Kogan (1975), Guth-

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rie(1975), Farrell (1977), and Russell (1978) on the general principles of screening plants for resistance to insects. These publications highlight a number of features common to all screening for host-plant resistance to insects.

Pest Biology

Knowledge of the biology of the pest and its relationship to the phenology of the host plant is essential before realistic screening tests for host-plant resistance can be developed. Information on the distribution, feeding, and reproductive habits, and on factors that affect the growth, survival, and fecundity of the pest are all important. Screening tests should fall within the range of normal pest behavior and activities on the host and should not preclude the expression of any aspect of resistance to the pest.

Assessment Methods

Screening methods for resistance use either a plant reaction or an insect response to quantify host variation in resistance to the pest. Dahms (1972) identified 16 criteria that could be used to evaluate resistance in plants, involving both insect-based and plant-based assessment techniques.

In initial studies involving large numbers of diverse plant lines, rating schemes that quantify broad differences in plant damage or insect numbers are adequate, although phenology differences among lines should be taken into account. More detailed and precise evaluations on levels and types of resistance are required for those lines showing some resistance in initial tests. Evaluation methods must be adequate to identify genetic plant-to-plant or line-to-line variation in resistance in heterogeneous populations.

Insect Infestation Methodology

The level of pest infestation required is one that maximizes discrimination between susceptible and resistant plants, rather than simply a very severe infestation. Too heavy an infestation may mask moderate, but still useful, levels of resistance and unnecessarily narrow the gene base of the crop. However, too light an infestation will increase the number of plants that escape attack and will not show adequate differences between susceptible and resistant genotypes.

Insect Biotypes

Insect biotypes with the ability to infest previously resistant plant genotypes have been detected in some insect pests of legumes. There has been no evidence that any *Heliothis* species have developed such biotypes (Gallun and Khush 1980).

Biology of *Heliothis* Species

On legumes, the most important *Heliothis* species are *H. armigera, H. punctigera, H. virescens,* and *H. zea.* The biology of these species exhibits basic similarities (Hardwick 1965; Turnipseed 1973; Kogan et al. 1978; Turner 1980). All four species are polyphagous, feeding on a wide range of cultivated and uncultivated plant species.

On legumes, the *Heliothis* larvae feed on the leaves, growing points, flowers, fruits, and seeds. When periods of *Heliothis* activity occur during vegetative growth stages, significant amounts of leaf feeding can occur. However, once flowering commences, feeding occurs preferentially on reproductive plant parts. *Heliothis* species have a marked preference for oviposition on plants that are flowering (Parsons 1940; Cruz 1975; Johnson 1975; Hillhouse and Pitre 1976). Hillhouse and Pitre (1976) found that on soybeans, this preference was not as strong for *H. virescens* as *H. zea.* On soybeans, most *Heliothis* eggs are laid on leaves in the upper two-thirds of the crop canopy, with the youngest fully expanded trifoliolate leaf being the most preferred oviposition site (Hillhouse and Pitre 1976; Panda and Daugherty 1976). Turner (1974, personal communication) found that most *H. armigera* eggs are laid on the fully expanded trifoliolate leaves of flowering common-bean plants.

Hatchett et al. (1976) observed that first- and second-instar larvae feed on leaves before attacking soybean pods. I have observed a similar situation with *H. armigera* on soybeans in Australia. Newly emerged *H. armigera* larvae feed on young soybean trifoliolate leaves before attacking the pods. Saxena (1978) records a similar sequence for *H. armigera* on pigeonpea in India. McWilliams and Beland (1977) found that *H. zea* larvae developed faster and had lower mortality on the uppermost expanding than on the older trifoliolate leaves.

In addition, when given a choice of leaves of different ages, *H. zea* larvae fed preferentially on the youngest leaf. Where first-instar *H. zea* larvae were given a choice of leaves, flowers, and pods, feeding was more common on leaves and pods than on flowers (Bailey 1979).

The usual sequence followed by a *Heliothis* infestation on legumes appears to be for moths to lay eggs on leaves in the upper part of the crop canopy during the flowering period; the newly hatched larvae feed on young trifoliolate leaves and flowers before completing larval development on the pods. Any screening test for resistance to *Heliothis* species in legumes should take this sequence into account. A less common occurrence is for larvae to feed on the leaves during the vegetative growth stages. A screening test for leaf-feeding resistance should be considered separately from a test to screen for resistance to the pest during the normal period of infestation, unless strong correlations exist between the two.

Resistance to *Heliothis* in Particular Legume Species

References reporting aspects of resistance to *Heliothis* species in legumes are summarized in Table 1. Some of these are incidental (Parsons et al. 1938; Parsons and Marshall 1939) or record differences noted during the course of other studies (Bishop and Holtkamp 1980). Duangploy (1978) reports the lack of a source of resistance to *Heliothis* in mung bean. For the other five legume species, the published data derive from conscious attempts to identify and utilize resistance to *Heliothis* species.

Arachis hypogaea (Groundnut)

Leuck et al. (1967) documented significant variation among 14 groundnut varieties in ratings of leaf defoliation in field-planted groundnuts. The defoliators were predominantly *H. zea,* with the velvet bean caterpillar *(Anticarsia gemmatilis),* fall armyworm *(Spodoptera frugiperda)* and red-necked peanut worm *(Stegasta bosqueella)* being present in smaller numbers. Leuck et al. also found a significant negative correlation between the rating of leaf damage by lepidopterous defoliators and a rating of thrips damage.

Campbell and Wynne (1980) reported low to moderate levels of resistance to *H. zea* in North Carolina breeding lines and in the cultivars Early Bunch and NC-6, with laboratory tests indicating that antibiosis is the mechanism of *H. zea* resistance in NC-6. This cultivar was originally developed for resistance to the southern corn rootworm *(Diabrotica undecimpunctata howardi)* but subsequently was shown to be resistant to thrips *(Frankliniella fusca)* and potato leafhopper *(Empoasca fabae)* as well as *H. zea.* Current research in North Carolina is directed towards combining this multiple pest resistance with resistance to some diseases.

Cajanus cajan (Pigeonpea)

ICRISAT has an active program for screening pigeonpea lines for resistance to *H. armigera* (Davies and Lateef 1978; Reed et al. 1980; ICRISAT 1980). This program was initiated in 1975 in an attempt to identify reduced susceptibility to *H. armigera* and the podfly (*Melanagromyza obtusa),* and one of its objectives was to ensure that lines generated by the ICRISAT plant breeders were not highly susceptible to *H. armigera.*

A field-screening technique, using augmented natural *H. armigera* populations, has been developed. Initial evaluations in small unreplicated plots have been conducted on almost 10 000 lines. Promising lines were retested in replicated trials of narrow maturity ranges, which include check cultivars of known susceptibility. Spatial and temporal variations in pest attack result in high coefficients of variation. The use of balanced lattice-square designs in the advanced testing stage gave useful increases in efficiency. The percentage of pods damaged and the seed yield under unsprayed infested conditions were used to quantify the two aspects of resistance of interest to the ICRISAT team.

Lines with reduced susceptibility to *H. armigera* attack have been identified, although none appear to have immunity. Even the less susceptible lines were severely attacked under heavy pest pressure. Lines vary widely in their ability to compensate for *H. armigera* damage, and this compensatory ability is an important selection criterion at ICRISAT. Considerable resistance to *H. armigera* has been identified in *Atylosia* species, close wild relatives of pigeonpea, and attempts are being made at ICRISAT to transfer this resistance to cultivated pigeonpea.

Sinha et al. (1979) also report varietal differences in susceptibility to *H. armigera* in pigeonpea.

Cruz (1975) provided the only record of differential susceptibility to *H. virescens* in pigeonpea

Table 1. Literature of host-plant resistance to Heliothis spp In legumes.

Legume species	*Heliothis* species	Reference
Arachis hypogaea (Groundnut)	*H. zea*	Leuck et al. (1967)
		Campbell and Wynne (1980)
Cajanus cajan (Pigeonpea)	*H. armigera*	Davies and Lateef (1978)
		Sinha et al. (1979)
		ICRISAT (1980)
		Reed et al. (1980)
	H. virescens	Cruz (1975)
Cicer arietinum (Chickpea)	*H. armigera*	Parsons et al. (1938)
		Singh and Sharma (1970)
		Srivastava et al. (1975)
		Davies and Lateef (1978)
		ICRISAT (1980)
		Reed et al. (1980)
Glycine max (Soybean)	*H. armigera*	Tuart and Rose (1979. personal communication)
		Rogers and Brier (unpublished data)
	H. punctigera	Tuart and Rose (1979. personal communication)
	H. virescens	Hatchett et al. (1976)
		Turnipseed and Sullivan (1976)
		Hatchett et al. (1979)
	H. zea	Clark et al. (1972)
		Beland and Hatchett (1976)
		Hatchett et al. (1976)
		Turnipseed and Sullivan (1976)
		Tester (1977)
		Bell (1978)
		Kea et al. (1978)
		Hatchett et al. (1979)
		Dreyer et al. (1979)
		Smith and Brim (1979a, 1979b)
		Joshi (1980)
Lablab purpureas (Hyacinth bean)	*H. armigera*	Parsons and Marshall (1939)
Medicago sativa (Lucerne)	*Heliothis* spp	Bishop and Holtkamp (1980)
Phaseolus vulgaris (Common bean)	*H. armigera*	Rogers (unpublished data)
Vigna radiata (Mung bean)	*Heliothis* spp	Duangploy (1978)

when he found significant differences in the number of *H. virescens* eggs laid on flowers and pods and in the percentage of pods infested on 13 pigeonpea lines.

Cicer arietinum (Chickpea)

Parsons et al. (1938) recorded differences between two chickpea cultivars in their suitability for *H. armigera* growth and development. Larvae feeding on a purple-flowered cultivar produced small pupae and adults with reduced fecundity, while larvae feeding on a white-flowered cultivar showed normal growth and development.

Singh and Sharma (1970) recorded variation in susceptibility to damage by *H. armigera,* with two lines being less damaged than three commercial cultivars. These two lines were also higher yielding, with good resistance to frost, wilt, and drought. Srivastava et al. (1975) studied 20 chickpea lines and found significant variation in the percentage of pods damaged. They found no correlation between seed yield and pod damage by *H. armigera.*

In recent years, ICRISAT has been screening chickpea lines for resistance to *H. armigera* (Davies and Lateef 1978; Reed et al. 1980; ICRISAT 1980). The approach to resistance screening and the parameters used to quantify resistance are the same as those used for pigeonpea.

Approximately 12 000 lines have been screened in the ICRISAT program, but no lines with immunity have been identified. However, considerable and consistent differences among chickpea lines in susceptibility to *H. armigera* have been demonstrated. As with pigeonpea, lines with substantial compensatory ability have also been identified. Selection of lines has been for reduced susceptibility to *H. armigera* and the ability to tolerate damage. Individual plant selection in open-field conditions has not proved to be a useful technique. F_2 populations derived from crosses using the less susceptible cultivars have been screened for resistance. Selection within existing cultivars for reduced susceptibility to *H. armigera* has also been investigated.

Glycine max (Soybean)

As indicated in Table 1, host-plant resistance to *H. armigera, H. punctigera, H.* virescens, and *H.* zea has been reported in soybeans.

Most of the research has been done on resistance to *H. zea* and *H. virescens.* Twenty-four soybean lines evaluated by Clark et al. (1972) for resistance to bean leaf beetle *(Cerotoma trifurcata),* striped blister beetle *(Epicauta vittata),* and bollworm *(H. zea)* included ten of the lines reported by Van Duyn et al. (1971) as having resistance to the Mexican bean beetle *(Epilachna varivestis).* Lines PI-171451, PI-227687, and PI-229358 had low pod-damage levels from *H. zea.* PI-227687 received more eggs than other lines but had the fewest damaged pods, suggesting antibiosis as the resistance mechanism. PI-171451 received fewer eggs than other lines.

Hatchett et al. (1976) evaluated the three resistant PI lines identified by Clark et al. (1972) and five susceptible commercial cultivars in the laboratory for leaf-feeding resistance to *H. zea* and *H. virescens.* All three PI lines produced higher larval mortality, reduced larval weight gains, and increased time to pupation in *H. zea* and *H. virescens.* Beland and Hatchett (1976) found that *H. zea* larval mortality occurred predominantly in the fifth to eighth instars and late in the intrastadial development in PI-229358. The larvae feeding on the resistant PI-229358 had at least one additional larval instar and a longer development period than those feeding on susceptible cultivars.

Turnipseed and Sullivan (1976) tabulated data on multiple pest resistance—to *H. zea, H. virescens, E. varivestis,* and *Pseudoplusia includens*—in breeding lines and indicated that where breeding lines derived from PI-229358 were selected for resistance to *E. varivestis,* some, but not all, lines were also resistant to *H. virescens* and *H. zea.* Hatchett et al. (1979) found that while PI-229358 was resistant to both *H. zea* and *H. virescens,* some of the breeding lines derived from it were resistant to *H. zea* but not to *H. virescens* (see also Table 2, for another example of this). Hatchett et al. (1979) and Smith and Brim (1979a, 1979b) also examined selection for multiple pest resistance in crosses between resistant PI lines and susceptible commercial cultivars. Data from all four papers (Turnipseed and Sullivan 1976; Hatchett et al. 1979; Smith and Brim 1979a, 1979b) indicate that while it is possible to recover lines with resistance to more than one pest, direct selection for resistance to one pest species does not necessarily result in indirect selection for resistance to other pests.

In laboratory studies, ED 73-541 had substantial levels of resistance to *H.* zea and *H.* virescens in the USA (Turnipseed and Sullivan 1976) but is

Table 2. Comparative development of Heliothis armigera, *H. virescens*, and *H. zea* on four soybean lines.[a]

Soybean line	*H. armigera*[a] Larval weight 10 days	*H. virescens*[b] Larval weight 13 days	*H. zea*[c] Larval weight 14 days
Davis	478.2a	297.9a	377.8a
ED 73-173	491.1a	243.2b	340.7a
ED 73-541	474.2a	159.6d	207.8b
ED 73-371	338.1b	186.7c	192.1b

a. Means in each column followed by the same letter are not significantly different at the 5% level.

b. Data from laboratory experiment conducted by H.B. Brier and D.J. Rogers, 1981.

c. Data from Turnipseed and Sullivan 1976.

susceptible to *H. armigera* in Australia (Brier and Rogers, unpublished data). These cases indicate that indirect selection for resistance to a *Heliothis* species may be ineffective. In addition, it cannot be assumed that a breeding line resistant to one *Heliothis* species will be resistant to other species of *Heliothis.* These studies indicate that multiple pest-resistant parent lines such as PI-227687 and PI-229358 contain a number of independently inherited causes of resistance to insects.

Joshi (1980) examined the effect of planting dates and cultivars on soybean pod damage by *H, zea* and found that the insect-resistant breeding line ED 73-371 had the highest amount of active *H. zea* infestation, but low levels of pod damage. This contrasted with the findings of Kea et al. (1978) that ED 73-371 had significantly lower natural *H. zea* populations than cv Bragg.

Two studies on possible chemical bases of insect resistance in the PI lines have been published (Tester 1977; Dreyer et al. 1979). Tester (1977), examining total nitrogen, carbohydrates, and sterols, found that susceptible varieties accumulated more total nitrogen and at a faster rate than the resistant lines. At pod filling, resistant lines had 33% more soluble carbohydrate. The resistant lines accumulated sterols faster than susceptible cultivars and, by pod filling, contained 20 to 50% more than susceptible cultivars. Tester (1977) suggested that insect resistance in the PI lines may result from the presence of plant sterols with juvenile hormone activity. He indicated that exposure of later instar larvae to juvenile hormone analogues would prevent normal development to the adult stage and result in the formation of supernumerary larvae that fail to survive. This suggestion is compatible with the findings of Beland and Hatchett (1976) on the symptoms of *Heliothis* larval death on the resistant lines. Dreyer et al. (1979) have isolated pinitol (3-0-methyl-chiro-inositol) from soybean leaves. Pinitol caused a 50% reduction in weight gain of *H. zea* larvae when present at 0.7% in a synthetic diet. In both cv Davis and PI-229358, the yield of crystalline pinitol was about 1 % of dry weight (Dreyer et al. 1979); however, as there is a substantial difference in the response of *H. zea* to these two lines, it appears unlikely that pinitol is the cause of resistance to *Heliothis* in the line PI-229358.

Kea et al. (1978) and Bell (1978) studied the effect of insect-resistant soybean lines on the control of H. zea by other methods. In laboratory studies, *H. zea* larvae fed leaves of the line ED 73-371 were more susceptible to methomyl and *Bacillus thuringiensis,* compared with larvae fed on cv Bragg (Kea et al 1978). In the field, higher levels of *H. zea* control were obtained with methyl-parathion and *B. thuringiensis* on ED 73-371 than on cv Bragg, at the same pesticide application rates. Bell (1978) examined the interactions between the pathogens S. *thuringiensis* and *Nomuraea rileyi* and insect-resistant and susceptible soybeans. He found a combination of the resistant line PI-227687 and either of the pathogens caused higher *H. zea* larval mortality in a shorter period of time than single factors acting alone.

Research on resistance to *H. armigera* and *H. punctigera* have been conducted by Tuart and Rose (personal communication 1979) and Brier and Rogers (unpublished data). Tuart and Rose, in a laboratory feeding study using three PI lines and cv Bragg, found higher larval mortality, slower larval growth, and an extended larval development period for both *H. armigera* and *H. punctigera.* PI-227687 was the line most resistant to *H. armigera.*

More detailed laboratory feeding studies have been conducted by H.B. Brier and myself on *H. armigera,* using Australian commercial varieties, the three resistant PI lines and a number of breeding lines supplied by M.J. Sullivan, Clemson University, South Carolina, USA. We have not found the high levels of larval mortality documented by Tuart and Rose (personal communication, 1979), or by American workers for *H. zea* and *H. virescens.* However, the three PI lines and some of the breeding lines have caused prolonged larval development periods and smaller pupae. Our studies support the finding of Tuart and Rose (1979) that of the three PI lines, PI-227687 is the most resistant to *H. armigera.* Of the breeding lines, ED 73-371 had the highest level of resistance, affecting *H. armigera* growth and development to the same extent as PI-227687.

Lablab purpureas (Hyacinth Bean)

The only record of variation in susceptibility to *Heliothis* species in *L. purpureus* is a brief reference by Parsons and Mitchell (1939). They noted that extensive oviposition occurred on a Rhodesian strain of *L. purpureus* before flowering, while on two other varieties, oviposition began only after flowering commenced. The Rhodesian strain emitted a strong scent even when young, while the other two strains did not.

Medicago sativa (Lucerne)

Bishop and Holtkamp (1980) documented significant differences in susceptibility to *Heliothis* attack among the lucerne cultivars Condura 73, CUF-101, and Hunter River. Hunter River had significantly more, and CUF-101 had significantly fewer, infested stems than Condura 73. As the *Heliothis* larvae developed fully on all three varieties, Bishop and Holtkamp (1980) suggested that ovipositional nonpreference may be the cause of the differences.

Phaseolus vulgaris (Common Bean)

Since 1977, I have conducted a research program on resistance to *H. armigera* in the common bean, with the main emphasis on white-seeded dry beans. Some work has also been done on *H. armigera* resistance in snap-bean cultivars.

Bean lines were screened in the field, using augmented natural *H. armigera* populations. Initial evaluations were in small replicated plots laid out in lattice-square designs. Promising lines were retested in larger plots with more replications and laid out in lattice-square or rectangular-lattice experimental designs. In the initial screening experiments, relative infestation levels were quantified using the percentage of pods and seeds damaged. A sample of 50 pods per plot was found to be adequate in most situations. *H. armigera* larval population levels were also recorded in evaluations of promising lines, in addition to the two plant-damage parameters. Where there was variation among lines in days to flowering, serial plantings of a photoperiod-insensitive, early-flowering susceptible cultivar were made, to provide a basis for comparisons among the lines under test.

Of 600 lines evaluated, no lines were found with immunity to attack. However, susbstantial and consistent differences in levels of *H. armigera* infestation and pod and seed damage were demonstrated. Some lines were considerably more susceptible to *H. armigera* infestation than others (Table 3). In addition to evaluating lines from germplasm collections, lines bred by E.C. Gallagher in a dry-bean breeding program have been evaluated for relative susceptibility. Some experimental work has been done on bean-pod fiber content and *H. armigera* resistance status. The feasibility of single-plant selection for *H. armigera* pod-feeding resistance under field conditions has been investigated. In 1980, laboratory studies were initiated to obtain data on the mechanisms of resistance. Both leaf- and pod-feeding studies have been conducted.

Vigna radiata (Mung Bean)

Duangploy (1978) listed *Heliothis* species as important pests of mung bean in Thailand and states that severe damage can occur. He indicates that no source of resistance to *Heliothis* species has been reported in mung bean.

General Comments

In groundnut, lucerne, and soybeans, the reported cases of resistance to *Heliothis* species are in plant

Table 3. Resistance to Heliothis *armigera* In Phaseolus vulgaris, as Indicated by percent pod damage.

Identity	Pods[a] damaged by *H. armigera* (%)
Brown Swedish	51.3
Royal Windsor	38.7
Brown Beauty	38.0
Texcoco 4	36.7
Dwarf Horticultural	36.7
Orbit 131373	33.3
Standard Pink No. 38	28.0
Pintous No. 14	26.0
Light Red Kidney	26.0
PR-6	23.3
Negro 325 (P-438)[c]	23.3
Jamapa (P-460)	22.0
Tara (P-567)	22.0
PR-16	22.0
PI-208769 (P-231)	21.3
PI-150414	18.7
PI-309796 (P-303)	18.7
Negro 321 (P-437)	18.0
PI-310814 (P-8)	17.3
Antioquia 23	15.3
Veranic 2 (P-538)	15.3
Negro 324 (P-436)	14.7
Small White FM 52	14.0
PI-207262 (P-684)	14.0
Pi-165426	12.7
LSD-(0.05)	12.6
CV (%)	34.2

a. All lines commenced flowering 7-10 March 1979.

b. Susceptible check cultivar.

c. All P-numbers in parentheses are CIAT Promising Line numbers (Source: Anonymous 1978).

lines already known to be resistant to other pests (Campbell and Wynne 1980; Bishop and Holtkamp 1980; Clark et al. 1972). In each case, resistance to the first pest was identified in a germplasm screening program in which most lines were discarded because of susceptibility to the pest. It is possible that additional useful sources of resistance to *Heliothis* may have been overlooked because they were susceptible to the other pest species. Screening the original germplasm specifically for resistance to *Heliothis* may be worthwhile.

What constitutes an appropriate assessment method of screening for *Heliothis* resistance is important. In situations where *Heliothis* leaf feeding is of most concern, methods that quantify the amount of leaf feeding or the size of pest populations feeding on the leaves would be appropriate. Where pod feeding by *Heliothis* is the reason for its pest status, assessment methods based solely on measurements of leaf feeding do not appear to be entirely satisfactory unless strong correlations exist between the two. Hatchett et al. (1976) recognized this problem. Parameters that have been used successfully to quantify pod-damage levels are: the percentage of damaged pods (Singh and Sharma 1970; Srivastava et al. 1975; ICRISAT 1980; Rogers unpublished data), the number of damaged pods (Clark et al 1972; Joshi 1980), and a rating of pod damage (Joshi 1980). In other publications, only leaf-damage ratings are given (Hatchett et al. 1976, 1979; Smith and Brim 1979a, 1979b).

The effect of phenology of lines on screening for pod-feeding resistance to *Heliothis* has been recognized, and experimental methods devised to circumvent the problem. In chickpea and pigeonpea lines are divided into narrow maturity-range groups (ICRISAT 1980), while in common bean, serial plantings of a susceptible cultivar are used (Rogers, unpublished data). In photoperiod-sensitive crops, such as soybeans, an additional approach in mass-screening programs may be to use maturity isolines of a susceptible cultivar to allow comparison of lines with different maturities.

In some studies of *Heliothis* resistance in legumes, insects from laboratory colonies have been used in laboratory and field experiments (Clark et at. 1972; Beland and Hatchett 1976; Hatchett et al. 1976,1979; Bell 1978; Kea et al. 1978; Smith and Brim 1979a). However, the documented differences in behavior and population genetic structure between *Heliothis* field populations and laboratory colonies (Raulston 1975; Sluss et al. 1978) suggest that some caution should be exercised when using laboratory-bred *Heliothis* for evaluation of legumes for *Heliothis* resistance.

Evaluation of legumes for *Heliothis* resistance has usually involved laboratory feeding studies. While in general there appears to be a close correspondence between the results of field and laboratory tests, this does not always occur. For example, the ft soybean line IR-5 was found to produce significant effects on *H. zea* growth and development in the laboratory, but most of the inbred lines derived from IR-5 were found susceptible to *H. zea* in the field by Hatchett et al. (1979). They suggest that in segregating plant populations, laboratory bioassay tests may give only a partial indication of field response. This particular example suggests that dependence on laboratory tests alone is inadequate in evaluating legumes for resistance to *Heliothis* and that field experimentation should always be an important part of any such program. Most laboratory bioassays have involved leaf feeding; however, the biology of *Heliothis* on legumes suggests that a more realistic test would be one that involves larval leaf feeding for the first few days, followed by pod feeding until pupation.

Heliothis resistance in legumes is not immunity; its evaluation therefore cannot be based merely on the presence or absence of insects or damage. It requires precise quantification of the relative amount of infestation or damage. Work on chickpea and common bean (ICRISAT 1980; Rogers, unpublished data) indicates that spatial and temporal variation in pest attack make it very difficult to detect real relative differences in *Heliothis* damage or infestation of pods on single plants in the field. This suggests that selection for resistance in F_2 populations in the field would not be worthwhile, though screening of F_2 populations may be possible in a more controlled situation, such as in a greenhouse. Attempts are being made at ICRISAT to screen F2 chickpea populations (Reed et al. 1980). A number of workers have evaluated F_3 to F_6 lines in the field and laboratory and found significant differences among breeding lines. Some of these breeding lines were as resistant to *Heliothis* as the resistant parents (Beland and Hatchett 1976; Turnipseed and Sullivan 1976; Hatchett et al. 1979; Smith and Brim 1979a, 1979b). Adequate field assessments and laboratory bioassay tests for pod-feeding resistance to *Heliothis* require reasonable amounts of plant material. This can be obtained when using F_3 and later lines, but not with F2 populations. Where leaf-feeding resistance to *Heliothis* is required, it is possible that selection within F_2 populations may present fewer problems. However, in general, it appears that in a *Heliothis* resistance plant-breeding program, selection on the performance of F3 and later lines, in field and laboratory tests, may be a better approach than selection on a single-plant basis in F2 populations.

Conclusion

Breeding cultivars for resistance to *Heliothis* species is a rapidly expanding area of legume entomology. Since its beginnings in the late 1960s and early 1970s, rapid progress has been made in the identification of Heliothis-resistant lines. While progress has not been as rapid in incorporation of these resistances into commercially acceptable cultivars, considerable advances have been made. Increased knowledge of optimal *Heliothis*-resistance screening methods for segregating populations would increase progress substantially. The work that has been done on the influence of Heliothis-resistant cultivars on other control techniques is extremely valuable. Such knowledge will provide the basis for the incorporation of *Heliothis*-resistant cultivars into integrated pest management systems for legume crops.

References

ANONYMOUS. 1978. Catalogue of promising bean materials. Centra Internacional de Agricultura Tropicale, Cali, Colombia. 90 pp.

BAILEY, J.C. 1979. Preference of day-old bollworms (Lepidoptera; Noctuidae) for selected parts of soybean plant. Journal of the Kansas Entomological Society 52(3): 621 -622.

BASS, M.H., and ARANT, F.S. 1973. Insect pests. Pages 383-428 *in* Peanuts—culture and uses. American Peanut Research and Education Association. 684 pp.

BELAND, G.L., and HATCHETT, J.H. 1976. Expression of antibiosis to the bollworm in two soybean genotypes. Journal of Economic Entomology 69: 557-560.

BELL, J.V. 1978. Development and mortality in bollworms fed resistant and susceptible soybean cultivars treated with *Nomuraea rileyi* or *Bacillus thuringiensis.* Journal of the Georgia Entomological Society 13: 50-55.

BISHOP, A.L., and HOLTKAMP, R.H. 1980. *Heliothis* species on three varieties of lucerne infested with blue-green aphid *Acyrthosiphon kondoi* Shinji. General and Applied Entomology 12: 10-12.

CAMPBELL, W.V., and WYNNE, J.C. 1980. Resistance of groundnuts to insects and mites. Pages 149-157 *in* Proceedings, International Workshop on Groundnuts, 13-17 Oct 1980, ICRISAT, Patancheru, A.P., India. 324 pp.

CLARK, W.J., HARRIS, F.A., MAXWELL, F.G., and HARTWIG, E.E. 1972. Resistance of certain soybean cultivars to bean leaf beetle, striped blister beetle and bollworm. Journal of Economic Entomology 65: 1669-1672.

CRUZ, C. 1975. Observations on pod borer oviposition and infestation of pigeonpea varieties. Journal of the Agricultural University of Puerto Rico 59: 63-68.

DAHMS, R.G. 1972. Techniques in the evaluation and development of host-plant resistance. Journal of Environmental Quality 1: 254-259.

DAVIES, J.C., and LATEEF, S.S. 1978. Recent trends in grain legume pest research in India. Pages 25-31 *in* Pests of grain legumes; ecology and control, eds. S.R. Singh, M.H. van Emden, and T.M. Taylor. London, UK: Academic Press.

DREYER, D.L., BINDER, R.G., CHAN, B.G., WAISS, A.C., HARTWIG, E.E., and BELAND, G.L. 1979. Pinitol, a larval growth inhibitor for *Heliolhis zea* in soybeans. Experientia 35:1182-1183.

DUANGPLOY, S. 1978. Breeding mung bean for Thailand conditions. Pages 228-229 *in* Proceedings, First International Mungbean Symposium, ed. R. Cowell. Asian Vegetable Research and Development Centre, Taiwan. 263 pp.

FARRELL, J.A.K. 1977. Plant resistance to insects and the selection of resistant lines. New Zealand Entomologist 6: 244-261.

GALLUN, R.L., and KHUSH, G.S. 1980. Genetic factors affecting expression and stability of resistance. Pages 63-86 *in* Breeding plants resistant to insects, eds. F.S. Maxwell and P.R. Jennings. New York, USA: John Wiley. 683 pp.

GUTHRIE, W.D. 1975. Entomological problems involved in developing host-plant resistance programs. Iowa State Journal of Research 49: 519-525.

HARDWICK, D.F. 1965. The corn earworm complex. Memoirs, Entomological Society of Canada No. 40. Ottawa, Canada. 248 pp.

HATCHETT, J.H., BELAND, G.L., and HARTWIG, E.E. 1976. Leaf-feeding resistance to bollworm and tobacco budworm in three soybean plant introductions. Crop Science 16: 277-280.

HATCHETT, J.H., BELAND, G.L., and KILEN, T.C. 1979. Identification of multiple insect resistant soybean lines. Crop Science 19: 557-559.

HILLHOUSE, T.L., and PITRE, H.N. 1976. Oviposition by *Heliothis* on soybeans and cotton. Journal of Economic Entomology 69:144-146.

ICRISAT. 1980. Pigeonpea entomology. Pages 98-103 *in* ICRISAT annual report, 1978-79. Patancheru, A.P., India: ICRISAT.

JOHNSON, M.W., STINNER, R.E., and RABB, R.L. 1975. Ovipositional response of *Heliothis zea* (Boddie) to its major hosts in North Carolina. Environmental Entomology 4. 291-297.

JOSHI, J.M. 1980. Effect of planting dates and soybean cultivars on pod damage by corn earworm. Crop Science 20: 59-63.

KEA, W.C., TURNIPSEED, S.G., and CARNER, G.R. 1978. Influence of resistant soybeans on the susceptibility of lepidopterous pests to insecticides. Journal of Economic Entomology 71: 58-60.

KOGAN, M. 1975. Plant resistance in pest management. Pages 103-146 *in* Introduction to insect pest management, eds. R.L. Metcalf and W.Luckmann, New York, USA: John Wiley.

KOGAN, J., SELL, D.K., STINNER, R.E., BRADLEY, J.R., and KOGAN, M. 1975. The literature of arthropods associated with soybean. V. A bibliography of *Heliothis zea* (Boddie) and *H.* virescens (F.) (Lepidoptera: Noctuidae). University of Illinois, INTSOY Series 17, Urbana, Ill, USA. 242 pp.

LEUCK, D.B., HAMMONS, R.O., MORGAN, L.W., and HARVEY, J.E. 1967. Insect preference for peanut varieties. Journal of Economic Entomology 60: 1546-1549.

McWILLIAMS, J.M., and BELAND, G.L. 1977. Bollworm: effect of soybean leaf age and pod maturity on development in the laboratory. Annals of the Entomological Society of America 70: 214-216.

NIELSON, M.W., and LEHMAN, W.F. 1980. Breeding approaches in alfalfa. Pages 277-312 *in* Breeding plants resistant to insects, eds. F.S. Maxwell and P.R. Jennings. New York, USA: John Wiley. 683 pp.

ORTMAN, E.E., and PETERS, D.C. 1980. Introduction. Pages 3-14 *in* Breeding plants resistant to insects, eds. F.S. Maxwell and P.R. Jennings. New York, USA: John Wiley. 683 pp.

PANDA, N., and DAUGHERTY, D.M. 1976. Ovipositional preference of *Heliothis zea* (Hubn.) on glabrous and dense soybean genotypes. Madras Agricultural Journal 63: 227-230.

PARSONS, F.S. 1940. Investigations on the cotton bollworm. *Heliothis armigera* Hubn. III. Relationships between oviposition and the flowering curves of food-plants. Bulletin of Entomological Research 31:147-177.

PARSONS, F.S., and MARSHALL, J. 1939. Pages 28-35 *in* Progress reports from experiment stations, season 1937-38. Empire Cotton Growing Corporation, London (original article not seen. Abstract in Review of Applied Entomology 27: 4879).

PARSONS, F.S., HUTCHINSON, H., and MARSHALL, J. 1938. Pages 26-32 *in* Progress reports from experiment stations, season 1936-37, Empire Cotton Growing Corporation, London. (Original article not seen. Abstract in Review of Applied Entomology 26:3644).

RAULSTON, J.R. 1975. Tobacco budworm: Observations on the laboratory adaptation of a wild strain. Annals of the Entomological Society of America 68: 139-142.

REED, W., SESHU REDDY, K.V., LATEEF, S.S., AMIN, P.W., and DAVIES, J.C. 1980. The contribution of

ICRISAT to studies on plant resistance to insect attack. Presented at the Scientific Working Group Meeting on Use of Naturally Occurring Plant Products in Pest and Disease Control, May 1980, Nairobi, Kenya. 14 pp. (Mimeographed.)

RUSSELL, G.E. 1978. Plant breeding for pest and disease resistance. London, UK: Butterworth's. 485 pp.

SAXENA, H.P. 1978. Pests of grain legumes and their control in India. Pages 15-23 *in* Pests of grain legumes: ecology and control, eds. S.R. Singh, H.F. van Emden.and T. Ajibola Taylor. London, UK: Academic Press.

SINGH, H., and SHARMA, S.S. 1970. Relative susceptibility of some important varieties of gram to *Heliothis armigera* Hubner. Indian Journal of Entomology 32:170-171.

SINHA, M.M., YADAV, R.P., and KUMAR, A. 1979. Multidirectional approach for pest-management in arhar *(Cajanus cajan)* in Bihar. Pesticides (Bombay) 13: 14-16.

SLUSS, T.P., SLUSS, E.S., GRAHAM, H.M., and DUBOIS, M. 1978. Allozyme differences between *Heliothis virescens* and *H. zea* Annals of the Entomological Society of America 71: 191-195.

SMITH, C.M., and BRIM, C.A. 1979a. Field and laboratory evaluations of soybean lines for resistance to corn earworm leaf feeding. Journal of Economic Entomology 72: 78-80.

SMITH, C.M., and BRIM, C.A. 1979b. Resistance to Mexican bean beetle and corn earworm in soybean genotypes derived from PI-227687. Crop Science 19:313-314.

SRIVASTAVA, A.S., SRIVASTAVA, K.M., and SINGH, L.N. 1975. Studies on relative resistance or susceptibility of gram varieties to gram pod borer, *Heliothis armigera* Hubner. Labdev Journal of Science and Technology 13B: 264-265.

TESTER, CF. 1977. Constituents of soybean cultivars differing in insect resistance. Phytochemistry 16: 1899-1901.

TURNER, J.W. 1980. Insect pests of peanuts in southern Queensland. Queensland Agricultural Journal 106: 172-176.

TURNER, J.W., and TITMARSH, I. 1979. When is a soybean 'pest' a pest? Queensland Agricultural Journal 105:355-362.

TURNIPSEED, S.G. 1973. Insects. Pages 545-572 *in* Soybeans: improvement, production and uses, ed. BE. Caldwell. American Society of Agronomy Monograph 16, Madison, Wis, USA. 681 pp.

TURNIPSEED, S.G., and SULLIVAN, M.J. 1976. Plant resistance in soybean insect management. Pages 549-560 *in* World soybean research, ed. L.D. Hill. Danville, Ill, USA: Interstate. 1073 pp.

VAN DUYN, J.W., TURNIPSEED, S.G., and MAXWELL, J.D. 1971. Resistance in soybeans to the Mexican bean beetle. I. Sources of resistance. Crop Science 11:572-573.

Discussion — Session 5

In the discussion following this session, many details in the papers were questioned; the points of general interest that emerged are summarized here.

Screening for plant resistance should be comprehensive, probably including laboratory, greenhouse, and field-testing. The field testing should be done both under natural infestation, to determine nonpreference for oviposition, and under artificial infestation to minimize the escape problem. Evaluation systems need to be refined to allow the identification of small differences in susceptibility. Evaluations must be made over several sowing dates and locations. For most successful screening programs, laboratory-rearing facilities for mass rearing the pests, preferably on synthetic diets, and a methodology for the release of these pests on the materials to be screened, may be essential. However, some screening programs have been successful using only natural field infestations. Laboratory-bred test insects should be continually monitored to ensure that they do not differ materially from the insects in the wild. Although at CIMMYT no adverse effects were observed after 18 generations of H. zea were reared on synthetic diet, care is taken to introduce fresh insects from the wild at frequent intervals.

For laboratory testing a knowledge of the feeding activity and of the plant parts used as food is essential. For example, gossypol content was assumed to be an important factor in the resistance of cotton to Heliothis, but careful study showed that Heliothis larvae when feeding simply avoid the glands containing gossypol. In the case of phloem feeders such as jassids, analysis of phloem content rather than of whole leaves is required when chemicals involved in resistance/susceptibility are investigated.

The antibiosis mechanism of resistance would appear to be the most useful, for nonpreference can break down when insects do not have a choice, particularly when a resistant cultivar is grown over a wide area. It was pointed out, however, that for polyphagous pests such as Heliothis, nonpreference may hold for a long period and the development of biotypes of the pest is likely to be much slower in such insects than in more specific pests such as the brown plant hopper. Fortunately, the development of biotypes in Lepidoptera in response to resistant crops is virtually unknown. There is an obvious need to check carefully the mechanism of resistance to ensure that this does not reduce the quality of a food or feed crop.

In any crop, the level of resistance that will be of practical use will depend upon many factors, including the economic threshold for the pest and the probable pest populations that the crop is likely to face. There is a possibility that low levels of resistance in the crop may act synergistically with other pest-management elements. For example, larvae feeding on resistant plants may be more susceptible to pesticide use. However, it is also possible that resistant plants may have an adverse effect upon the natural enemy complex. Also the incorporation of resistance in a plant to one pest may change the susceptibility of that plant to other insects in the pest complex.

It was stressed that new high-yielding cultivars should be no more susceptible than those that are to be replaced. Morphological characters are the easiest to manage from the plant-breeding standpoint and should be given special emphasis in screening programs. Multigenic resistance is most desirable, for it has broader utility and has generally proved to be most stable.

Wild species of plants may provide a valuable reservoir of insect-resistance genes and are expected to be of increasing utility in plant breeding programs. The possibility of using genetic engineering should be studied, and it is essential that entomologists make full use of new developments.

Session 6

Novel Methods of *Heliothis* Management

Chairman: M. Jacobson

Cochairman: H. Rembold

Rapporteurs: H.C. Sharma

C.S. Pawar

The Present Status and Potential for Novel Uses of Pheromone to Control *Heliothis*

A.N. Sparks, J.R. Raulston, J.E. Carpenter, and P.D. Lingren*

Abstract

Some 20 years after research was initiated on Heliothis zea *(Boddie) and* Heliothis virescens *(F.) pheromones, they were identified in 1979. Since then, laboratory and field tests have been conducted to explore potential uses of these pheromones to monitor andlor disrupt mating ot* Heliothis spp. *populations. Pheromone traps have been designed and those measured have catch efficiencies in the 5 to 60% range, but the relationship of trap catch to actual population density remains unknown. Several experiments, limited to large-cage of small-field plots, have shown that* Heliothis *pheromone and/or mimics have measurable effects on* H. zea *or* H. virescens*, but none have shown mating inhibition of the native female in her nocturnal habitat. This paper reviews results of those studies and discusses some pertinent field behavior ot* H. zea *and* H. virescens *as related to their pheromones.*

Résumé

Etat actuel et potentiel d'utilisation de phéromones dans la lutte contre Heliothis*: C'est en 1979, soit une vingtaine d'années après le début de la recherche sur les phéromones d'*Heliothis zea *(Boddie) et* Heliothis virescens *(F.), que ces phéromones ont été identifiées. Depuis, des essais en laboratoire et sur le terrain ont été réalisés, afin d'évaluer le potentiel d'utilisation de ces phéromones pour surveiller ou causer une confusion sexuelle chez les populations d'*Heliothis *spp. Des pièges à phéromone ont été concus et ceux qui furent évalués ont permis d'avoir une efficacité de capture allant de 5 à 60%, mais le rapport entre les captures des pièges et la densité réelle des populations reste inconnu. Plusieurs essais, limités à de grosses cages ou de petites parcelles sur le terrain, ont démontré que les phéromones d'*Heliothis *et/ou produits d'imitation ont des effets mesurables sur* H.zea *ou* H. virescens*, cependant, aucun n'a montré une inhibition d'accouplement des femelles indigènes dans leur habitat nocturne. Cette communication porte sur les résultats de ces études et sur certains comportements pertinents, en conditions naturelles, d'*H. zea *et* H. virescens*, en fonction de leur phéromone.*

Entomologists of the USDA-Agricultural Research Service became actively interested in pheromone research for insects of economic importance in the late 1950s. The senior author's continuing association with *Heliothis* pheromone research began in the early summer of 1960. At that time, a memorandum of instruction from a USDA-ARS chemist outlined procedures by which field entomologists were to determine the existence of a pheromone for Lepidoptera. Several wooden clothes pins separated by about 5 cm were attached to a 0.5 cm x 0.5 cm x 30 cm piece of wood with wooden bases about 7 cm high at each end. Virgin *Heliothis* females were secured in a heads-up, all wings behind-the-back position with the clothes pins. In a similar position, unmated males were secured with a clothes pin held in the sex-attractant tester's hand. Males were held in close proximity to the secured females. If they attempted to curl their abdomens toward the females, the presence of a sex attractant was confirmed. These tests were conducted in open laboratory space at the convenience of the entomologist. With the current knowledge of the relationship between *Heliothis* behavior and pheromone interactions one is understandably amused at those initial efforts to document the existence of a *Heliothis* sex attractant.

Since those early beginnings, many significant

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*U.S. Department of Agriculture, Agricultural Research Service. respectively: Southern Grain Insects Research Laboratory, Tifton, Ga; Cotton Insects Research Laboratory, Brownsville, Tex; Southern Grain Insects Research Laboratory. Tifton, Ga; and Cotton Insects Laboratory, Phoenix, Ariz, USA.

International Crops Research Institute for the Semi-Arid Tropics. 1982. Proceedings of the International Workshop on *Heliothis* Management, 15-20 November 1981, Patancheru, A.P., India.

advances have been made. This paper reviews more than 20 years of *Heliothis* pheromone research and explores the potential novel uses for *Heliothis* pheromones.

Pheromone Identification

Gentry et al. (1964) documented the presence of a sex attractant in ether extracts of whole virgin females and/or hexane extracts of the last two abdominal segments of *Heliothis virescens* (F.). Berger et al. (1965) could not obtain active extracts, but demonstrated that male *Heliothis zea* (Boddie) and *H. virescens* entered extreme sexual activity when exposed to certain gases emerging from the detector outlet of a gas liquid chromatographic (GLC) apparatus. The identification of these pheromones was delayed for several years because techniques had not been developed for rearing *Heliothis* spp in numbers large enough to collect the quantities of pheromone needed for identification. The development of procedures for mass rearing *Heliothis* was begun in 1967; Burton (1969) and Raulston and Lingren (1969, 1972) have reported on systems devised to mass rear *H. zea* and *H. virescens,* respectively.

Several scientists researched the identification of *Heliothis* pheromones and contributed to the literature on the subject in the 1970s. McDonough et al. (1970) reported partial structures of two compounds believed to be sex pheromones of *H. zea.* One was thought to be a mono-unsaturated 14-C alcohol, while the other was characterized as a mono-unsaturated 14-C acetate, probably trans-7-tetradecen-1-ol acetate.

Jacobson et al. (1972), in a news release in *Chemical Engineering News,* suggested that the sex pheromone for *H. zea* was cis-9-tetradecen-1-ol formate (Z-9-TDF). In a 1973 paper presentation session at the national meeting of the Entomological Society of America, Sparks' summarized results of cooperative research with Dr. A.A. Sekul[2] of the Southern Grain Insects Research Laboratory, in which they concluded that (Z)-11-hexadecenal (Z-11-HDAL) was a major component of the *H. zea* pheromone. Roelofs et al. (1974) and Tumlinson et al. (1975) identified Z-11-HDAL and (Z)-9-tetradecenal (Z-9-TDAL) as the pheromone of *H. virescens.*

Finally, Klun et al. (1979,1980a, 1980b) reported that *H. zea* females produce (Z)-7-hexadecenal (Z-7-HDAL), Z-11-HDAL, and hexadecenal. In addition to those aldehydes, *H. virescens* were found to produce Z-9-TDAL, tetradecenal, and (Z)-11-hexadecenol (Z-11-HDOL). The pheromone mixtures and approximate mean percent composition of each component for each species, as reported by Klun et al. (1979) are shown in Table 1.

Table 1. Components and approximate percentage of each comprising *Heliothis* zae and *H. virescens* pheromones.

Component	Mean percentage *H. zea*	 *H. virescens*
(Z (-Hexadecenal	92.4	81.4
Hexadecenal	4.4	9.5
(Z)-9-Hexadecenal	1.7	1.3
(Z)-7-Hexadecenal	1.1	1.0
(Z)-9-Tetradecenal		2.0
Tetradecenal		1.6
(Z)-11-Hexadecen-1-ol		3.2

Source: Klun et al. (1979).

Sparks et al. (1979b, 1979c) thoroughly field-tested these chemical components and concluded that the mixtues containing all components in the approximate ratios identified from female ovipositor washes by Klun et al. (1979) were the pheromones for *H. zea* and *H. virescens.* They determined that 133.6 ug of the four-component pheromone evaporated from a cigarette filter over one night's activity period was about 75% as effective as four virgin *H. zea* females in capacity to attract and *lure males into* traps. They compared the seven-component mixture against Virelure (16:1 ratios, Z-11-HDALZ-9-TDAL) and *H. virescens* virgin females in tests located in Tifton, Georgia; Brownsville, Texas; and Phoenix, Arizona. Data averaged across locations and three designs of traps showed that 122.4µg Virelure was about 40% as effective in catch of males as four virgin females, and 151.8µg of the seven-component mixture was 135% as attractive as females used as bait.

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[1] A.N. Sparks, 1973, Summary of progress in *H. zea* pheromone research at Southern Grain Insects Research Laboratory (Unpublished data.) Paper No. 63, ESA Meeting, Dallas, Tex, USA.

[2] Currently at USDA-ARS, Southern Regional Research Laboratory, New Orleans, LA.

Heliothis Pheromones for Monitoring

The economic importance of *Heliothis* spp to agronomic crops necessitates a readily available system for monitoring the seasonal populations of these species. Light traps were the primary method of monitoring adult *Heliothis* spp populations prior to the use of traps containing virgin females or synthetic pheromone as baits to lure and trap males. Walden (1942) presented the first comprehensive report on seasonal occurrence and abundance of the corn earworm, based on light-trap collections. Newcomb (1967) and Beckham(1970) used light traps to index the populations of *H. zea* and *H. virescens,* and reported that a significantly lower percentage of the *H. virescens* populations responded to black-light lamps in traps than did *H. zea.* However, Agee (1972) reported that both species had similar ranges of sensitivity to emitted UV light.

Virgin females were used as bait in traps to index populations of *H. zea* on the Island of St. Croix, U.S. Virgin Islands (Snow et al. 1968). Hendricks et al. (1972) showed the utility of *H. virescens* virgin females used as bait in traps. Several groups of researchers (Snow et al. 1972; Hendricks et al. 1973; Roach 1975) made the comparison of indexing populations of *Heliothis* spp in light traps vs virgin female traps. Typical results are shown (Figs. 1, 2) in data presented by Roach (1975). These data reconfirm that *H. virescens* is not very responsive to light traps while *H. zea* responds well. Light-trap catches may index seasonal fluctuations of populations of *H. zea* more accurately than virgin female traps; however, for both species, the data indicate that virgin female traps are more sensitive to low populations early in the season and decline in efficiency with high populations late in the season.

Is there a possibility of monitoring both *Heliothis* spp simultaneously in pheromone traps? Haile et al. (1973) used virgin females of both species together as lures for electric grid traps. They reported catch reductions of 24.2% for *H. virescens* and 77.5% for *H. zea* over catches made with single-species lures. However, Roach (1975) suggested that chemically synthesized pheromones might be used in the same trap, since the antagonism was apparently behavioral. Since the structures of the pheromones for *H. zea* and *H.*

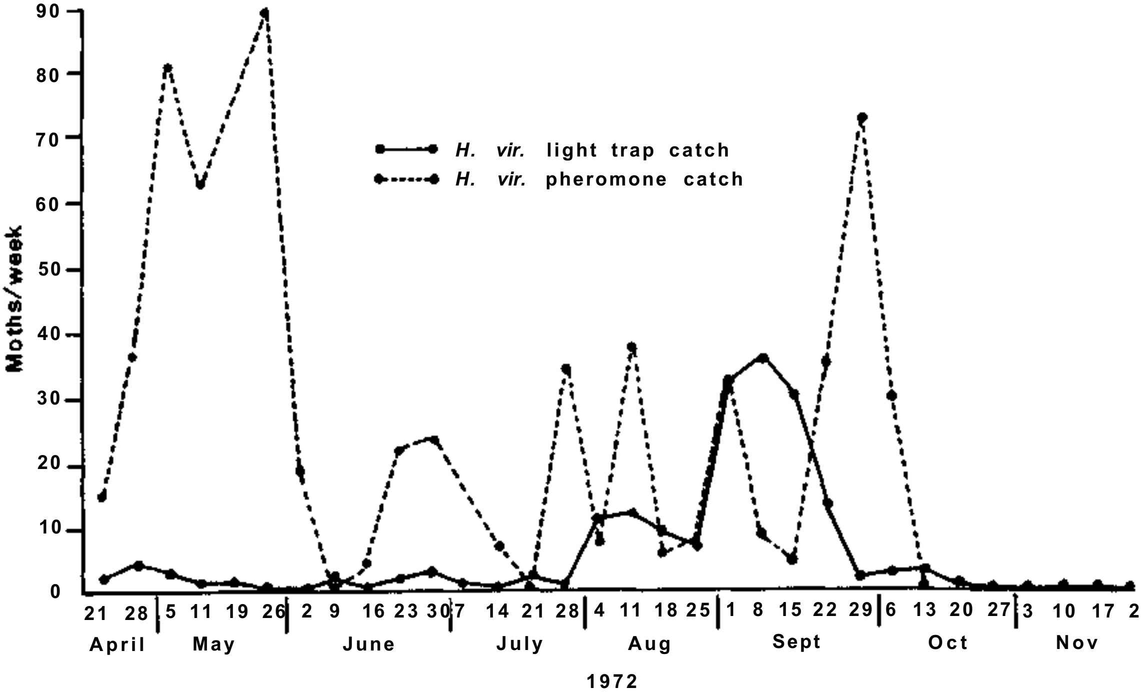

Figure 1. Seasonal H. virescens *light- and pheromone-trap catches at Pee Dee, SC, USA (Source: Roach 1972.)*

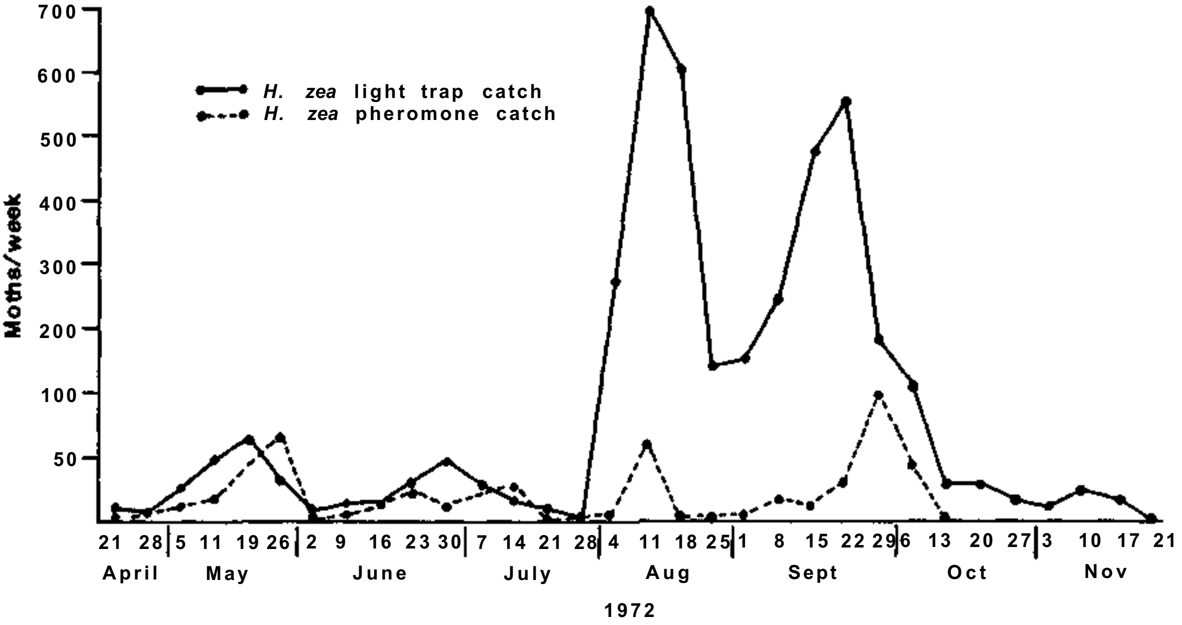

Figure 2. Seasonal H. zea *light- and pheromone-trap catches at Pee Dee, SC, USA. (Source: Roach 1972.)*

virescens have been described (Klun et al. 1979a, 1980a, 1980b), no reports have been published of their use together as lures in a single trap.

Although numerous researchers use pheromone traps to obtain information on *Heliothis* spp, the relationship of trap catch and actual populations has not been determined. However, methods have been developed over the past few years to study the nocturnal behavior of adult *Heliothis* spp (Lingren et al. 1978, 1982a, 1982b) and to relate behavior of the species to pheromones and other factors. Responses of male *H. zea* spp to pheromone traps have been shown to be influenced by trap location, type of trap, time of night within the activity period, age structure and mating status of the population, and weather parameters (Sparks et al. 1979a, 1979b; Raulston et al. 1979).

Heliothis Pheromones for Population Suppression

Population Suppression via Traps

Sparks et al. (1979a, 1979b) field-tested the *Heliothis* pheromones identified by Klun et al. (1979). The effects of several factors on trap catch were evaluated. Three types of traps—pie-plate sticky trap (Snow and Copeland 1969), wind-vane (Raulston et al. 1980), and electrocutor grid (Hollingsworth et al. 1963)—were tested in Georgia, and a fourth type—baffled cone—was tested in Arizona (Hollingsworth et al. 1978). The grid trap was the most efficient in capturing *H.* zea males lured to within 1 meter of the trap in Georgia. Disregarding stimuli used as bait, the pie-plate, wind-vane, and grid traps captured an average of 5.7%, 27.5%, and 57.5%, respectively, of all *H. zea* males lured to within 1 m of those traps. In the Phoenix test, disregarding baits, the baffled-cone trap captured about 10% as many males as did the wind-vane trap.

Raulston et al. (1980) compared catches of *H. virescens* males in modified wind-vane and cone traps. The wind-vane with half the floor removed was 42% efficient, while the baffled cone captured 11.4% of males responding.

Naturally, stimuli used as bait in traps resulted in significant differences in male catch. Virelure captured about 40% as many males as did virgin females and the total-complement pheromone captured about 135% as many males as did virgin females (Sparks et al. 1979a). The same data show that males respond differently to pheromone-baited traps, depending upon time within the normal nocturnal activity period. For example, *Heliothis virescens* males do not respond to pheromone-baited traps prior to entering their normal searching-for-mates behavior pattern. Virgin females and the seven-component pheromone captured males most efficiently during the early part of the sexual activity period; relative efficiency decreased with length of time after initiation of this sexual activity period.

Heliothis spp males will readily respond to synthesized pheromones, and cone, wind-vane, and electrocutor-grid pheromone traps are capable of capturing hundreds of male *Heliothis* spp per trap per night. Our data show they do so on occasion in late season, when high populations are present (unpublished data). However, Raulston et al. (1979) published results of a study in which field emergence, collection of single insects, collection of mating pairs, and males caught in pheromone traps were observed and graphed (Fig. 3). Note that peak emergence and peak mating occurred 8 to 9 days prior to peak capture in pheromone traps.

The grid trap is the most efficient in catch of *Heliothis* males (about 60%) lured to within 1 m, but impractical because of power supply demand. Thus, if a mass-trapping control program were initiated, a trap (wind-vane or cone) less than 45% efficient would have to be used. Further, males respond to pheromone traps most actively approximately 1 week after peak emergence and peak

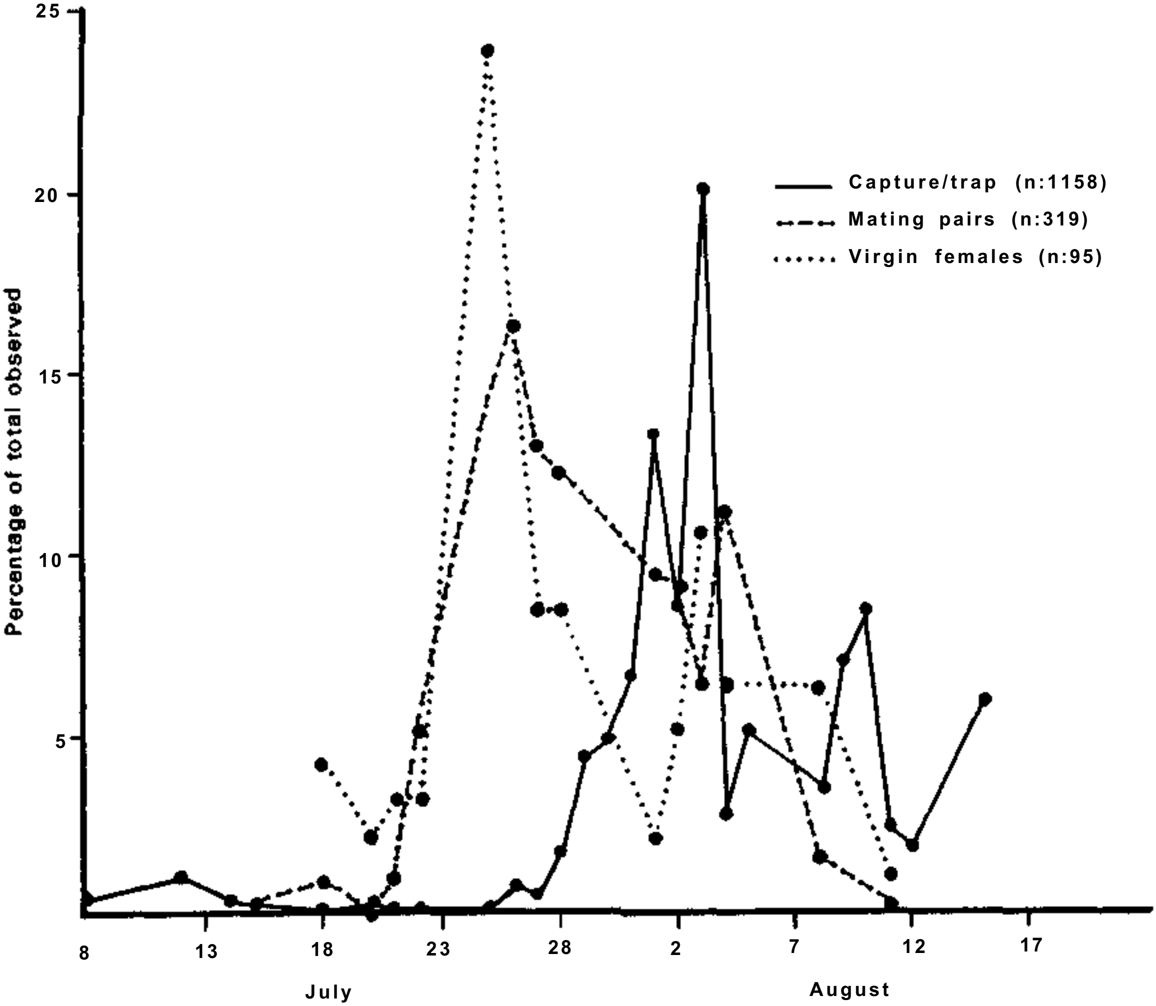

Figure 3. The Interrelationship of collections of Heliothis virescens *virgin females, mating pairs, and males in virgin female traps during one generation in a cotton field. (Raulston et al. 1979).*

mating; therefore it is highly unlikely that a mass-trapping program would ever be successful in removing a high percentage of *Heliothis* males from a population in time to prevent mating, oviposition, and larval infestations.

Knipling and McGuire (1966) made theoretical calculations based on trap competitiveness, moth emergence patterns, survival rates, and protandry and calculated that an initial trap.female ratio of at least 5:1 would be needed to obtain 95% suppression of mating. Based on current knowledge of *Heliothis* behavior, inefficiency of currently designed traps, and our inability to formulate the aldehyde-type pheromones for proper release over an extended period of time, the future for effectively mass trapping *Heliothis* spp does not look promising.

Population Suppression via Air Permeation

Beroza (1960) was the first to suggest permeating the atmosphere of crop environments with sex pheromones to disrupt mating, prevent reproduction, and reduce infestations of economically damaging insect pests. Knipling (1979) reviewed the theory and modeled the potential use of the air-permeation technique as a method of control. Rothschild (1981) summarized the developments and prospects for mating disruptions with Lepidoptera. His review noted 170 mating-disruption trials, of which 25% were classified as successful in decreasing crop infestations and 75% as exploratory. In more than 40% of the trials, reduction of male catch at pheromone or virgin female sites was the sole criterion for disruption. In about 50% of these trials, success was measured by responses of males to tethered, clipped-wing or otherwise decoyed females in forest insect trials, and about 25% in field and orchard insect trials. Thus, in the majority of cases, the mating status and behavior of native females were completely ignored, although these are the most important parameters for evaluating the success of mating disruption with highly mobile Lepidoptera.

Knipling and McGuire (1966) constructed seven hypothetical models to demonstrate principles involved in the use of living insects or extracts containing insect pheromones to control low-level populations. Several field trials involving *Heliothis* spp and their pheromones, components of their pheromones, or pheromone mimics have been conducted, and brief discussions of those follow.

Sekul et al. (1975) placed µg quantities of Z-11-HDAL on cigarette filters near virgin females used as bait in traps and found that as little as 50 ug of the cis isomer inhibited male catch more than 99%. The trans isomer at the same rate produces only 11% inhibition. These authors suggested that this naturally occurring chemical, Z-11-HDAL, might be used as a mating disruptant because of the behavioral effect on corn earworm males.

Gaston et al. (1967) were the first to obtain experimental confirmation that the premating communication between the sexes could be disrupted by permeating the atmosphere with an insect pheromone. Their demonstration was with *Trichoplusia ni* (Hubner) in 27 m^2 plots in which a virgin-female trap was deployed among 100 planchets from which 17 mg (about 17 000 female equivalents) of synthetic pheromone per planchet were evaporated. The criterion was reduction of male catch in the virgin-female trap.

Mitchell et al. (1975,1976) at the Insects Attractants, Behavior, and Basic Biology Laboratory reported highly succesful results in attempts to disrupt mating of *H. zea* and *H. virescens* with Z-9-TDF and Z-11-HDAL. In one test, they placed virgin females in traps in the middle of an 81 m^2 plot, surrounded those traps with 16 polyethylene caps containing 25 mg of test chemical releasing 300 ug/min per cap, and measured disruption of pheromonal communication by reduction of male catch in virgin-female traps operated in the check vs the treated plots.

With these experimental procedures, disruption for *H. zea* and *H. virescens* was measured above 95% when Z-9-TDF was dispensed. In another test, similar techniques were employed, with the exception that laboratory-reared females with clipped wings were placed in the center of plots in cages that permitted mating. In this test, *H. zea* mating was reduced 96.7% by Z-9-TDF and 85.5% by Z-11-HDAL, while *H. virescens* mating was reduced 81.2% by Z-9-TDF and 95.8% by Z-11-HDAL.

McLaughlin et al. (1981) reported results of *H. zea* mating-disruption studies in Florida. They evaporated Z-11-HDAL, Z-9-HDAL, and Z-7-HDAL, individually and in combination, to compare with Z-9-TDF as mating disruptants. Reduction of catch of males in a trap baited with the four-component *H. zea* pheromone and located in the center of 100-m to 300-m plots was the criterion for disruption. They concluded Z-11-HDAL was the disruptant of choice.

Carpenter and Sparks (1982a) tested all components individually and mixtures of the components of the *H. zea* pheromone in a wind tunnel to determine which, if any, of the compounds served as a close-range attractant. They suspected that one of the minor components, based on percent of total pheromone, might serve as a close-range attractant and could serve as a potent mating inhibitor. They found that Z-11 -HDAL was the most attractive of all the components, but that male moths were able to discern "preferred" components and/or mixtures of components in the presence of other components and mixtures. These data suggest that suppression of *H. zea* mating by confusing males through air permeation with less than the full-complement pheromone is not a viable possibility.

Beroza (1972) and Knipling (1976) agreed that the degree of inhibition of mating by disruption of the pheromone communication system would be decreased if the target insect possessed supplementary mate-detection mechanisms other than pheromone signals. Carpenter and Sparks (1982b) studied the effects of vision on the mating behavior of the male corn earworm moth. All tests were conducted in a wind tunnel (0.91 x 0.91 x 2.5 m) mounted on wheels and stationed in a cotton field. Male moths were allowed a choice of mock female + 100 µg pheromone vs cigarette filler impregnated with 100 µg pheromone; dead *H. zea* male moth + pheromone vs filter + pheromone; and mock female vs filter with pheromone. Male moths selected mock females and dead males pinned to cigarette filters containing 100 µg pheromone over cigarette filters impregnated with 100 ug pheromone when separation distances of up to 16 cm were involved (Fig. 4). The maximum distance at Fig. 4 which male *H. zea* can orient visually was calculated to be 16 to 22 cm. When mock females (no pheromone) were compared with 100 ug pheromone impregnated in a cigarette filter, males preferred the mock female at a separation distance of 4 cm and the filter-pheromone at separation distances of 8 to 12 cm (Fig. 5). Pheromone-stimulated males flying upwind in a pheromone plume were observed leaving the plume to veer toward the mock female only to return to the pheromone plume when the two lures were separated by 12 cm. These data show that *H. zea* males use visual cues in their mate-searching behavior.

Generally, the effect of mating disruptants is conveniently measured by evaporating test chemicals into the air around a trap baited with synthetic

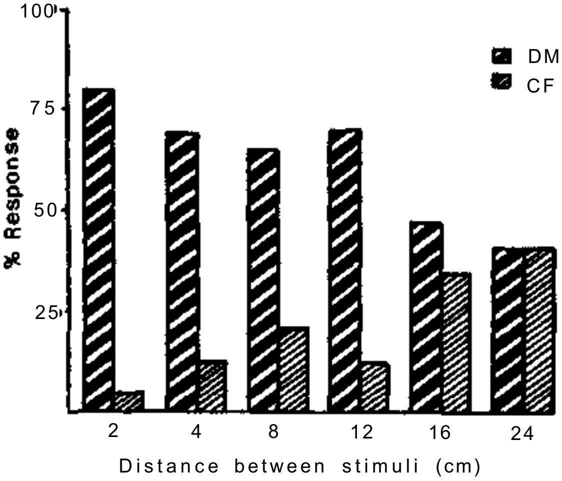

Figure 4. Comparison of **Heliothis zea** *male moth response to a dead* **H.zea** *male moth (DM) pinned to a cigarette filter and a cigarette filter (CF) without a male moth, both of which were inoculated with 100 ug of* **H. zea** *female* **sex pheromone and** *placed in* **a fine across** *the air flow in a wind tunnel allowing the formation of individual pheromone plumes.*

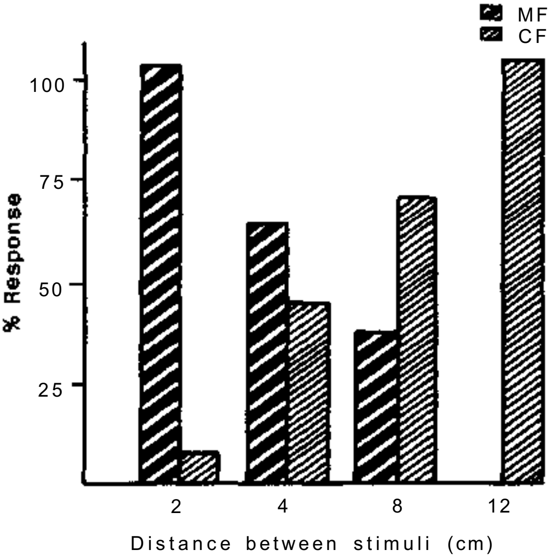

Figure 5. Comparison of **Heliothis zea** *male response to a cigarette filter (CF) inoculated with 100 µg of H. zea female sex pheromone and a mock female moth (MF), both placed in a line transverse to the air flow in a wind tunnel allowing the formation of individual pheromone plumes.*

pheromone or virgin female, and comparing catches of males in treated vs control area. This technique overlooks the behavioral aspects, population density, population movement, age of insects, mating status of insects, and the ability of feral females within the test area to secure a mate.

In the summer of 1979, A.N. Sparks and J.E. Carpenter (unpublished data) planted cotton in 9 x 30 x 4.1 m Saran® screen-covered cages. From the time the cotton began fruiting until *early fall,* a series of disruption studies was conducted. *Heliothis* spp pheromone components were impregnated individually and in mixtures in cigarette filters that were later stapled to cotton plant terminals. Rates of pheromones applied were 186 mg, 18.6 g, and 186 g/ha. Laboratory-reared males and females were released at opposite ends of the cage and observed for mating. Numbers of pairs released ranged from 50 to 100 per cage per test night. Pheromone-impregnated filters were used only on one test night. In these tests, mating was never significantly inhibited, although the 186 g/ha rate of the full-complement *H. virescens* pheromone delayed the onset of mating for approximately 1 to $1^1/_2$ hr.

Beroza and Knipling (1972) postulated that the effectiveness of the air permeation technique would be influenced by population density. Criticism of the numbers of insects released encouraged Carpenter et al. (1982) to repeat the experiment, using wider dosage ranges of pheromone and releasing fewer numbers of insects. Without applying pheromone, they established no significant differences in mating of *H. zea* in three cages (9 x 30 x 4.1 m) planted to cotton when 10, 20, and 40 pairs per cage were released. Pheromone rates of 3.7, 37, and 370 g/ha were dispensed on 100 cigarette filters per cage (3700/ha). Laboratory tests indicated that the estimated quantity of pheromone evaporating after 7 hours was approximately 13%.

Mating data from tests run in early vs late season with no pheromone treatments showed highly significant differences in percentage of the population mating. Regardless of population released in the cage, early-season mating averaged approximately 70%, while late-season mating averaged about 30%. The mating observed ranged from 32.5% to 35.0% to 15.0% for the 3.7, 37, and 370 g/ha treated plots, respectively, when 10 pairs were released per cage (Table 2). When 40 pairs per cage were released, mating ranged from 45.0 to 52.5% to 29.4% for the 3.7, 37, and 370 g/ha treatments, respectively. These data do show significant differences in percent mating observed at varying densities of insects subjected to this range of applied pheromone treatments. However, in no case could successful inhibition of mating be claimed. Finally, in this series of tests, only five pairs per cage were released after application of 37 g/ha of full-complement *H. zea* pheromone or (Z)-11-hexadecenal. This late-season test showed wide variation in mating, but indicated some possibility for reducing mating of extremely low populations of *H. zea* with a high concentration of pheromones (37 g/ha).

Commercial efforts have been made to disrupt *Heliothis* spp mating. In late-season 1979, Lingren et al. (1982) observed and evaluated one such trial. A large field of cotton (ca. 230 ha) had been treated

Table 2. Mean percentage of mating at three population levels of *Heliothis zea* on cotton in field cagas containing pharomona Altar.[a]

Population level (pairs/cage)	Mean percent mating (± SE)[b] with pheromone level of 3.7 g/ha 30 June-3 July	37 g/ha 23 June-26 June	370 g/ha 7 July-10 July
10	32.5 ± 12.6 b	35.0 ± 19.2 b	15.0 ± 10.0 a
20	58.8 ± 14.4 a	52.5 ± 12.6 a	27.5 ± 15.6 a
40	45.0 ± 20.7 ab	52.5 ± 14.0 a	29.4 ± 10.5 a

a. The 9 x 30 m screen field cages were planted with cotton and 100 cigarette filters containing 3.7, 37, and 370 g/ha of pheromone were evenly spaced throughout the cages.

b. Means followed by the same letter in each column are not significantly different at 5% level, Duncan's multiple range test.

four or five times with 8.7 g/ha per application of the seven-component *H. virescens* pheromone. The cotton appeared to have been fruiting well throughout the season and showed very little damage. A nearby 32-ha field was used as a check.

On the night following the sixth application of pheromone (Table 3), we evaluated check (C) and treated (T) fields from 2100 to 0430 hr. We observed two completely different adult populations. The C field adult population contained twice as many males as females with a virginity rate of 93%. The T field had an equal male:female ratio with a virginity rate of 13%. Most of the adults collected as singles in the C field were extremely docile and easily collected. Such docile adults are normally freshly emerged and have not made an initial flight. The population observed and collected in the T field was indicative of "old" population. The sex ratio was 1:1, and single collected females averaged 1.8 but ranged up to five previous matings. In view of the lack of insect pressure in the previous generation, these adults had probably moved into the field. This is a striking example of the population differences that may be encountered even in adjacent fields. In programs dealing with mobile adult insects, such examples demonstrate the need for a complete and thorough assessment of in-field wild populations in terms of their sex ratio and age structure as a prerequisite to program evaluation.

Besides these qualitative differences in the age structure, the two populations also exhibited quantitative differences. The larger population was present in the C field, as indicated by the capture/man hour data presented in Table 3. Only five and three mating pairs were collected, respectively, in the C and T fields. Considering the quantitative differences observed between the populations, no significant differences in mating can be assigned between T and C fields on night 0. During the afternoon following the first night's observations, all fields were treated with a mixture of methyl parathion, acephate, and chlordimeform insecticides. We observed from 2400 to 0430 hr, about 24 hours after the insecticide application, and the data reinforced the population assessments we had made the previous night. The "old" population in the T field was effectively annihilated, and the few adults that were observed were freshly emerged, as indicated by the 100% female virginity. The emerging population in the C field had a male:female ratio of 7.4:1, indicating that the population had passed the emergence peak and that the previously emerged population had been annihilated by the insecticide treatment. No mating pairs were found in either field, further supporting the conclusion that sexually mature insects had beeen killed by the insecticide application. With these data in mind and considering the large quantitative differences observed on this night, resulting in an adult capture/man hour of 1.8 in the T and 15.2 in the C field, it is clear the C field had received infestation pressure the previous generation, while the T field had not.

Observations (2400-0430 hr) the fourth night following pheromone application began to indicate "recovery" of the population from the insecticide application 72 hours previously and indicate a relatively homogeneous population in the T and C fields. Recalling that the "old" population observed initially in the T field had been annihilated by the insecticide application, it now appears that young, sexually mature adults had begun moving into the field as indicated by the high percentage of female virginity and the increase in mating. A similar pattern was observed in the C field, and the reduction in virginity in this field in comparison with the previous observation nights indicated that the preponderance of emergence had occurred, the adults were now dispersing, and the population was beginning the "aging" process. This conclusion is further demonstrated by a return to a 1:1 sex ratio resulting from dispersal.

Observations on night 4 again indicated that the pheromone treatment had no effect on *H. virescens* mating in the field. In fact, considering differences in population density, as indicated by the single insect capture/man hour, more mating was observed in the pheromone field than in the check field. This difference is probably not significant when the population sources in the two fields are considered. The population in the C field probably had a residual emergence occurring; thus for a unit of population there were more sexually immature adults in this field than in the T field, which consisted almost totally of sexually mature insects that moved into the field.

Observations reported here are not meant to be taken as an absolute evaluation of the program. They simply address the inherent pitfalls of evaluating such a program without intensive observations on the adult population and the inferences that can be drawn from such observations. Consider the use of infestation records. The data collected on night 0 indicated a heavily mated population in the T field. Considering the maturity

Table 3. Quantitative, observed, 0-, 2-, and 4-day differences in affects of 8.75 g/ha seven-component Heliothis virescens pheromone formulatad in the Conrel fiber, applied by plane to a 230-ha field of cotton In Phoenix, Ariz, USA.

	Total capture	Ratio male:female	Virgin females (%)	Average spermatophore	Capture/man hour	Ratio of single hourly capture: total mating pair collection
				Night 0		
Treated						
Singles	30	1:1	13.3	1.8	5	1.6:1
Mating Pairs	3	-	0	2.3	-	
Untreated						
Singles	41	1.9:1	92.9	0.1	8.2	1.6:1
Mating Pairs	5	-	20	1.8	-	
				Night 2		
Treated						
Singles	7	2.5:1	100	0	1.8	
Mating Pairs	0	-	-	-	-	-
Untreated						
Singles	76	7.4:1	100	0	15.2	
Mating Pairs	0	-	-	-	-	-
				Night 4		
Treated						
Singles	3	1:1	100	0	1	0.2:1
Mating Pairs	5	-	60	0.4	-	
Untreated						
Singles	10	1:1	60	0.4	3.3	0.4:1
Mating Pairs	7	-	100	0	-	

Source: Lingren et al. (1982), in part.

and attractiveness of this cotton crop, had the heavily mated population been of adequate size, tremendous infestation pressure would have been exerted on the T field, regardless of where the mating had occurred. Under these cirumstances, infestation records would yield little information concerning the effect of the treatment on the target behavior (mating) and could indeed result in conclusions diametrically opposed to the true situation.

Two other techniques used for pheromone disruption evaluation, and perhaps the least understood are traps and mating tables, or variations thereof. Certainly, assessment of *Heliothis* populations through trap-capture data is very poorly understood because of the number of variables that affect trap capture, including (1) trap efficiency, (2) weather, (3) age structure of the population, and (4) attractant used to effect capture. All of these variables have a direct influence on our ability to decipher the meaning of trap capture as it relates to pheromone disruption. We can capture males in traps with semiochemicals, but we do not have the ability to relate catch in a positive manner, either qualitatively or quantitatively, to mating of wild insects in a pheromone-treated area. Another limitation of traps and mating tables in pheromone disruption assessment is their inability to sample the wild female population, the most important aspect of the entire program! Further, in essence each trap and each mating table emits one pheromone plume and is of little more value than a single sexually mature female as an evaluation tool, for if one male responds to a point source of pheromone (female, trap, or table), mating at that particular site is indicated.

The techniques and tools listed here should not be excluded from pheromone evaluation, but conclusions drawn from them should be evaluated in the light of intensive nocturnal field observations. It is very difficult to draw correct conclusions without having data on actual field mating, and so far we have not developed adequate methods to make this assessment beyond actual in-field nocturnal observation.

In the summer of 1979, Raulston (published in part, in Lingren et al. 1982) dispensed Virelure, the seven-component *H. virescens* pheromone, and each component individually, to determine the effects of *H. virescens* mating behavior in 0.4-ha field plots. He impregnated 1240 cigarette filters with 186 to 1240 mg of test material per hectare.

Table 4 shows the effects of dispensing pheromone components on clipped-wing female mating, male response to the seven-component pheromone, and trap capture. The greatest effects were observed when either the full-complement pheromone or Virelure was dispensed in the treated plot. A concentration of 372 mg/ha of these materials reduced mating for the clipped-wing females by about 90%, and male response to the single pheromone source by 100%. In addition, the 372 mg/ha concentration of Virelure reduced trap capture 100%; the trap response shown for the seven-component pheromone was obtained from a trap located 10 m downwind of the treated plot, and this may have resulted in the increased capture noted in this instance.

Dispensing individual components of the tobacco budworm pheromone had less effect; none reduced mating of the clipped-wing females by more than 55%. In most instances there was a greater reduction in male response to a single pheromone source than in clipped-wing female mating. This trend was also evident in the effect of the single components on trap capture. Indeed, 1240 mg/ha of Z-9-TDAL reduced trap capture about 99%, while almost half of the clipped-wing females were able to obtain mates. There was no reduction in wild female matings as indexed by the number of pairs collected in the treated and untreated plots. Clearly, there is no relationship between the clipped-wing female matings and trap captures.

Observations with night-vision goggles were made of males responding to the single source of seven-component pheromone located in the centre of the plot treated with the individual components. Males that responded to the pheromone source were observed entering the pheromone plume, turning 90° upwind toward the source, approaching and in many instances making contact with the source with claspers extended. These behavioral responses were identical to the responses observed to the pheromone source in the untreated area. The only identifiable response differences were quantitative and not qualitative, which would suggest that, at least in small plots such as we were working in (0.4 ha), sexually active males may be repelled by the chemicals rather than confused. Certainly this is a point that must be addressed, for it is imperative to know the kinds of behavior affected by our so-called mating-disruption techniques.

Table 5 shows data collected on the wild population in the treated and untreated plots. The adult singles collections were made between 2100 and

Table 4. Effect of dispensing pheromone components in cotton on mating of clipped-wing females, male response to point source of pheromone, and trap capture of Heliothis virescens.

Component	Cone./ha (mg)	Percent reduction in: Clipped-wing female mating	Response to pheromone	Trap capture
Seven-component pheromone	186	69	100	100[a]
Seven-component pheromone	372	90	100	67.3[a]
Seven-component pheromone	1240	100	100	100
Virelure	372	86.8	100	100
Hexadecenal + Tetradecenal 16:1	372	9.1	55	25
(Z)-11-Hexadecenal	186	49.1	76.6	89.1[a]
(Z)-11-Hexadecenal	372	44.4	76.7	57.4[a]
(Z)-11-Hexadecenal	1240	28.6	71.4	86.0
(Z)-9-Tetradecenal	372	9.1	73.0	73.9
(Z)-9-Tetradecenal	1240	53.7	77.4	98.6
(Z)-9-Hexadecenal	1240	19.6	64.5	32.9
(Z)-7-Hexadecenal	186	10.3	58.8	46.2
(Z)-7-Hexadecenal	372	31.1	0	54.6
(Z)-11-Hexadecen-l-ol	1240	52.6	29.3	59.4

Source: Lingren et al. (1982) in part.

a. Traps located 10m downwind of treated and untreated plots.

Table 5. Effect of dispensing pheromone components on mating of native *Heliothis virescens*ns.

Component	Cone./ha (mg)	Singles Collection				Mating pairs/ha	
		No. Treated	Females/ ha Untreated	No. Treated	Males/ha Untreated	Treated	Untreated
Seven-component pheromone	186	17	22	9	17	0	7.5
Seven-component pheromone	372	8	22	8	37	0	7.5
Seven-component pheromone	1240	105	82	98	74	2.5	7.5
Virelure	372	60	82	119	82	10.0	0
•Hexadecenal + Tetradecenal 16 : 1	372	15	74	30	30	7.5	7.5
(Z)-11-Hexadecenal	186	120	96	83	68	16.9	7.5
(Z)-11 -Hexadecenal	372	179	128	114	82	5.0	30.0
(Z)-11-Hexadecenal	1240	82	60	143	74	69.4	0
(Z)-9-Tetradecena l	372	53	60	15	98	7.5	2.5
(Z)-9-Tetradecenal	1240	113	37	60	37	10.0	0
(Z)-9-Hexadecenal	1240	22	30	0	11	0	0
(Z)-7-Hexadecenal	186	128	68	150	68	24.8	7.5
(Z)-7-Hexadecenal	372	120	74	150	115	30.0	15.2
(Z)-H-Hexadecen-l-ol	1240	113	143	53	83	12.4	7.5

Source: Lingren et al. (1982), in part.

2400 hr during the major feeding and ovipositing periods and indicate no consistent quantitative differences between the treated and untreated areas. The quantitative differences in singles collections noted between components are due to population cycles during the test period. Further, none of the treatments consistently reduced mating of wild adults in the treated area; in many instances, greater numbers of mating pairs were collected in the treated than in the untreated area. These data were inconsistent with the trap captures, which were invariably reduced by the single-component treatments. Again, this indicates the weakness of using trap-capture reductions as an index to disruption of precopulatory behavior.

We concluded that at the concentrations tested, none of the individual components of the multicomponent tobacco budworm pheromone resulted in the confusion of the wild male.

Henneberry et al. (1981) studied mating disruption of pink bollworm and tobacco budworm in Arizona, using 16 treated cotton fields of 16 ha each and one 4-ha field as a check. Materials tested against the budworm included 1 -tetradecenal formate (TF), (Z)-9-T-tetradecen-1 -of formate (Z-9-TDF) and Virelure (Z-11-HDAL + Z-9-TDAL). A total of 13 applications was made in which 269.6, 158.7, and 142.7 g/ha of TF, Virelure, and Z-9-TDF were applied, respectively. The "inhibitors" were formulated in polymeric plastic laminated flakes that released from 22 to 92% of the chemicals in 7 to 28 days. Rates of chemical per application in g/ha ranged thus: TF (12.4-30.1), Virelure (7.4-14.8), and Z-9-TDF (8.7-19.8).

Virelure gave the best reduction of male capture in traps (21 of 30 sample dates), while TF and Z-9-TDF significantly lowered male budworm moth catches on only 10 of 30 sample dates. These findings in 16-ha plots differ grossly from the small-plot tests of Mitchell et al. (1975,1976) and Lingren et al. (1982).

Through September, egg counts, egg hatch, and larval counts were not statistically different in treated vs check fields. In October, on two sampling dates, more eggs were found in control fields.

Nocturnal observations of the adult populations of *Heliothis* spp revealed about twice as many *H. virescens* as *H. zea* adults. Mating of both species was reduced the night following an afternoon application, but the percentages of females mating the night before and night after were not affected. Number of spermatophores/female in treated vs control fields was not affected.

Heliothis Pheromones: Potential for Novel Uses

Pheromones for *Heliothis* spp have been identified and are highly attractive to males of the species. Their efficiency in trapping attracted males over an extended period of time remains a problem of chemistry, engineering, and entomology. Entomologists must learn more about *Heliothis* adult behavior and cooperate with engineers to develop more efficient traps and with chemists to formulate long-lasting, highly attractive lures. Entomologists must learn more about *Heliothis* behavior to equate actual catch with population densities, i.e., how trap catch is affected by population density, age, mating status, trap design, host plants, lure, and weather parameters. Only when these problems have been researched thoroughly can we research the potential of traps to suppress *Heliothis* populations.

The literature reveals that in cases where chemicals are reported to be highly effective *Heliothis* mating inhibitors or pheromonal communication disrupters, the criterion for disruption has been the reduction of male catch in traps baited with virgin females or pheromones. The real evaluation criterion should be the effect of the disruptant on the behavior of the adult *Heliothis* population in the field, with particular emphasis on the number of females copulating.

The largest known field application of pheromone in which nocturnal observations of effects have been conducted involved about 230 ha. This size plot may be entirely too small for successful application of the concept of "inhibiting mating of *Heliothis* populations." Callahan et al. (1972) trapped *H. zea* in 15 traps mounted on a TV tower from 7.7 to 322.2 m throughout the growing season. The catch of mated females averaged 39.4%. Sparks et al. (1975) and Sparks (1979) showed that numerous species of insects of economic importance move on southbound cool fronts up to 160+ km into the Gulf of Mexico. Forty-six percent of *H. zea* females captured in light traps during this movement through the northern Gulf of Mexico were mated. French and Hurst (1969), Sparks (1972,1979), and Raulston (1979) have presented more evidence to show that *H. zea, H. virescens,* and *H. armigera* migrate for extended distances. However, Phillips (1979) believes that the bollworm complex that produces serious problems on occasion in Arkansas is a local product of that state.

Based on the above information, it is apparent that if the technique of permeating the air with pheromones is to successfully inhibit mating of *Heliothis* spp, huge areas of *Heliothis* hosts must be treated. Again, entomologists must learn more about *Heliothis* spp movement and behavior to cooperate with engineers to develop suitable delivery systems and chemists to develop longer lasting, highly effective chemicals.

References

AGEE, H.R. 1972. Sensory response of the compound eye of adult *Heliothis zea* and *H. virescens* to ultraviolet stimuli. Annals of the Entomological Society of America 65: 701 -705.

BECKHAM, CM. 1970. Seasonal abundance of *Heliothis* spp in the Georgia Piedmont. Journal of the Georgia Entomological Society 5: 138-142.

BERGER, R.S., McGOUGH, J.M., and MARTIN, D.F. 1965. Sex attractants of *Heliothis zea* and *H. virescens.* Journal of Economic Entomology 58: 1023.

BEROZA, M. 1960. Insect attractants are taking hold. Agricultural Chemistry 15: 37-40.

BEROZA, M. 1972. Insect sex attractant pheromones, a tool for reducing insect contamination in the environment. Toxicology and Environmental Chemical Review 1:109-134.

BEROZA, M., and KNIPLING, E.F. 1972. Gypsy moth control with sex attractant pheromone. Science 177:19-27.

BURTON, R.L. 1969. Mass rearing of the corn earworm in the laboratory. U.S. Department of Agriculture, ARS 33-134, Washington, DC, USA. 8 pp.

CALLAHAN, P.S., SPARKS, A. N., SNOW, J.W., and COPELAND, W.W. 1972. Corn earworm moth: vertical distribution in nocturnal flight. Environmental Entomology 1:497-503.

CARPENTER, J.E., and SPARKS, A.N. 1982a. The specificity of *Heliothis zea* pheromone components in eliciting precopulatory responses from *H. zea* male moths. Journal of the Georgia Entomological Society (in press).

CARPENTER, J.E., and SPARKS, A.N. 1982b. Effects of vision on mating behavior of the male corn earworm moth. Journal of Economic Entomology (in press).

CARPENTER, J.E., SPARKS, A.N., and GUELDNER, R.C. 1982. Effects of moth population density and pheromone concentration on mating disruption of the *corn* earworm in large screened cages. Journal of Economic Entomology (in press).

FRENCH, R.A., and HURST, G.W. 1969. Moth immigrations in the British Isles in July 1968. Entomologist's Gazette 20: 37-44.

GASTON, L.K., SHOREY, H.H., and SAARIO, C.A. 1967. Insect population control by the use of sex pheromones to inhibit orientation between the sexes. Nature 213 (5081): 1155.

GENTRY, C.R., LAWSON, F.R., and HOFFMAN, J.D. 1964. A sex attractant in the tobacco budworm. Journal of Economic Entomology 57: 819.

HAILE, D.G., SNOW, J.W., and GOODENOUGH, J.L. 1973. Reduced capture of tobacco budworm and corn earworm males in electric grid traps baited simultaneously with virgin females of both species. Journal of Economic Entomology 66: 739-740.

HARTSTACK, A.W., WITZ, J.A., and BUCK, D.R. 1979. Moth traps for the tobacco budworm. Journal of Economic Entomology 72: 519-522.

HENDRICKS, D.E., GRAHAM, H.M., GUERRA, R.J., and HARTSTACK, A.W., Jr. 1972. Catch of tobacco budworm moth influenced by color of sex lure traps. Environmental Entomology 1:48-51.

HENDRICKS, D.E., GRAHAM, H.M., GUERRA, R.J., and PEREZ, C.T. 1973. Comparisons of numbers of tobacco budworms and bollworms caught in sex pheromone traps vs blacklight traps in the Lower Rio Grande Valley, Texas. Journal of Economic Entomology 64: 361 - 364.

HENNEBERRY, T.J., BARIOLA, L.A., FLINT, H.M., LINGREN, P.D., GILLESPIE, J.M., and KYDONIEUS, A.K.1981. Pink bollworm and tobacco budworm mating disruption studies on cotton. Pages 267-283 *in* Management of insect pests with semiochemicals: concepts and practices, ed. E.R. Mitchell. New York, USA: Plenum Press.

HOLLINGSWORTH, J.P., HARTSOCK, J.G., and STANLEY, J.M. 1963. Electric insect traps for survey purposes. U.S. Department of Agriculture, ARS 42-3-1, Washington, DC, USA. 24 pp.

HOLLINGSWORTH, J.P., HARTSTACK, A.W., BUCK, D.R., and HENDRICKS, D.E. 1978. Electric and non-electric moth traps baited with synthetic sex pheromone of the tobacco budworm. U.S. Department of Agriculture, ARS-5-173, Washington, DC, USA.

JACOBSON, M., LANDIS, B.J., HENDRICKS, D.E., and PREISNER, E. 1972. Science concentrates. Chemical Engineering News. (Dec 4, 1972): 50.

KLUN, J.A., PLIMMER, J.R., BIERL-LEONHARDT, B.A., SPARKS, A.N., and CHAPMAN, O.L. 1979. Trace chemicals: The essence of sexual communication systems in *Heliothis* species. Science 204: 1328-1330.

KLUN, J.A., PLIMMER, J.R., BIERL-LEONHARDT, B.A., SPARKS, A.N., PRIMIANI, M., CHAPMAN, O.L., LEE, G.H., and LEPONE, G. 1980a. Sex pheromone chemistry of female corn earworm moth, *Heliothis zea.* Journal of Chemical Ecology 6: 165-175.

KLUN, J.A., BIERL-LEONHARDT, B.A., PLIMMER, J.R., SPARKS, A.N., PRIMIANI, M., CHAPMAN, O.L., LEPONE, G., and LEE, G.H. 1980b. Sex pheromone chemistry of the female tobacco budworm moth, *Heliothis virescens.* Journal of Chemical Ecology 6:177-183.

KNIPLING, E.F. 1976. Role of pheromones and kairomones for insect suppression systems and their possible health and environmental impacts. Environmental Health Perspective 14:145-152.

KNIPLING, E.F. 1979. The basic principles of insect population suppression and management. Pages 421-488 *in* U.S. Department of Agriculture Agricultural Handbook 512, Washington, DC, USA.

KNIPLING, E.F., and McGUIRE, J.U., Jr. 1966. Population models to test theoretical effects of sex attractants used for insect control. U.S. Department of Agriculture Agricultural Information Bulletin 308, Washington DC, USA.

LINGREN, P.D., SPARKS, A.N., RAULSTON, JR., and WOLF, W.W. 1978. Applications for nocturnal studies of insects. Bulletin of the Entomological Society of America 24: 206-212.

LINGREN, P.D., RAULSTON, JR., SPARKS, A.N., and WOLF, W.W. 1982a. Insect monitoring technology for evaluation of suppression via pheromone systems. *In* Insect suppression with controlled release pheromone systems, eds. G. Zewig, A.L. Kydonieus, and M. Beroza, Boca Raton, Florida, USA: CRC Press. (In press.)

LINGREN, P.D., and WOLF, W.W. 1982b. Nocturnal activity of tobacco budworm and other insects. *In The* role of biometeorology in integrated pest management, eds. J.C. Hatfield and IS. Thomason. New York, USA: Academic Press. (In press.)

MCDOUNOUGH, L.M., GEORGE, D.A., and LANDIS, B.J. 1970. Partial structure of two sex pheromones of the corn earworm, *Heliothis zea* Journal of Economic Entomology 63: 408-412.

MCLAUGHIN, JOHN R., MITCHEL, E.R., and CROSS, J.H. 1981. Field and laboratory evaluation of mating disruptants of *Heliothis zea* and *Spodoptera trugiperda* in Florida. Pages 243-251 *in* Management of insect pests with semiochemicals: concepts and practices. New York, USA: Plenum Press.

MITCHELL, E.R., BAUMHOVER, A.H., and JACOBSON, M. 1976. Reduction of mating potential of male *Heliothis* spp. and *Spodoptera trugiperda* in field plots treated with disruptants. Environmental Entomology 5: 484-486.

MITCHELL, E.R., JACOBSON, M., and BAUMHOVER, A.H. 1975. *Heliothis* spp.: Disruption of pheromonal communication with (Z)-9-tetradecen-1 -of formate. Environmental Entomology 4: 577-599.

NEWCOMB, D.D. 1967. Comparative behavior of adult *Heliothis zea* (Boddie) and *Heliothis virescens (F.)* to light. M.S. thesis. Texas A&M University, College Station, Tex, USA. 59 pp.

PHILLIPS, J.R. 1979. Migration of the bollworm *Heliothis zea* (Boddie). Pages 419-441 *in* Movement of Highly mobile insects: concepts and methodology in research, eds. R.L. Rabb and G.G. Kennedy. North Carolina State University, Raleigh, NC, USA.

RAULSTON, J.R. 1979. *Heliothis virescens* migration. Pages 412-419 *in* Movement of highly mobile insects: concepts and methodology in research, eds. R.L. Rabb and G.G. Kennedy. North Carolina State University, Raleigh, NC, USA.

RAULSTON, J.R., and LINGREN, P.D. 1969. A technique for rearing larvae of the bollworm and tobacco budworm in large numbers. Journal of Economic Entomology 62: 959-961.

RAULSTON, J.R., and LINGREN, P.D. 1972. Methods of large-scale rearing of the tobacco budworm. U.S. Department of Agriculture Production Research Report 145, Washington DC, USA.10 pp.

RAULSTON, J.R., LINGREN, P.D., SPARKS, A.N., and MARTIN, D.F. 1979. Mating interaction between native tobacco budworms and released backcross adults. Environmental Entomology 8: 349-353.

RAULSTON, JR., SPARKS, A.N., and LINGREN, P.D. 1980. Design and cooperative capture of a wind-oriented trap for capturing live *Heliothis* spp. Journal of Economic Entomology 73: 586-589.

ROACH, S.H. 1975. *Heliothiszea* and *H. virescens* moth activity as measured by blacklight and pheromone traps. Journal of Economic Entomology 68: 17-21.

ROTHSCHILD, G.H.L. 1981. Current status and prospects for mating disruption of lepidopterous pests. Pages 207-228 *in* Management of insect pests with semiochemicals: concepts and practices, ed. E.R. Mitchell, New York, USA: Plenum Press.

ROELOFS, W.L., HILL, A.S., CARDE, R.T., and BAKER, T.C. 1974. Two sex pheromone components of the tobacco budworm moth *Heliothis virescens.* Life Science 14: 1555-1562.

SEKUL, A.A., SPARKS, A.N., BEROZA, M., and BIERL, B.A. 1975. A natural inhibitor of the corn earworm moth sex attractant. Journal of Economic Entomology 68: 603-604.

SNOW, J.W., and COPELAND, W.W. 1969. Fall armyworm: use of virgin female traps to detect males and to determine seasonal distribution. U.S. Department of Agriculture product research report 110, Washington DC, USA. 9 pp.

SNOW, J.W., CANTELO, W.W., BURTON, R.L., and HENSLEY, S.D. 1968. Population of fall armyworm, corn earworm, and sugarcane borer on St. Croix, U.S. Virgin Islands. Journal of Economic Entomology 61:1757-1760.

SNOW, J.W., SPARKS, A.N., and LEWIS, W.J. 1972. Seasonal capture of corn earworm adults in light traps near Tifton, Georgia, compared with captures in traps baited with virgin females. Journal of the Georgia Entomological Society 7: 85-89.

SPARKS, A.N. 1972. *Heliothis* migration. *In* Distribution, abundance, and control of *Heliothis* species in cotton and other host plants. Southern Cooperative Series Bulletin 169, Oklahoma Agricultural Experiment Station, Oklahoma State University. Stillwater, Okla, USA. 92 pp.

SPARKS, A.N. 1979. An introduction to the status, current knowledge, and research on movement of selected Lepidoptera in Southeastern United States. Pages 382-385 *in* Movement of highly mobile insects: concepts and methodology in research, eds. R.L. Rabb and G.G. Kennedy. North Carolina State University, Raleigh, NC, USA.

SPARKS, A.N., JACKSON, R.D., and ALLEN, C.L. 1975. Corn earworms: Capture of adults in light traps on unmanned oil platforms in the Gulf of Mexico. Journal of Economic Entomology 68: 431 -432.

SPARKS, A.N., CARPENTER, J.E., and MULLINIX, B.G. 1979a. Field responses of male *Heliothis zea* (Boddie) to pheromonal stimuli and trap design. Journal of the Georgia Entomological Society 14: 318-325.

SPARKS, A.N., RAULSTON, J.R., LINGREN, P.D., CARPENTER, J.E., KLUN, J.A. and MULLINIX, B.G. 1979b. Field response of male *Heliothis virescens* (F.) to pheromone stimuli and traps Bulletin of the Entomological Society of America 25: 268-274.

TUMLINSON, J.H., HENDRICKS, D.E., MITCHELL, E.R., and BRENNAN, M.M. 1975. Isolation, identification, and synthesis of the sex pheromone of the tobacco budworm. Journal of Chemical Ecology 1:203-214.

WALDEN, H.H. 1942. Owlet moths (Phalaenidae) taken at light traps in Kansas and Nebraska. U.S. Department of Agriculture, Circular 643, Washington DC, USA. 25 pp.

Practical Development of Pheromones in *Heliothis* Management

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Abstract

The sex pheromones of Heliothis armigera, H. subflexa, H. virescens, *and* H. zea *have been identified, and field-active synthetic pheromonal blends have been reported for these species and for* H. punctigera. *The greatest potential use for these male attractants is in biomonitoring. Commercial formulations for baiting traps are available, and reasonably efficient traps have been developed. At present, traps are used chiefly to detect males and monitor very gross changes in populations of adults. Further research is needed to utilize trap captures as a predictive tool to aid in pest-management decisions. Mass annihilation of males with traps is not considered a promising approach; however, the ability* of *sex pheromones to aggregate males may eventually prove useful.*

The air-permeation technique can be used to prevent mating of Heliothis, *and can be integrated with all other control methods discussed at this workshop. The major obstacle to effective use of* Heliothis *pheromones in this manner is lack of a formulation that adequately protects and releases the aldehyde pheromonal components. Even if technological problems are solved, it is not clear that this method of control is economically feasible.*

Résumé

Développement pratique de phéromones dans la lutte contre Heliothis: *Les phéromones sexuelles d'*Heliothis armigera, H. subflexa, H. virescens et H. zea *ont été identifiées et des mélanges de phéromones de synthèse actives sur le terrain ont été signalés pour ces espèces et* H. punctigera. *Le plus grand potentiel d'utilisation de ces produits attractifs des mâles est la surveillance biologique. Des préparations commerciales pour appâter des pièges sont disponibles et des pièges assez efficaces ont été mis au point. Actuellement, les pièges servent surtout à détecter les mâles et surveiller de très grands changements dans les populations adultes. Il faudra effectuer de recherches plus poussées, afin que les captures des pièges puissent servir comme outil permettant de prévoir et faciliter la prise de décision dans la lutte contre les ravageurs. La destruction massive des mâles avec les pièges ne semble pas une approche prometteuse; cependant, la capacité des phéromones sexuelles à rassembler les mâles pourra être éventuellement utile.*

*La technique de diffusion dans l'air peut servir à prévenir l'accouplement d'*Heliothis. *On peut l'intégrer avec toutes les autres méthodes de lutte qui ont fait l'objet de discussions lors de cet atelier. Le principal obstacle à une utilisation efficace des phéromones d'*Heliothis *de cette manière est l'absence d'une préparation qui protège suffisamment et libère les composants aldéhydiques des phéromones. Même si les problèmes techniques sont surmontés, il n'est pas sûr que cette technique de lutte soit viable du point de vue économique.*

The sex pheromones of moths are such an important element in reproduction that researchers have long felt that they could be exploited as pest-management tools. The potential uses of lepidopteran pheromones have been exhaustively reviewed in recent works (Silverstein 1981, and reviews cited therein). They fall into three broad categories of biomonitoring, mass annihilation of attracted males, and disruption of mating communication via permeation of the air with pheromones or pheromone-like chemicals. The pheromonal mating communication system is also an important element in programs that rely upon the attraction

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and subsequent mating of native and released insects.

Potential Uses of Lepidopteran Pheromones

Biomonitoring

Meaningful biomonitoring requires an understanding of the behavior of the insect and the chemicals utilized in pheromonal communication. Progress with *Heliothis* species has been slow, but in recent years the chemical messages of *H. zea* (Boddie), *H. virescens* (F.), *H. armigera* (Hbn), *H. subflexa* (Gn.), and *H. punctigera* (Wallgn.) have been worked out to the extent that field monitoring with synthetic chemical blends is possible (Table 1).

At present, our knowledge of heliothid pheromones comes primarily from analyses of compounds extracted with organic solvents from the suspected pheromone glands. Elucidation of the exact pheromone systems will occur by analysis of the compounds and ratios of compounds actually released into the air. Such research is difficult, but indications with U.S. species are that advances in our ability to attract or trap males can be expected (Teal, personal communication).

Efforts are under way to expand our understanding of the detailed chemical ecology of *H. virescens, H. zea, and H. subflexa in* the USA (Primiani 1979, Teal et al. 1981 a, Fig. 1), and it is hoped these revelations will increase our ability to trap those species or interdict reproduction.

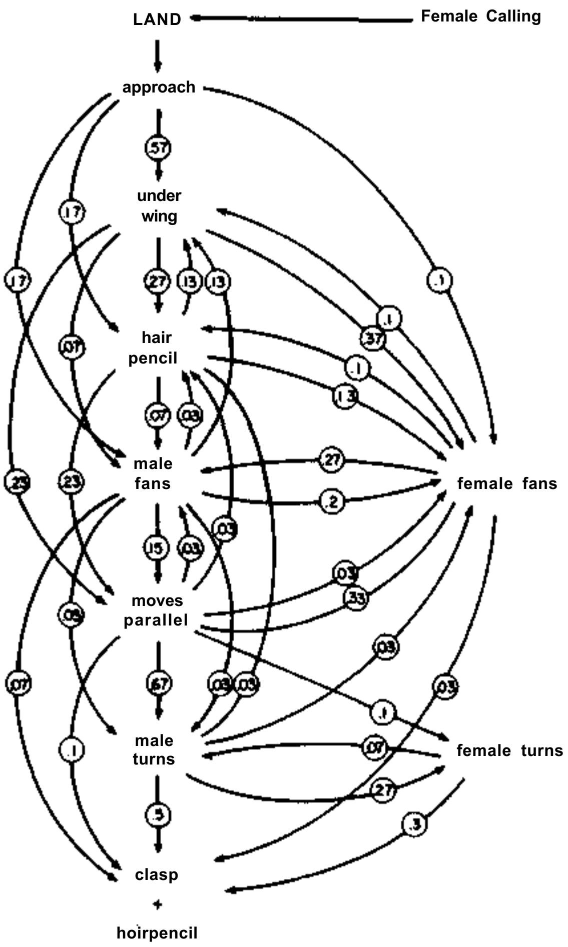

Figure 1. Comprehensive ethogram of H. virescens *courtship behavior. (Source: Teal et al. 1981a.)*

Table 1. Field-active sex pheromone components of *Heliothis* species..

Heliothis species	Chemical (Ratio)							
	Z11:16A1	Z9:16A1	Z 7:16A1	16A1	Z11:16Ac	9:16Ac	Z 7:16Ac	Z9:14A1
H. armigera	(97)	(3)	-	-	-	-	-	-
H. punctigera	(50)	-	-	-	(50)	-	-	(1)
H. subflexa	(40)	(30)	-	-	(12)	(6)	(2)	-
H. virescens	(16)	-	-	-	-	-	-	(1)
H. zea	(116)	(5)	(3)	(11)	-	-		-

Sources: *Heliothis armigera:* Kehat et al. (1980); *punctigera:* Rothschild (1978) (not identified from female); *subflexa:* Teal et al. (1981b); *virescens:* Tumlinson et al. (1975)'; *zea:* Klun et al. (1979, 1980).

The major problem in biomonitoring, however, is not in our ability to trap these insects, but in our inability to utilize the information obtained. There are as yet no reports in the literature of strong correlations of population relationships with trap data, although Tingle and Mitchell (1981) have reported some predictive data with pheromone traps for *H. virescens* in tobacco.

Mass Annihilation

This approach has not been extensively researched, probably because highly effective attractants and efficient traps have not been developed. The logistical requirements for mass annihilation projects are numerous, and this approach to control of widespread field-crop pests has not been appealing. Future development of highly virulent pathogens or other agents that might be spread by males or used to kill aggregated males may open new possibilities for pheromonal manipulation.

Mating Disruption via Air Permeation

The most researched and most controversial use of *Heliothis* sex pheromones has been their direct application as mating disruptants. Several hypotheses have been advanced as to how mating can be eliminated by overloading the environment with an insect's sex pheromone. A male-confusion technique was proposed by Beroza in 1960 (Beroza 1976), prior to the identification of any insect sex pheromone. His hypothesis was that if a synthetic sex pheromone were emitted from many dispersed particles, the males responding to the pheromone would be unable to distinguish between the synthetic odor and that of the relatively few females present in the same area; thus no mating would occur. The mechanism of effect is that of misdirection of males in the presence of a large number of competing pseudofemales (Beroza 1976).

Research with the pheromone of the cabbage looper, *Trichoplusia ni* (H'ubner), established the feasibility of disrupting sex pheromone communication by distributing evaporators of the synthetic pheromone throughout cabbage fields (Gaston et al. 1967; Shorey et al. 1967). Gaston and Shorey realized that sensory thresholds must be affected in the presence of physiologically large amounts of omnipresent pheromone, and hypothesized that sensory adaptation and/or habituation would be the primary mechanism of effect. This hypothesis was expanded (Shorey et al. 1976; Shorey 1977) to include both misdirection and sensory fatigue when a material that attracts males is used as the disruptant. These authors emphasized that disorientation effects are not crucial, because many nonattractive chemicals are effective disruptants.

Shorey and colleagues worked with what was believed at that time to be a monochemical pheromone system. Most lepidopteran sex pheromones are now known to be multichemical blends. Klun et al. (1973, 1975), while studying the multicomponent pheromone systems of the European corn borer, *Ostrinia nubilalis* (Hiibner) and the redbanded leafroller, *Argyrotaenia velutinana* (Walker), proposed that the best strategy to achieve mating control might involve either the alteration of the chemical blend received by the male or sensory fatigue causing loss of response to a pheromonal chemical responsible for very short-range phases of mating communication. For example, with insects that depend upon specific ratios of geometric isomers for aggregation and mating, the most efficient approach might be to utilize the isomer present in the least amount in the pheromonal blend.

Roelofs (1978) hypothesized that the best disruptant should be that blend of chemicals most closely tuned to the receptor system. Thus, the degree of mating disruption achieved with a given concentration (release rate) of a disruptant blend should be in proportion to the degree to which the blend approximates the natural pheromone.

Carde (1981) has proposed that pheromone communication may be camouflaged by raising the concentration of synthetic pheromone sufficiently above that of the density emanating from the female that the boundaries of the natural plumes become indiscernible. Thus, one is not dealing with sensory fatigue or misdirection or competition, but with a system in which the message is so omnipresent that a male cannot negotiate a typical zigzag upwind course to a female.

These are all appealing explanations for the phenomenon of mating disruption. Since none of them appears to be universally true, research into the selection and application of mating disruptants in field situations has been largely empirical. In the case of *Heliothis* spp, research has been more confusing because the applied work was begun before the sex pheromones were reasonably well defined by the chemists. An illustration of our progress (or lack of it, depending upon the critic) can be made with the corn earworm, *H. zea.*

The feasibility of using the air-permeation technique for mating disruption of *H. zea* was demonstrated by Mitchell et al. (1975,1976) using either the pheromonal component, (Z)-11 -hexadecenal (Z11:16A1), or a parapheromone, (Z)-9-tetradecen-1 -ol formate (Z9:14F), dispensed from closed polyethylene vials. These materials were also effective against *H. virescens.* The chemicals were tested concurrently for their effect on the mating of clipped-wing virgin females in the field and on male captures in female-baited traps. The reductions in mating and in trap captures were in close agreement.

A microencapsulated formulation of Z9:14F also reduced mating in small test plots (Mitchell et al. 1976). However, a series of subsequent tests of mating disruptants formulated in various microcapsules, primarily in soybeans against the soybean looper, *Pseudoplusia includens* Walker, and *T. ni,* gave highly variable results, depending upon weather conditions (McLaughlin, unpublished data). Thus, this type of formulation was not considered reliable for large-scale field tests.

In 1979, McLaughlin et al. (1981) conducted a series of experiments to identify the disruptant of choice for *H. zea.* This research was prompted by developments in formulations for sex pheromones by the Albany International Company (hollow fiber dispensers) and the Hercon Division of Health-Chem Corporation (laminated plastic dispensers) and by the breakthrough definition of the *H. zea* pheromone gland contents by Klun et al. (1979, 1980, Table 1).

The initial small-plot tests (100 m^2 to 300 m^2) in peanut fields using plastic laminate dispensers attached to stakes established that the major ovipositor component, Z11:16A1, was a more effective disruptant of mating communication, measured via reductions in the capture of males in synthetic pheromone-baited traps, than the components Z9:16A1 or Z7:16A1 (Table 2). The activity of Z11:16A1 was not significantly increased with the use of the pheromonal mixture reported by Klun et al. (1979,1980); however, the blends of pheromonal components were significantly more effective than Z9:14F at the wide evaporator spacing (Table 2).

An additional test was conducted to evaluate the potential of plastic laminate flake formulations of *Heliothis* aldehydes as *H. zea* disruptants. These materials were applied by air using a latex-based sticker (McLaughlin et al. 1981). The tests were evaluated with female-baited and synthetic (Table 1) pheromone-baited traps. The results with both types of trap were statistically equivalent and are pooled in Table 3. These results were possibly compromised to some extent because the experimental spray equipment was not precise and there was undoubtedly some overspray that may have contaminated adjacent plots. The results indicated that the Z11:16A1 and Z9:14F were equally effective as disruptants and as good as or better than the Z11:16A1 -Z9:16A1 mixture. Also, Virelure, the 16:1 aldehyde mixture that is an effective trap bait for *H. virescens* appeared to be a good disruptant for *H. zea.*

Testing to this point was intended to develop a disruptant and formulation that could be used in a larger scale experiment to control *H. zea.* Therefore, in 1979, we also tested aerial application systems for the plastic laminate flake and for hollow fiber dispensers in 5.5-ha plots. The H. *zea* disruptant tested was Z9.14F, because the hollow fiber system then in use was incompatible with *Heliothis* aldehydes. This test (McLaughlin et al. 1981) established the hollow fiber system as more reliable and efficacious and thus the hollow fiber-Z9:14F formulation was chosen for a large-scale test in 1980, even though the disruptant of choice appeared to be Z11:16A1.

During the summer of 1980 (Mitchell and McLaughlin 1982), a 12-ha field of corn was treated with Z9:14F and a nearly identical 12-ha field less than 1 km away was treated with (Z)-9-tetradecen-1 -ol acetate (Z9:14Ac), a disruptant of fall armyworm, *Spodoptera frugiperda* (J.E. Smith), sex pheromone communication. The *H. zea* disruptant does not affect S. *frugiperda* and vice versa. The Albany International system for aerially dispersing hollow fibers in a polybutene sticker was used to treat each field at 7- to 9-day intervals. The *H. zea* field received a total of 217.3 g of Z9:14F in six applications from 2 June to 9 July. This was 1975.3 g of formulated fiber (11% Z9:14F). The S. *frugiperda* field received 183.7 g of Z9:14Ac in a similar formulation.

Data on mating were collected on eight nights between 19 June and 14 July. Using headlamps, observers (two/field) walked through each field and collected mating pairs of feral *H. zea* and S. *frugiperda.* Because of the oviposition habits of S. *frugiperda,* the observers were also able to collect S. *frugiperda* egg masses from the corn plants. These examinations were started at 2400 hr and continued until 0300 hr. The number of egg masses and mating pairs of the two species were recorded

Table 2. Mean (± 8E) captures of male H. zea In traps baited with synthetic pheromone (Table 1) and placed in plots permeated with sex pheromone components evaporated from 3.2 cm^2 plastic laminates (16 evaporators/plot).

Permeating chemical	Plot size (m^2) 100	300
	Test 1 (16-20 July)	
Control	6.4 ± 3.0	
Z11:16A1	0.3 ± 0.1	
Z9:16A1	3.7 ± 0.9	
Z7:16A1	4.5 ± 4.8	
16A1	15.7 ± 4.8	
	Test 2 (1-6 Aug)	
Control	43.8 ± 15.6	
Z11:16A1	6.6 ± 3.5	
Z11:16A1 and Z9:16A1 (1:1)	9.0 ± 5.4	
Z11:16A1 and Z7:16A1 (1:1)	9.6 ± 5.8	
	Test 3 (27-31 July)	(9-13 Aug)
Control	13.3 ± 2.5	37.5 ± 8.5
Z11:16A1	1.2 ±0.3	5.4 ± 1.8
Z11:16A1 and Z9:16A1 (1:1)	0.8 ±0.3	2.7 ± 1.5
Z9:14F	2.1 ± 2.5	12.7 ± 3.5
CEW 4-component (trapping ratio)	2.1 ± 2.5	12.7 ± 3.5

Table 3. Captures of male *H.* zea In female-baited traps placed In 0.81-ha plots of sweet corn treated by air with mating disruptants (10 g al/plot).

Chemical	Days to first moth capture	Mean/trap/ night (4 plots-14 nights)
Z11:16A1 and Z9.16A1 (1:1)	3	2.8
Z11:16A1 and Z9:14A1 (16:1)	2	0.8
Z9:14F	14	0.4
Z11:16A1	11	1.1
Control	1	4.7

at 15-minute intervals (=1 replicate) throughout the examination period.

Mating by *H. zea* in the field treated with Z9:14F compared with mating in the field treated with Z9:14Ac is shown in Figure 2. Mating by S. *frugiperda* is shown in Figure 3. The average reduction in *H. zea* mating was 50%; that is *S.frugiperda,* 86%. Moreover, oviposition by S. *frugiperda* was reduced 84%.

Because these fields were surrounded by cornfields and other alternative hosts, these tests demonstrated that mating in both species could be influenced even in relatively small fields. Damage by *H. zea,* however, was substantial, and much of that damage was probably due to larvae originating from females that mated within the test field.

The poor level of mating control achieved with *H. zea* was possibly due to inefficient delivery of the material by the application system. Observations indicated that most of the fibers aerially applied to corn 15 to 24 cm high fall to the ground, and even in larger corn many fibers did not adhere to the plants. The equipment was calibrated to deliver at its maximum rate, and the treatment level was attained by

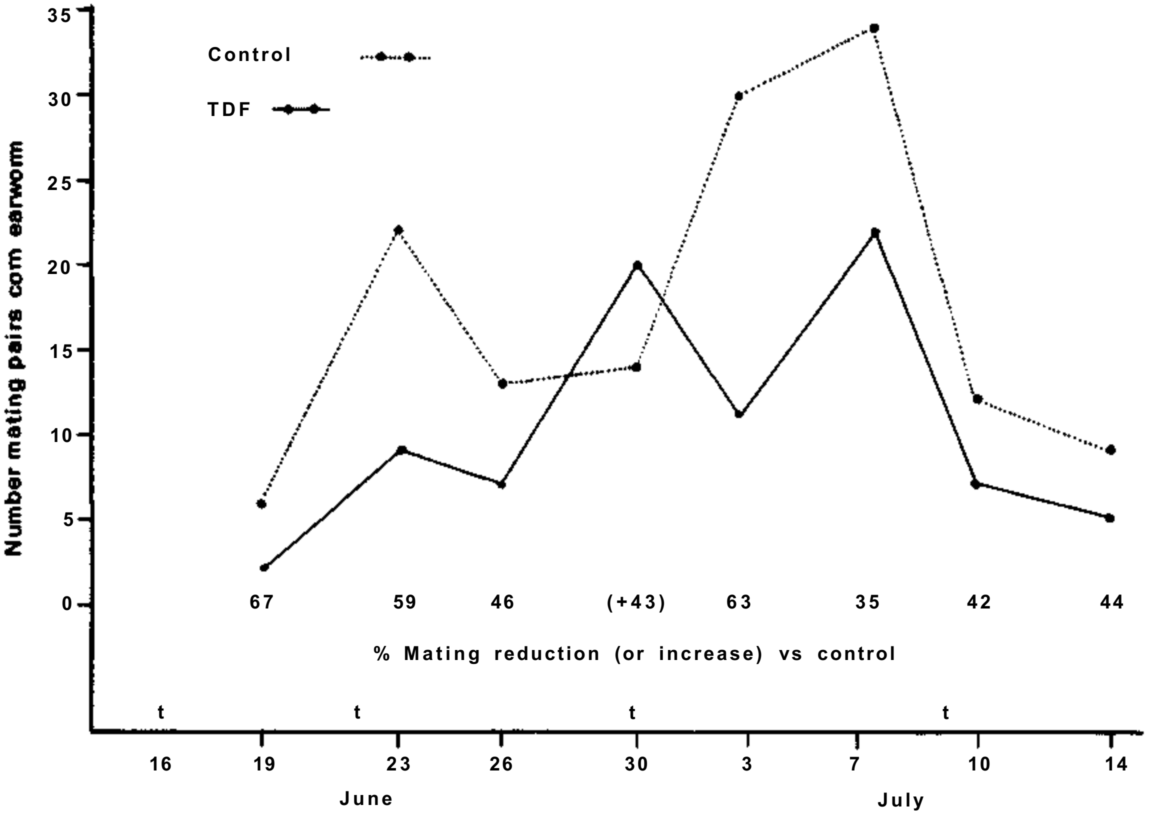

Figure 2. Effects of Z9:14F (TDF) treatments on mating by corn earworm (H. zea) *in a 12-ha field of corn. Dates of application indicated by "t."*

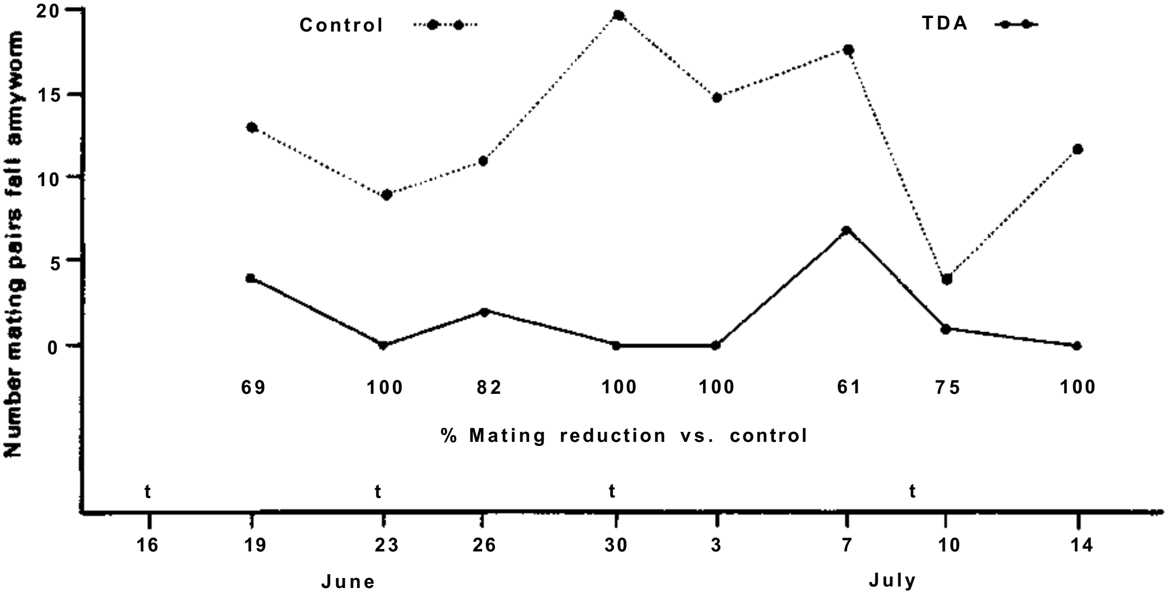

Figure 3. Effects of Z9:14Ac (TDA) on mating by fall armyworm (S. frugiperda) *in a 12-ha field of corn. Dates of application indicated by "t."*

flying each swath twice. Thus, higher rates with the same formulation were not investigated, even though subsequent small-plot tests with Z9:14F dispensed from polyethylene vials attached to the corn plants reaffirmed that higher levels of communication disruption than those obtained in the 12-ha field were possible using Z9:14F (Mitchell, unpublished data).

In the fall of 1980, the Albany International Company brought a new black hollow fiber formulation to our laboratory for testing. A small-plot test indicated, for the first time, a very marked difference between the disruptive effects of Z11:16A1 (more effective) and Z9:14F. This was further investigated in a set of small-plot tests conducted in soybean fields in late summer of 1981. The method was similar to that employed in the 1979 screening tests. The test materials, in 25-fiber packets, were attached to wooden stakes set in a 6 x 6 grid (36 point sources/plot) with 3 m between stakes (plots 15 m x 15 m). The estimated release rate of Z11:16A1 from a hollow fiber is about 3.0 ng/min (Teal, personal communication), and this system evaporated approximately 2700 ng of test material per minute per plot (7.1 mg/ha/hr).

Each treatment was monitored using female-baited traps and virgin female moths tethered onto the plants with light cotton thread glued to the thorax. Impact was assessed by the reduction in trap capture or number of females that were mated relative to these parameters in the untreated control plots (Table 4). The primary *H. zea* aldehyde, Z11:16A1 was about six times more effective in reducing trap captures than was Z9:14F throughout the test and was at least three times as effective in reducing mating by the fourth day of the test.

The poor performance of the 16:1, Z11:16A1-Z9:14A1, mixture was a disappointment. This would probably be the disruptant of choice for *H. virescens,* and often one would wish to affect these species simultaneously in the same crop. The Z9:14A1 is not a disruptant of *H. zea* and may have acted as a diluent to reduce the evaporation of the active component, Z11:16A1, below the point where it would be effective. A subsequent small-plot test with double the above rate of the *H. virescens* 16:1 mixture and Z11:16A1 alone appeared to substantiate this (Table 5). Unfortunately, the number of matings in the controls was small, and thus further tests are needed.

The results of past experiments (McLaughlin 1981) and the more recent tests presented here demonstrate that, excluding economic factors, the major obstacle to direct mating control of *H. zea*

Table 4. Percent of 10 tethered virgin female *H. zee*[a] that mated In a 225 m^2 plot treated with pheromonal components evaporated from 36 stations In a 6 x 6 grid (25 hollow fibers/station).

Treatment (Ratio)	Day							
	2	3	4	5	8	9	10	11
Control	100	100	86	86	70	75	78	75
Z11:16A1	0	14	22	29	10	11	11	13
Z9:14F	22	57	78	-	-	-	-	-
Z11:16A1 + Z9:14A1 (16:1)	37	57	100	-	-	-	-	-
CEW4 (a)	-	17	22	0	20	10	29	12
CEW3 (b)	-	-	-	-	-	-	22	20
Z11.16A1 + 16A1 (90:10)	-	-	-	25	33	25	-	-
Z11: +Z7:16AI (99:1)	-	-	-	14	0	25	-	-
Z11: +Z9:16A1 (98:2)	-	-	-	-	-	-	50	22

(a) = Z11-Z9-Z7-16A (93-2-2-4) - Hexadecenals.

(b) = Z11-Z9-Z7- (97-2-1)-Hexadecenals.

a. Recovery of tethered females from 70 to 100%.

Table 5. Percent of 10 tethered virgin female *H.* MI that mated In a 225 m^2 plot treated with pharomonal oomponanta evaporated from 38 stations in a 6 x 6 grid (50 hollow flbers/station).

Treatment (Ratio)	Day 1	2	3	4	13	20
Control	77.8	100	50	55.5	50	40
Z11 :16A1	0	0	0	0	0	0
Z11 :16A1 +Z9:14A1 (16:1)	0	0	11.1	0	0	0

and therefore other heliothids is the reliability of the formulation and delivery system. The original quantified studies of air permeation established that disruption of mating is obtained when the amount of chemical evaporated remains above some critical value per unit area and that the effect is quickly lost with lesser amounts (Shorey et al. 1972; McLaughlin et al. 1972). Moreover, male mate-seeking behavior is apparently not reduced (Farkas et al. 1975, Richerson 1977). Thus, an extremely reliable system for maintaining the disruptant in the crop environment is essential.

Teal (unpublished data) has found that decomposition still occurs in even the more advanced formulations of *Heliothis* aldehydes. This makes their use problematical, but the recent formulation progress is encouraging. Alternative chemicals, with greater stability, such as Z9:14F or olefinic analogs of Z11:16A1 (Carlson and McLaughlin 1982, and unpublished data) have not produced materials with the potency of Z11: 16A1.

Conclusions

The use of heliothid pheromone traps to monitor adult activity is now feasible; however, as with most other lepidopteran pheromones, the information required to make good use of trapping data is lacking. Hopefully, the next generation of trapping studies will concentrate on the parameters necessary to generate predictive models of insect populations. The formulation of pheromonal components for use in traps is still in a state of flux; however, these problems should be more easily overcome than those involved in the development of formulations for disruption.

The fortunes of air permeation as a control approach are less clear. The method appears more feasible with increased technological input. It has not yet been demonstrated that disruption of sex pheromone communication can be used to protect a crop from *Heliothis* damage. The marked reduction in S. *frugiperda* oviposition observed during simultaneous trials with *H. zea* (Mitchell and McLaughlin 1982) indicate that a noctuid species in corn can be markedly influenced by this approach. Research thus far suggests that formulation deficiencies and the movement of mated females among local crops have hampered efforts to demonstrate efficacy with *H. zea.*

One largely unexplored area is the combination of host odors with pheromones. *H. zea,* for example, is apparently attracted by volatiles from corn silk (Cantelo and Jacobson 1979). Semiochemical blends that simulate an attractive stage of host before the host reaches that stage might be used to more closely estimate the potential mating and/or oviposition pressure from a pest. Such chemicals may help to stabilize pheromone-trap captures, which now vary with the relations of trap to crop and stage of crop.

Thus far we have attempted to exploit only the most obvious aspects of *Heliothis* behavior, and have expected these to supply near-total control. The impact upon mating now apparently possible with air permeation may provide the margin required for control when integrated with other measures. Pheromones have not been included to any extent in integrated control research projects. We have not yet explored the behavioral depths of species' communication in *Heiothis.* Mate-finding, host-finding, and the basic process of olfaction are critical to any organism's survival and, as such, vulnerable to our manipulation.

References

BEROZA, M. 1976. Control of the gypsy moth and other insects with behavior-controlling chemicals. Pages 99-118 *in* Pest management with insect attractants, ed. Morton Beroza. American Chemical Symposium Series 23, Washington, DC, USA.

CANTELO, W.W., and JACOBSON, M. 1979. Corn silk volatiles attract many pest species of moths. Journal of Environmental Science and Health A14.695-707.

CARDE T. 1981. Disruption of long-distance pheromone communication in the Oriental fruit moth: camouflaging the natural aerial trials from females? Pages 385-398 *in* Management of insect pests with semiochemicals, ed. E.R. Mitchell. New York, USA: Plenum Press.

CARLSON, D.A., and MCLAUGHLIN, J.R. 1982. Diolefin analog of a sex pheromone component of *Heliothis zea* active in disrupting mating communication. Experientia (in press).

FARKAS, S.R., SHOREY, H.H., and GASTON, L.R. 1975. Sex pheromones of Lepidoptera. The influence of prolonged exposure to pheromone on the behavior of males of *Trichoplusia ni.* Environmental Entomology 4:737-741.

GASTON, L.K., SHOREY, H.H., and SAARIO, C.A. 1967. Insect population control by the use of sex pheromones to inhibit orientation between the sexes. Nature 213:1155.

KEHAT, M., GOTHILF, S., DUNKELBLUM, E., and GREENBERG, S. 1980. Field evaluation of female sex pheromone components of the cotton bollworm, *Heliothis armigera,* Entomologia Experimentalis et Applicata 7:188-193.

KLUN, J.A., CHAPMAN, O.L., MATTES, K.C., WOJTKOWSKI, P.W., BEROZA, M., and SONNET P.E. 1973. Insect sex pheromones: minor amount of opposite geometrical isomer critical to attraction. Science 181:661-663.

KLUN, J.A., CHAPMAN, O.L., MATTES, K.C., and BEROZA, M. 1975. European corn borer and redbanded leafroller: Disruption of reproduction behavior. Environmental Entomology 4:871 -876.

KLUN, J.A., PLIMMER, J.R., BIERL-LEONHARDT, B.A., SPARKS, A.N., and CHAPMAN, O.L. 1979. Trace chemicals: The essence of sexual communication systems in *Heliothis* species. Science 204:1328-1330.

KLUN, J.A., PLIMMER, J.R., BIERL-LEONHARDT, B.A., SPARKS, A.N., PRIMIANI, M., CHAPMAN, O.L., LEE, G.H., and LEPONE, G. 1980. Sex pheromone chemistry of female corn earworm moth, *Heliothis zea* Journal Chemical Ecology 6:165-175.

MCLAUGHIN. J.R., SHOREY, H.H., GASTONI, L.K., KAAE, R.S., and STEWART, F.D., 1972. Sex pheromones of Lepidoptera. XXXI. Disruption of sex pheromone communication in *Pectinophora gossypiella* with hexalure. Environmental Entomology 1:645-650.

MCLAUGHLIN, J.R., MITCHELL, E.R., and CROSS, J.H. 1981 Field and laboratory evaluation of mating disruptants of *Heliothis zea* and *Spodoptera frugiperda* in Florida. Pages 243-251 *in* Management of insects with semiochemicals, ed. E.R. Mitchell. New York, USA:Plenum Press.

MITCHELL, E.R., JACOBSON, M., and BAUMHOVER, A.H. 1975. *Heliothis* spp.: Disruption of pheromonal communication with (Z)-9-tetradecen-1-ol formate. Environmental Entomology 4:577-579.

MITCHELL, E.R., BAUMHOVER, A.H. and JACOBSON, M. 1976. Reduction of mating potential of male *Heliothis* spp. and *Spodoptera frugiperda* in field plots treated with disruptants. Environmental Entomology 5:484-486.

MITCHELL, E.R., and McLAUGHLIN, J.R. 1982. Suppression of mating and oviposition by fall armyworm and mating by corn earworm in corn using the air permeation technique. Journal of Econonomic Entomology (in press).

PRIMIANI, N.M. 1979. Ethological significance of compounds comprising the female sex pheromone of *Heliothis zea* and *Heliothis virescens.* Ph.D. Dissertation, University of Maryland , Md, USA. 110 pp.

RICHERSON J.V. 1977. Pheromone-mediated behavior of the gypsy moth. Journal of Chemical Ecology 3:291 - 308.

ROELOFS, W.L. 1978. Threshold hypothesis for pheromone perception. Journal of Chemical Ecology 6:685-699.

ROTHSCHILD, G.H.L. 1978. Attractants for *Heliothis armigera* and *H. punctigera.* Journal of Australian Entomology 102:389-390.

SHOREY, H.H., GASTON, L.K., and SAARIO, C.A. 1967. Sex pheromones of noctuid moths. XIV. Feasibility of behavioral control by disrupting pheromone communication in cabbage loopers. Journal of Economic Entomology 60:1541-1545.

SHOREY, H.H., KAAE, R.S., GASTON, L.K., and MCLAUGHLIN, J.R. 1972. Sex pheromones of Lepidoptera. XXX. Disruption of sex pheromone communication in *Trichoplusia ni* as a possible means of mating control. Environmental Entomology 1:641 -645.

SHOREY. H.H., GASTON, L.K., and KAAE, R.S. 1976. Air-permeation with gossyplure for control of the pink bollworm. Pages 67-74 *in* Pest management with insect sex attractants, ed. Morton Beroza. American Chemical Society Symposium Series 23, Washington, DC, USA.

SHOREY, H.H. 1977. Manipulation of insect pests of agricultural crops. Pages 353-367 *in* Chemical control of insect behavior, eds. H.H. Shorey and J.J. McKelvey, Jr. New York, USA: John Wiley.

SILVERSTEIN, R.M. 1981. Pheromones: background and potential for use in insect pest control Science 213:1326-1332.

TEAL, P.E.A., MCLAUGHLIN, J.R., and TUMLINSON, J.H. 1981a. Analysis of the reproductive behavior of *Heliothis virescens* (F.) under laboratory conditions. Annals of the Entomological Society of America 74:324-330.

TEAL, P.E.A., HEATH, R.R., TUMLINSON J.H., and MCLAUGHLIN, J.R. 1981b. Identification of a sex pheromone *of Heliothis subllexa* (Gn.) (Lepidoptera: Noctuidae) and field trapping studies using different blends of components. Journal of Chemical Ecology 7:1011 -1022.

TINGLE, F.C., and MITCHELL, E.R. 1981. Relationships between pheromone trap catches of male tobacco budworm, larval infestations, and damage levels in tobacco. Journal of Economic Entmology 74.437-440.

TUMLINSON, J.H., HENDRICKS, D.E., MITCHELL, E.R., DOOLITTLE, R.E., and BRENNAN, M.M. 1975. Isolation, identification, and synthesis of the sex pheromone of the tobacco budworm. Journal of Chemical Ecology 1:203-324.

Preliminary Studies on the Female Sex Pheromones of *Heliothis* Species and Their Possible Use in Control Programs in Australia

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Abstract

The role of pheromone traps in scouting for Heliothis *spp was examined in cotton crops in eastern Australia. A 50:50:1 mixture of (Z)-11-hexadecenal, (Z)-11-hexadecenyl acetate, and (Z)-9-tetradecenal was a specific attractant for* H. punctigera. *Males of* H. armigera *were captured at baits containing a 10:1 mixture ot(Z)-11-hexadecenal, and (Z)-9-hexadecenal, but significant numbers of* H. punctigera *were also taken when this species was abundant. A comparison was made between adult captures at pheromone (and light) traps and egg counts in the crop. Analyses of the data, using a linear model, indicated that* 85% *of the deviance in the relationship between egg counts and pheromone-trap catches could be accounted for by the regression, while the corresponding figure for light-trap captures and egg counts was 78%. There was also a significant positive relationship between pheromone-trap captures and temperatures during the daily flight period, and some additional evidence for interactions with wind speed and direction. Although there was a highly significant correlation between pheromone-trap captures and egg counts, it appeared that the confidence limits for predicting egg numbers from catch data may have been unacceptably large in practical terms; decisions to spray are often based on relatively low egg counts.*

The use of pheromones for mating disruption of Heliothis spp *in Australia is being considered, but the level of work in this area will depend on the outcome of studies on the suitability of these insects for such a control strategy. Limiting factors may include local dispersal or long-distance migration of mated females.*

Résumé

*Etudes préliminaires sur les phéromones sexuelles des femelles d'espèces d'*Heliothis *et leur utilisation éventuelle dans des programmes de lutte en Australie: Le rôle des pièges à phéromone dans la surveillance d'*Heliothis *spp a été étudié chez des cultures cotonnières à l'est de l'Australie. Un mélange 50:50:1 de Z11-16:ALD [(Z)-11-hexadecenal], Z11-16:Ac [(Z)-11-hexadecenyl acetate] et Z9-14:ALD [(Z)-9-tetradecenal] fut un attractif spécifique pour* H. punctigera. *Des mâles* H. armigera *ont été capturés par des appâts contenant un mélange 10:1 de Z11-16:ALD et Z9-16:ALD [(Z)-9-hexadecenal], mais un nombre significatif de* H. punctigera *ont aussi été capturés quand il y avait une abondance de cette espèce. Une comparaison a été faite entre les captures d'adultes aux pièges à phéromone (et lumineux) et le nombre d'oeufs dans la culture. L'analyse des données, en utilisant un modèle linéaire, a montré que 85% de la déviance du rapport entre le nombre d'oeufs et les captures des pièges à phéromone pouvait être expliquée par la régression, tandis que le chiffre correspondant pour les captures des pièges lumineux et le nombre d'oeufs était de 78%. Il y a aussi eu une relation positive significative entre les captures des pièges à phéromone et la température durant la période journalière de vol et il y eu des preuves additionnelles d'interactions avec la vitesse du vent et la direction. Bien qu'il y ait eu une forte corrélation significative entre les captures des pièges à phéromone et le nombre d'oeufs, il a semblé que les seuils de confiance pour prévoir le nombre d'oeufs à partir des données des captures peuvent être trop larges au niveau pratique; la décision de pulvériser est souvent basée sur un nombre d'oeufs relativement bas.*

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International Crops Research Institute for the Semi-Arid Tropics. 1982. Proceedings of the International Workshop on *Heliothis* Management, 15-20 November 1981, Patancheru, AP., India.

L'utilisation de pheromones dans le but de causer une confusion lors de l'accouplement d'Heliothis spp en Australie est envisagee, mais le travail dans ce domaine dependra des resultats des etudes sur la r6ponse de ces insectes a une telle strategie de lutte. Les facteurs limitants peuvent etre une dispersion locale ou une migration sur de tongues distances des temelles accouplees.

Two species of *Heliothis* are of particular importance as pests of crops in Australia: *H. punctigera* Wallengren, a species native to Australia and adjacent islands, and the well-known *H. armigera* (Hubner), which is widely distributed throughout the Old World.

The sex pheromones of *Heliothis* have recently become the subject of investigation in Australia, and significant progress in the development of specific attractants for the two major species has been made in the past 2 years. This report describes the current status of work on the identification of the components of the female sex pheromone blends, and discusses attempts to use these materials as trap baits to monitor the activity and abundance of *Heliothis* species. The study was prompted by requests from government and commercial agencies involved in scouting for *Heliothis* infestations, particularly in cotton. Most scouting methods are based on egg counts, but it is not possible to assign eggs or early larval instars to a particular species. It is of some importance to know the species composition of individual crop infestations, as this may influence the control strategy used; for example, *H. armigera* is resistant to a number of insecticides, whereas resistance has not yet been detected in *H. punctigera.*

Pheromone Blends of *H. armigera* and *H. punctigera*

The search for attractants for *H. armigera* and *H. punctigera* began in 1975, with the screening of compounds known at that time to be components of the sex pheromones of New World species of *Heliothis, H. zea* and *H. virescens:* (Z)-11-hexadecenal (Z11-16.ALD) and (Z)-9-tetradecenal (Z9-14:ALD) (Roelofs et al. 1974; Tumlinson et al. 1975). These trials (Rothschild 1978) indicated that *H. armigera* was attracted to mixtures of the aldehydes, with the greatest catches at traps baited with mixtures of the two compounds containing less than 10% of the Z9-14;ALD. Relatively few males were attracted to Z11 -16;ALD alone, although baits with this single component have been used elsewhere in commercially available monitoring kits, with variable results (Bourdouxhe 1980). Only small numbers of *H. punctigera* males were taken in traps baited with the aldehydes, but catches were greatly increased by the addition of (Z)11 -hexadecenyl acetate (Z11 -16;Ac).

The presence of Z11 -16:ALD in female *H. armigera* was confirmed by Piccardi et al. (1977), who attributed the poor results of their field tests to low moth populations. As noted above , a more likely explanation was that the aldehyde was not particularly attractive in the absence of other components present in the natural blend. This was confirmed by the work of Nesbitt et al. (1979, 1980), which included joint field trials with the CSIRO Division of Entomology. The most important minor component of *H. armigera* females was shown to be (Z)-9-hexadecenal (Z9-16:ALD)—Z9-14:ALD could not be detected in female extracts or effluvia. The increase in catches, in traps baited with Z11-16:ALD, together with up to 10% of Z9-16;ALD, was significantly greater than that when Z9-14:ALD was added to Z11-16:ALD.

The identity of the female sex pheromone of *H. punctigera* is only partially resolved, but work so far indicates that the major components are Z11-16:ALD, Z11 -16:Ac and (Z)-11 -hexadecenol (Z11-16:OH) with some evidence for the presence of (Z)-7-hexadecenal (Z7-16.ALD) and hexadecanal (16:ALD) (Rothschild et al. 1982). In the field, *H. punctigera* males are captured in significant numbers with mixtures of equal parts of Z11-16:ALD and Z11-16:Ac, but only if 1 to 10% of Z9-14:ALD is also included. So far, however, it has not been possible to detect the last compound in the female.

At present, monitoring of *Heliothis* species in Australia is based on a 50:50:1 mixture (Z11-16:ALD:Z11-16:Ac:Z9-14:ALD) for *H. punctigera,* and a 10:1 mixture of Z11 -16:ALD and Z9-16:ALD for *H. armigera.* The *H.punctigera* traps are highly specific—of 15990 males captured in ten localities in 1978-1980, only 46 were *H. armigera* (0.3%); similar levels of *H. armigera* males were recorded in blank traps. Considerable "contamination" (< 20%) of *H. armigera* catches by *H. punctigera* males was noted when Z9-14:ALD was used in the baits, but this was reduced to an average of 6% when the compound was replaced by Z9-16:ALD, the naturally occurring minor component. However, unacceptably high levels of "contamination" are still being recorded in the season, particualrly in Queensland, and further work is required to increase the specificity of the *H. armigera* bait.

Pheromone Dispensers and Traps

Many types of dispensers have been used as substrates for *Heliothis* pheromones, ranging from filter-paper wicks (Tumlinson et al. 1975) to PVC laminates (Hendricks and Hartstack 1978). In the Australian trials, small pieces of red rubber tubing were used (Rothschild 1978), impregnated with 500 µg of Z11 -16:ALD (plus corresponding quantities of the other components), together with an equal quantity of an antioxidant (BHT-2,6-di-tert-butyl-p-cresol), were effective for at least 2 weeks under the hottest summer conditions (day temperatures>40°C).

Many types of traps have been devised for trapping *Heliothis* species, particularly in the USA. Traps used in preliminary screening trials in Australia relied on adhesive-covered liners to retain captures, and have been described elsewhere (Rothschild 1978). Water traps, which are more efficient than adhesive-lined ones, were used in the monitoring trials discussed in this report: these consisted of a plastic tray (35 x 30 x 10 cm) containing 2 liters of water plus a little detergent. The tray was located on a wooden support, and protected by a wooden cover from which the bait was suspended. In more recent trials these trays have been replaced by dry funnel traps of the type described by Kehat and Greenberg (1978), as these are easier to maintain. In most monitoring trials, traps have been located immediately adjacent to the crop (preferably between blocks), at just above crop height and at a spacing of 20 to 50 m.

Monitoring Activity of *Heliothis* Species

The objectives of the limited monitoring trials so far undertaken have been to compare the captures of males at pheromone-baited traps with numbers of males and females taken in light traps, and numbers of eggs laid in the crop—the latter being the main criterion used by scouting agencies when making decisions on the necessity for applying chemical control measures. The results discussed here relate to only two seasons, in the second of which *Heliothis* numbers, in terms of crop infestations, were particularly low. However, more extensive studies are now being undertaken in a wide range of crops by entomologists in three Australian States, using pheromone baits from the same source, the CSIRO Division of Entomology.

Field Tests—Namoi Valley, 1978-80

During the 1978-79 season, *Heliothis* activity was monitored in cotton crops in nine sites located along about a 60-km east-west transect in the lower Namoi Valley (New South Wales). Three *H. armigera* and three *H. punctigera* traps were placed immediately adjacent to the crop at each site. A mercury-vapor light trap was also located in one of the sites. At this particular locality, captures from the light traps and the pheromone traps were removed daily for 4 successive days each week, followed by one collection after the remaining 3 days. The numbers of eggs on plants in six randomly selected 1 -m rows were also recorded on the same occasions. White eggs (<24 hours old) were scored separately from older brown eggs. In the remaining sites, captures at pheromone traps and egg counts were obtained twice weekly. Identical *H. punctigera* baits were used in 1978-79 and 1979-80, but Z9-16:ALD replaced Z9-14:ALD in the *H. armigera* blend in the second season, following the identification of the former compound in female effluvia in that year (Nesbitt et al. 1979, 1980).

Trapping results and egg counts for two seasons, from the site at which sampling was most regular, are shown in Figures 1 and 2. Analysis of data from the remaining sites is still incomplete, and only general comments can therefore be made about capture patterns between localities.

Species Composition of Catches

H. punctigera was the dominant species in both pheromone- and light-trap catches, but there was little correspondence between catches in the two

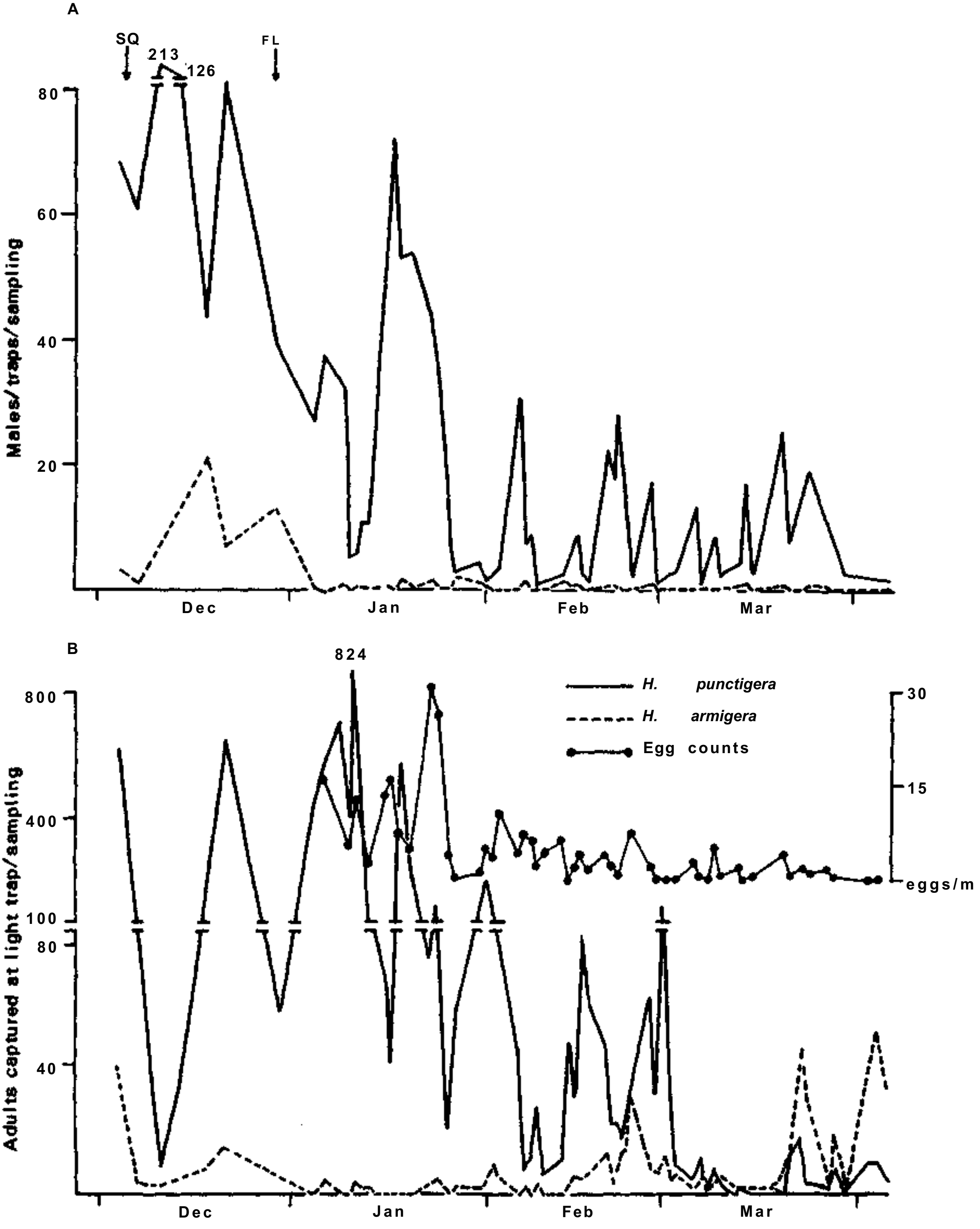

Figure 1. A. Male Heliothis *adults captured at pheromone* traps, *Myall Vale, 1978-79. SQ, FL: Square and flower formation In cotton crop.*

B. Heliothis *adults (both sexes) captured at a light trap, and egg counts per meter row of cotton. Myall Vale, 1978-79.*

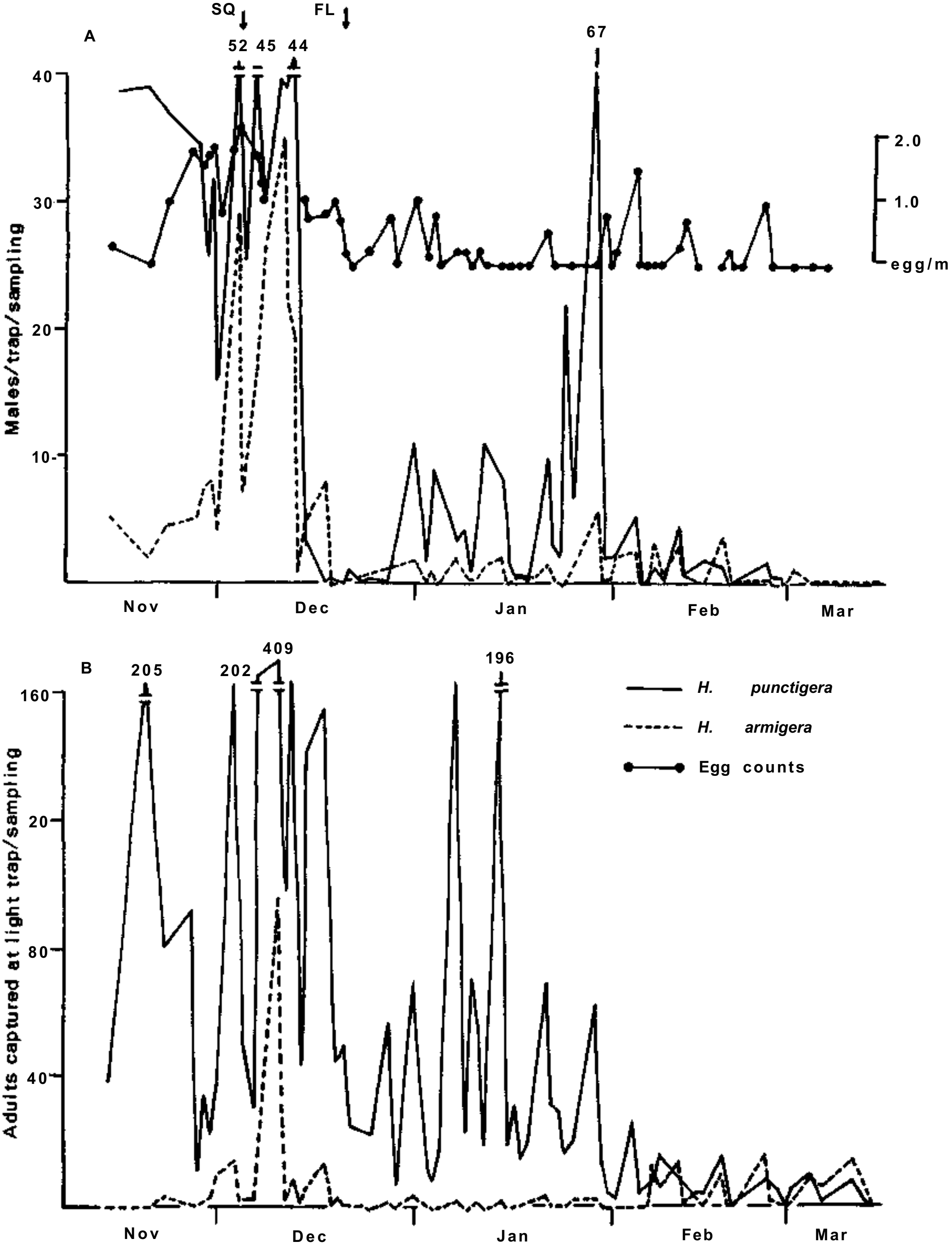

Figure 2. A. Male **Heliothis** *adults captured at pheromone traps and egg counts per meter row of cotton, Myall Vale, 1979-80. SQ, FL: Square and flower formation in cotton crop.*
B. **Heliothis** *adults (both sexes) captured at a light trap, Myall Vale, 1979-80.*

monitoring devices, regardless of whether male or female captures in light traps were being considered. Comparisons of the relative numbers of each species taken in pheromone traps in 1979-80 were probably more meaningful than those made in 1978-79, as a more effective bait for *H. armigera* was used in the second season. There was insufficient information from larval rearing to compare trapping figures for each species with species composition of larvae infesting the crop. Pheromone-trap captures in crops such as wheat and maize, which are hosts of *H. armigera,* but rarely *H. punctigera* (Wardhaugh et al. 1980), included a much greater proportion of the former species (42%) than captures in cotton (12%).

Prediction of Egg Counts from Trap Captures

As noted earlier, it is not possible to distinguish between the eggs of the two *Heliothis* species, and comparisons of egg numbers with catches at light traps and pheromone traps were therefore based on pooled counts of *H. armigera* and *H. punctigera.* The data in Figure 1 indicate that there is a general relationship between egg counts and pheromone-trap catches, and, to a lesser extent, light-trap captures in 1978-79, when the infestation level (in terms of oviposition in the crop) was high; in the following season, when the infestation was much lower (Figure 2), there was no apparent relationship between trap captures and egg counts.

The 1978-79 data were analyzed using a linear model, which related the total egg count for a day to the pheromone- or light-trap catch for that day, and environmental factors such as temperature and wind speed and direction. A log scale was used for both the egg counts and trap catches. Only white eggs were considered in the analysis of data derived from daily counts, as such eggs were less than 24 hours old.

The analysis indicated that 85% of the deviance in the relationship between egg counts and pheromone-trap catches could be accounted for by the regression, while the corresponding figure for the relationship between light-trap captures and egg counts was 78%. Analysis of egg counts on a given day and pheromone trap catches on the same or each of the previous 7 days, indicated that data collected on the same day produced the highest correlation of 0.60, decreasing to 0.48 and 0.10 by days 5 and 7 respectively. There is thus no evidence of a 'lag' effect in the relationship between numbers of adults (males) captured in pheromone traps and eggs laid in the crop.

Although the relationship between egg counts and pheromone-trap captures in 1978-79 was statistically significant, it may not prove possible, on the basis of these data, to predict egg numbers in the crop from moth captures with sufficient accuracy to be of practical value. A figure of 5 eggs/ m of row (or m^2 of crop) has been cited as a threshold density in the Namoi Valley, above which chemical control measures may be required (Room 1979). In the present analysis, a density of >5 eggs/m was associated with mean pheromone-trap captures (both species)/trap per night that ranged (in terms of extreme values) from 2.3 to 53.7. For egg counts of <5 eggs/m, the corresponding captures ranged from 0 to 53.3. It will be necessary to test the practicality of the confidence limits of this relationship under field conditions.

In the 1979-80 season, when egg numbers rarely exceeded 1 per m (Fig. 2), less than 50% of the deviance in the relationship between egg counts and pheromone traps (or light traps) could be accounted for by the regression.

Failure to obtain sufficient daily data for analysis may have been responsible for the imprecision of the relationship between egg counts and pheromone-trap captures, but it is equally probable that at least some of the variability arises from the effects of the many factors that influence both oviposition in the crop and the capture rate of *Heliothis* males at pheromone traps. These could include the sudden influx of migrants, particularly mated and unmated females; the former would provide a sudden boost to egg numbers, and the latter might divert males away from pheromone traps. Dramatic increases in daily egg counts without any comparable change in pheromone trap captures were noted in some of the Namoi Valley sampling sites, particularly early in the season; these increases were largely attributed to *H. punctigera* (A.G.L. Wilson, unpublished data).

The influence of the type of crop and flowering pattern on the relationship between trap captures and egg counts is not clear. Flowering crops are particularly attractive to ovipositing *Heliothis* females, and the flowering period may range from 7 to 14 days in sunflowers to over 50 for lucerne and over 120 days for cotton (Wardhaugh et al. 1980). Recent comparisons of egg counts and pheromone-trap captures (3-day totals prior to egg counts) in Queensland produced statistically significant positive correlations in lucerne and sunflowers but not in cotton or soybeans (B. Pyke, Department of Entomology, University of Queensland, personal communication).

Effect of Weather on Pheromone-Trap Catches

The linear regression model referred to above was employed to examine the relationship between egg counts and trap catches, and to determine whether this was further influenced by certain environmental variables. As discussed earlier, the regression accounted for much of the deviance, but there was also some evidence of an interaction with wind speed (significant at $P<0.1$ but not <0.05). The direct effects of temperature (daily average, maximum, minimum, and 2-hourly records during the daily flight period) and wind speed and direction (4-hourly records) on trap captures were examined. Rainfall (and irrigation) was not included in the analysis as this was recorded on relatively few of the sampling occasions.

The analysis indicated that average or minimum daily temperature accounted for 84% of the deviance in the regression with pheromone-trap captures. There was also evidence of an interaction with both wind speed and direction, but this was significant only at $P<0.1$ and not < 0.05; catches decreased with increasing wind speed and more moths were captured when traps were downwind of the crop. It could be expected that the two latter parameters would influence pheromone-trap performance as captures would be in part dependent on the numbers of *Heliothis* males flying upwind in response to windbome odor cues. Temperature would influence both the level of flight activity of the males and the release rate of pheromone components from the trap baits. There was no evidence of a lower temperature threshold for captures at pheromone traps; this threshold is therefore presumably below 10°C, the lowest temperature recorded during the daily flight period in the cotton crop in 1978-79 or 1979-80. At light traps, captures of both *Heliothis* species ceased at approximately 13°C. The daily average or minimum temperatures accounted for about 90% of the deviance of the regression with light-trap catch. There was evidence of an interaction with wind speed but not direction. Wind speed presumably affected flight activity, but there was no directional effect as the light trap was open on all sides. The influence of these environmental variables on *Heliothis* captures at light traps in the Namoi Valley has been very fully analyzed by Morton et al. (1981).

Other Factors Affecting Catch

The effects of other environmental factors such as moonlight and barometric pressure on pheromone-trap captures have not yet been examined in Australia, although the raw data have now been collected. Moonlight and air pressure are said to influence captures of *Heliothis* spp in the USA (Hendricks and Hartstack 1978; Hartstack et al. 1978). Other information still to be analyzed includes the influence of pesticide treatments on captures at pheromone traps in Namoi Valley cotton crops.

Trap Captures and *Heliothis* Phenology

The trap captures shown in Figures 1 and 2 do not reveal any distinct flight periods that could be attributed to successive generations. To reveal such trends, it may be necessary to adjust catches in terms of environment variables in the manner suggested by Morton et al. 1981. Even after they had made such adjustments to light-trap captures, these workers were unable to distinguish distinct generations for *H. punctigera;* in this species there was presumably constant recruitment into cotton of individuals from a succession of other host plants. There was, however, evidence of three distinct periods of abundance of *H. armigera,* with this species replacing *H. punctigera* from midsummer (late December) onwards. This pattern was not evident in the present trials where *H. punctigera* appeared to predominate until late February, in both seasons (Figure 1 and 2).

The Use of Monitoring Traps in Control Programs

No attempts have yet been made to use pheromone traps as a basis for planning chemical control measures in Australia. At this stage, experimental results suggest that traps (1) indicate when moths first invade a crop, (2) provide crude information on probable oviposition levels (e.g. high, medium, or low), and (3) give an indication as to which *Heliothis* species is present. Although further work relating population levels in the crop to adult trap captures is clearly necessary, preliminary trials are to be undertaken to compare *Heliothis* control in fields where chemical treatments are based on egg counts alone, capture thresholds at pheromone traps alone, or a combination of the two measures of abundance.

In the USA, pheromone-trap captures have been incorporated into predictive models designed to provide information on probable oviposition patterns and population abundance of *Heliothis* spp in cotton crops (Hendricks and Hartstack 1978; Hartstack et al. 1978). Results so far suggest that the traps may provide a 2- to 4-day warning of significant increases in crop infestation early in the season, but that, later, there is a "drift" and peak captures may occur 3 or 4 days before or after peak egg laying.

Mating Disruption

No research has so far been undertaken in Australia to investigate the possibility of using synthetic pheromones or other behavior-modifying compounds for *Heliothis* control through mating disruption. It is planned to begin research on this problem in the 1981 -82 field season in cotton. All that has been done so far is to combine standard monitoring baits for *H. punctigera* and *H. armigera* with various compounds to see whether catches are reduced. Compounds tested in amounts of 10 000 and 1000 ug have included (Z)-9-tetradecenyl formate (Z9-14:Fo), a pheromone "mimic" of Z11-16:ALD known to disrupt mating of *Heliothis* spp in the USA (Mitchell et al. 1976), and (E) and (Z)-9-tetradecenyl acetate (Z9-14:Ac). There was no significant reduction in captures of *H. punctigera* or *H. armigera* in any of the treatments in tests over a 34-day period. Gothilf et al. (1978), however, have shown that captures of *H. armigera* are reduced by over 95% when septa loaded with 1000 ug of Z9-14:Fo or Z9-14z;Ac are placed adjacent to virgin females of this species. Possible reasons for the difference between the results of tests with virgin females and synthetic pheromone sources include (1) inhibition of female "calling" by the added compounds, or (2) the inability of males to perceive the female signal in the presence of these compounds, because the release rate and composition of the pheromone blend from the virgin female may differ significantly from that produced from the synthetic pheromone source.

At this stage it is possible to only speculate on the likely efficacy of mating disruption in *Heliothis* control in Australia. One critical question is whether mated females of *H. armigera* and *H. punctigera* are involved in long-distance migration or local dispersal. The extent to which such movements occur will have an important bearing on the outcome of mating disruption effected by the pheromone treatment. This question will be examined before extensive work with potential disruptants is undertaken.

Acknowledgments

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References

BOURDOUXHE, L. 1980. Study of changes in *Heliothis armigera* flights with synthetic pheromone traps in Senegal. FAO Plant Protection Bulletin 28:107-109.

GOTHILF, S., KEHAT, M., JACOBSON, M., and GALUN, R. 1978. Screening pheromone analogues by EAG technique for biological activity on males of *Earias insulana, Heliothis armigera,* and *Spodoptera littoralis.* Environmental Entomology 7:31 -35.

HARTSTACK, A.W., HOLLINGSWORTH, J.P., WIRTZ, J.A., BUCK, D.R., LOPEZ, J.D., and HENDRICKS, D.E. 1978. Relation of tobacco budworm catches in pheromone baited traps to field populations. Southwestern Entomologist 3:43-51.

HENDRICKS, D.E., and HARTSTACK, A.W. 1978. Pheromone trapping as an index for initiating control of cotton insects, *Heliothis* spp: a compendium. Proceedings, 1978 Beltwide Cotton Research Conference.

KEHAT, M., and GREENBERG, S. 1978. Efficiency of the synthetic sex attractant and the effect of trap size on captures of *Spodoptera littoralis* males in water traps and in dry funnel traps. Phytoparasitica 6:79-83.

MITCHELL, E.R., BAUMHOVER, A.H., and JACOBSON, M. 1976. Reduction of mating potential of male *Heliothis* spp. and *Spodoptera trugiperda* in field plots treated with disruptants. Environmental Entomology 5:484-486.

MORTON, R., TUART, L.D., and WARDHAUGH, K.G. 1981. The analysis and standardisation of light-trap catches of *Heliothis armiger* (Hubner) and *H. punctiger*

Wallengren (Lepidoptera:Noctuidae). Bulletin of Entomological Research 71:207-225.

NESBITT, B.F., BEEVOR, P.S., HALL, D.R., and LESTER, R. 1979. Female sex pheromone components of the cotton bollworm *Heliothis armigera.* Journal of Insect Physiology 25:535-541.

NESBITT, B.F., BEEVOR, P.S., HALL, DR., and LESTER, R. 1980. (Z)-9-Hexadecenal: a minor component of the female sex pheromone of *Heliothis armigera* (Hubner) (Lepidoptera:Noctuidae). Entomologia Experimentalis et Applicata 27:306-308.

PICCARDI, P., CAPIZZI, A., CASSANI, G., SPINELLI, P., ARSURA, E., and MASSARDO, P. 1977. A sex pheromone component of the old world bollworm *Heliothis armigera.* Journal of Insect Physiology 23:1443-1445.

ROELOFS, W.L., HILL, A,.S., CARDE, R.T., and BAKER, T.C. 1974. Two sex pheromone components of the tobacco budworm moth, *Heliothis virescens.* Life Sciences 14:1555-1562.

ROOM, P.M. 1979. A prototype 'on-line' system for management of cotton pests in the Namoi Valley, New South Wales Protection Ecology 1:245-264.

ROTHSCHILD, G.H.L. 1978. Attractants for *Heliothis armigera* and *H. punctigera.* Journal of the Australian Entomological Society 17:389-390.

ROTHSCHILD, G.H.L., NESBITT, B.F., BEEVOR, PS., CORK, A., HALL, D.R., and VICKERS, R.A. 1982. Studies of the female sex pheromone of the native budworm, *Heliothis punctiger* Wallengren. Entomologia Experimentalis et Applicata 31 (in press).

TUMLINSON, J.H., HENDRICKS, D.E., MITCHELL, E.R., DOOLITTLE, R.E., and BRENNAN, M.M. 1975. Isolation, identification, and synthesis of the sex pheromone of the tobacco budworm. Journal of Chemical Ecology 1:203-214.

WARDHAUGH, K.G., ROOM, P.M., and GREENUP, L.R. 1980. The incidence of *Heliothis armigera* (Hubner) and *H. punctigera* Wallengren (Lepidoptera: Noctuidae) on cotton and other host-plants in the Namoi valley of New South Wales. Bulletin of Entomological Research, 70:113-131.

The Potential for Hybrid Sterility in *Heliothis* Management

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Abstract

The discovery of inherited backcross male sterility as a result of hybridization has stimulated interest in controlling field populations of tobacco *budworms,* Heliothis virescens *(F.), by releasing backcross insects. In 1977, a pilot test was initiated on St. Croix, U.S. Virgin Islands, to test the feasibility of this technique in an isolated ecosystem. Released males did not disperse tar from release sites. The released females were active earlier in the evening than native insects, but mating interaction between released and native occurred at random when backcross pupae were placed in field cages and allowed to emerge and disperse. Further, by release of backcross insects, sterility was infused into native males in great enough numbers to prevent population buildup. This frequency of backcross insects increased as long as releases continued.*

Over 10 million backcross and H. virescens *pupae were reared by the Bioenvironmental Insect Control Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Stoneville, Mississippi, tor conduct of this pilot test during 1977-1980. During the period mid-August to mid-December 1980, over 5 million backcross pupae were shipped to St. Croix for release of about 40 thousand moths per day.*

Résumé

Potentiel de la stérilité des hybrides dans la lutte contre Heliothis: *La découverte de l'hérédité de la stérilité mâle de rétrocroisement, résultant d'une hybridation, a stimulé l'intérêt de la régulation des populations d'*Heliothis virescens *(F) sur le terrain par le lâcher d'insectes rétrocroisés. En 1977, un essai pilote a débuté à Sainte-Croix dans les Iles vierges (Etats-Unis), pour évaluer la faisabilité de cette technique dans un écosystème isolé. Les mâles lâchés ne se sont pas trop éloignés des sites des lâchers. Les femelles lâchées ont été actives plus tôt le soir que les insectes indigènes, mais l'interaction d'accouplement entre les insectes lâchés et indigènes a été aléatoire lorsque les pupes rétrocroisées ont été mises dans des cages sur le terrain et pu émerger et se disperser. De plus, grâce au lâcher d'insectes rétrocroisés la stérilité a été introduite chez des mâles indigènes en assez grand nombre pour empêcher un accroissement des populations. Cette fréquence d'insectes rétrocroisés a augmenté aussi longtemps que les lâchers se sont poursuivis.*

*Afin d'effectuer cet essai pilote en 1977-1980, il y a eu plus de dix millions de rétrocroisements et les pupes d'*H. virescens *ont été élevées au Bioenvironmental Insect Control Laboratory, ARS, Secrétariat à l'Agriculture des Etats-Unis, Stoneville, Mississipi. Entre le mi-août et la mi-décembre 1980, plus de 5 millions de pupes rétrocroisées ont été expédiées à Sainte-Croix pour effectuer des lâchers d'environ 40 milles papillons par jour.*

Literature Review

Knipling (1960) expressed the view that strains of insects with lethal characteristics might be produced without altering the mating behavior or ability to disperse and find mates in nature. These strains could be released to control populations in a manner similar to that of males sterilized by radiation. In 1972, Laster reported the successful hybridization of *Heliothis subflexa* (Guenee) and *H. virescens* (F.), (Laster 1972). The hybrid males were sterile, but hybrid females reproduced when crossed with *H. virescens* males. Further, sons of

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*U.S. Department of Agriculture, Agricultural Research Service; respectively: Virgin Islands Experiment Station, St. Croix. U.S. Virgin Islands; Delta Branch Experiment Station, Stoneville, Mississippi; and Bioenvironmental Insect Control Laboratory, Stoneville, Miss., USA.

International Crops Research Institute for the Semi-Arid Tropics. 1982. Proceedings of the International Workshop on Heliothis Management, 15-20 November 1981, Patancheru, A.P., India.

the hybrid females were sterile, but daughters were fertile when crossed with *H. virescens* males. This inherited backcross male sterility persisted through more than 100 subsequent generations. Laster suggested that the hybrid males from the *H. subflexa* female x *H. virescens* male cross be released to control populations of *H. virescens.* The differential in size and developmental time between the sexes was proposed as a means of obtaining only males for release. Subsequently, Knipling and Klassen (1976) and Laster et al. (1976) presented models that demonstrated the powerful suppressive potential or releasing hybrid and/or backcross females as well as males, so that the sterile-male trait would be introduced into the native population. Makela and Huettel (1978) refined and expanded these models. The powerful potential of this method of control stimulated considerable research along two lines: (1) to determine the behavior and competitive ability of the backcross insect in comparison with pure *H. virescens;* and (2) to collect basic biological and genetic data to establish the basis for the sterility.

Several facts have emerged from this research. Hybrids were produced from both interspecific crosses (Proshold and LaChance 1974). In the laboratory, behavior and mating performance of the two types of hybrid males were similar. Sterility was characterized by a lack of eupyrene sperm in the spermatheca, though apyrene sperm were commonly present. Eupyrene sperm bundles were produced by hybrid males in fairly normal quantities and were transferred to spermatophores during mating. However, the bundles failed to break down within the spermatophore and the eupyrene sperm were not included with the material ejected into the seminal duct (Proshold et al. 1975). Meiotic chromosomes from primary spermatocytes exhibited a high degree of desynapsis (Proshold and LaChance 1974) and many of the subsequent sperm cells contained a double amount of DNA in the head, were two- or multiple-tailed, and possessed other duplication deficiency abnormalities (Richard et al. 1975; Goodpasture et al. 1980).

When hybrid and backcross females were crossed with either *H.subflexa* or *H. virescens* for several generations, chromosome pairing and sperm duplication deficiency abnormalities in males gradually approached normal (Proshold, unpublished data and Goodpasture et al. 1980). If *H. virescens* was the female in the interspecific cross, in addition to normal chromosome pairing in the backcross male, his ability to transfer eupyrene sperm to the female's spermatheca was also restored, as was his fertility (Proshold and LaChance 1974; Karpenko and Proshold 1977). If *H. subflexa* was the P_1 female, normal eupyrene sperm transfer and fertility were restored only when hybrid and backcross females were crossed with *H. subflexa* males. When these hybrid and backcross females were crossed with *H. virescens* males, inherited backcross male sterility persisted for more than 90 generations (Martin et al. 1981a).

In one study, hybrid females *(H. subflexa* female x *H. virescens* male) and backcross females were crossed with *H. virescens* males for 35 generations. Chromosome pairing in spermatocytes of BC35 males exhibited no nonhomology. Then BC35 females were crossed with *H. subflexa* males. Spermatocytes of progeny from this cross exhibited the same types of desynapsis as observed in F_1 hybrid males. Females mated to these males failed to receive eupyrene sperm in their spermatheca and were sterile. But when the F_1 and backcross females were crossed with *H. subflexa* males, normal chromosome pairing, eupyrene transfer, and fertility were restored in the backcross males (Proshold, unpublished data). In another study, it was possible to transfer a dominant mutant gene from *H. virescens* to *H. subflexa* by crossing *H. subflexa* females with mutant *H. virescens* males and crossing mutant hybrid and backcross females with *H. subflexa* males (Proshold, Karpenko and Raulston, unpublished data).

Thus, at least two separate types of sterility are associated with *Heliothis* hybrids. One is associated with chromosome desynapsis and the subsequent spermiogenic abnormalities. This sterility is lost when females are crossed with the appropriate male so that the species genome is placed into the same cytoplasm. More importantly from a control standpoint, there is a persistent backcross male sterility that exists when the *H. virescens* genome is present in *H. subflexa* cytoplasm. This cytoplasmic sterility is maternally inherited. In some insects, such sterility is associated with maternally transmitted cytoplasmic microorganisms. This does not seem to be the case in *Heliothis,* at least for bacterial or rickettsial organisms (LaChance and Karpenko 1981). More probably this sterility is associated with mitochondrial DNA. The mitochondrial DNA of *H. virescens* is different from that of *H. subflexa,* and the mitochondrial DNA of BC insects is similar to that of *H. subflexa* (M. Huettel, personal communication).

In contrast to hybrid males, hybrid females differ greatly in appearance, biology, and reproduction depending upon the type of interspecific cross. When *H. subflexa* was the female in the interspecific cross, about 40% of the hybrid females entered an intense diapause from which few emerged (Laster 1972; Proshold and LaChance 1974). Most females that did not diapause contained few or no mature eggs and would not mate with males of either species. Those that did mate oviposited only about one-half and one-fourth the number of eggs oviposited by *H. subflexa* and *H. virescens* females, respectively. If mated, egg hatchability was as great as expected of females of either species (Proshold and LaChance 1974). At least three generations were required before mating frequency was as prevalent in backcross females as that in pure *H. virescens* (Laster et al. 1977).

In contrast, hybrid females from the reciprocal cross *(H. virescens* female x *H. subflexa* male) did not enter diapause. Further, they mated readily with either male, and if mated laid about the same number of eggs as *H. subflexa* females. However, eggs from these females did not hatch as frequently as eggs from either *H. virescens* or *H. subflexa* females (Proshold and LaChance 1974).

When hybrid and backcross females are crossed with *H. virescens* males, about half of the remaining *H. subflexa* chromosomal DNA is replaced by *H. virescens* DNA each generation. Thus, chromosomal DNA of BC3 insects should be nearly 94% *H. virescens.* The persistence of the backcross male sterility allows the use of insects that have been backcrossed to the point of being genetically similar to *H. virescens.* Thus, most of the research comparing the behavior and competitive ability of backcross insects with that of *H. virescens* was done with BC_3 or later generation insects.

Sex traps baited with BC females (one/trap) caught as many native *H. virescens* males as ones baited with *H. virescens* females (Laster et al. 1978a). Interestingly, females previously mated to BC males seemed to catch more males than virgin females caught, which would indicate that BC males did not satisfy the mating urge of females and they would readily remate. The fact that more males were trapped in the first instance can best be explained by selection. Not all virgin females placed in traps have the propensity to mate. Probably, these females would be precluded in traps baited with females mated to BC males. Pair et al. (1977a) found that females mated with BC males remated about twice as frequently as those mated with *H. virescens* males. Further, Pair et al. found synchrony in mating time between BC and *H. virescens* females; however, *H. subflexa* females mated earlier in the scotophase than the other two females. For the first mating, BC and *H. virescens* females were found in copula with both types of males in about equal proportions, but rematings occurred more frequently with BC males than *H. virescens* males for both types of females.

Females mated with BC males readily remate. Pair et al. (1977b) found that if the next mating was with a *H. virescens* male, then the female became fully fertile. In contrast, if females mated with *H. virescens* males and then with BC males, the females became infertile to partially fertile. The authors felt this was caused by apyrene sperm of the second mating replacing eupyrene sperm of the first mating. If these data prove true, then the value of the released BC male is greatly enhanced.

In an excellent study, Raulston et al. (1979) released BC insects in a cotton field and observed interaction between released and native insects. BC females mated readily with native males, but native females were rarely observed in copula with BC males. BC males were competitive with native males for BC females, but not for native females. In general, the BC insects' behavior was similar to that of the laboratory colony from which they were derived. Carpenter et al. (1979) observed similar results with BC females. Thus, the behavior of the BC insects in nature seemed to be dependent upon the genetic background from which the BC originated. As Raulston et al. (1979) suggest, this allows the engineering of behavior in released insects.

In a limited cage study in which *H. virescens* and BC insects were released in ratios of 1:1 or 1:5, Laster et al. (1978b) collected first- and second-generation eggs and larvae. Hatchability of first-generation eggs was lower in cages with both types of insects than in cages with only *H. virescens.* When adult males from eggs or larvae from various cages were crossed with females, from 59 to 100% of the females failed to reproduce, indicating infusion of the male sterility. Infusion of sterility was also observed following a one-time release in a semi-isolated plot of cotton and sesame (Martin et al. 1981 b). Furthermore, emergence from diapause of BC insects appeared to be in synchrony with that of *H. virescens* (Martin et al. 1981a; Stadelbacher and Martin 1981).

Based on this research, it was believed that a concentrated study was warranted on the feasibility of managing a native population of *H. virescens* releasing backcross insects. Thus, in 1977, the Agricultural Research Service of the U.S. Department of Agriculture, in cooperation with the Mississippi Agricultural and Forestry Experiment Station and with the College of the Virgin Islands Experiment Station, began a 4-year pilot test program on the island of St. Croix. BC insects were to be reared in Stoneville, Mississippi, and mailed to St. Croix, where they were to be released. Studies would be conducted on behavior and interaction in comparison with native insects, on infusion of male sterility into the native population, and on the potential for suppressing the native population by an all-island release.

Pilot Test for Release of Backcross Insects

St. Croix—the Site

St. Croix is one of the more isolated of the small Caribbean islands (Miskimen and Bond 1972). The nearest islands are 64.5 km northward. The prevailing eastwardly winds do not favor immigration from this direction. Windward, the nearest islands are 161.3 km away. St. Croix is about 37 km long east to west, and 9.7 km wide at the widest point, comprising an area of about 217.6 km^2. The eastern one-third of St. Croix consists of hills up to 152 or 183 m in altitude. Rainfall here averages below 510 mm annually. The northwestern portion of St. Croix contains the highest terrain (highest peak is 355 m). Rainfall becomes more abundant westward, with the greatest amount (about 1270 mm/year) in the northwest hills. The southwestern portion of St. Croix is much flatter than other parts of the island and was used extensively for sugarcane production until 1965. Temperatures vary little, either daily or seasonally; monthly means range from 22.2 to 29.4°C. Relative humidity averages 55 to 70% and evaporative rates average over 1.8 m per year because of the easterly trade winds. A short rainy period usually occurs from April through June and a longer season from September to December, but rainfall is quite variable, with periods of extreme drought occurring frequently.

Beginning in November 1977, and prior to the first release of backcross insects, 42 cone traps were established throughout St. Croix (Figure 1). The traps were baited with three virgin females and changed at least three times weekly. In December 1978, all traps were modified by inserting a 10.2 cm skirt (Hartstack et al. 1979).

In addition, up to 11 plots from various locations (Figure 1) were selected for study sites. At each site the two most important hosts for tobacco budworm on St. Croix, pigeonpea (*Cajanus cajan* [L] Millsp.), and *Bastardia viscosa* (Koth.) (Snow et at. 1974) were planted. Two types of pigeonpea were utilized, one (cv Norman) was indeterminate and the other was a local cultivar that bloomed only during the short photoperiod of October to March. Cv Norman would flower about 3 months after planting, regardless of time of year. *Bastardia* was an availa-

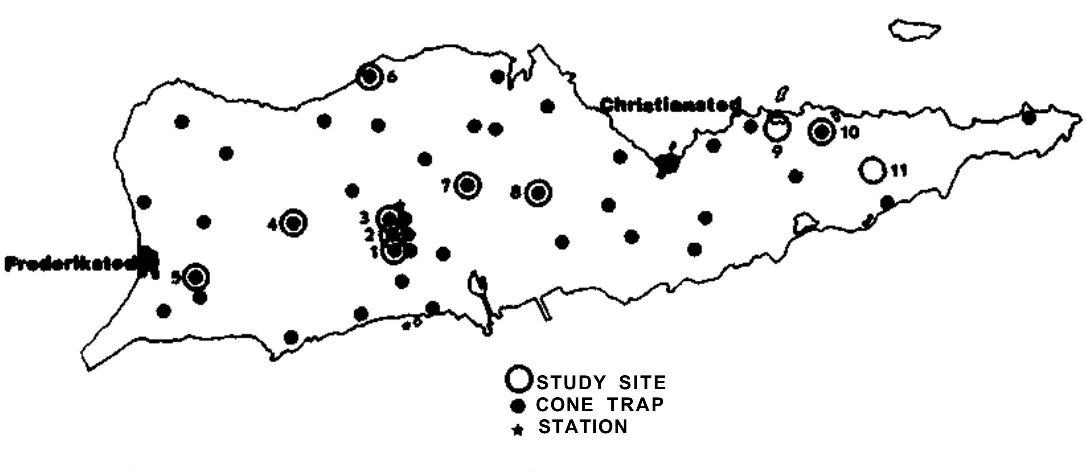

Figure 1. Cone traps were baited with virgin female backcross insects to monitor male **H. virescens** *and backcross populations. The 11 study sites were planted in pigeonpea and* **Bastardia** *to monitor egg and larval populations. St. Croix, U.S. Virgin Islands.*

ble host year round, though the suitability varied depending upon rainfall.

Rearing and Shipping the Insects

Over 10 million BC and *H. virescens* pupae were reared by the Bioenvironmental Insect Control Laboratory, ARS, U.S. Department of Agriculture, Stoneville, Mississippi, for conduct of this pilot test during 1977-1980. During the period mid-August to mid-December 1980, over 5 million BC pupae were shipped to St. Croix for release of about 40 thousand moths/day.

Backcross and *H. virescens* insects were reared with methods and diet similar to those reported by Raulston and Lingren (1972) for *H. virescens,* but more specifically by Hartley et al. 1982. Larval rearing was in a multicellular unit constructed from polystyrene light-diffusion louvers fitted into a fiberglass tray filled with insect diet. The tray was covered with porous polypropylene (125-micron openings) (Porex®, Glassrock, Plastics Group, Fairburn, Georgia 30213) followed by reinforcement structure and strapping together at each end. A diet of soybean flour and wheat germ, with corncob grits as a substitute for part of the agar, was used for larval rearing. Calco red®, an oil-soluble dye, was added to the larval diet to mark released moths and their eggs.

The trays containing eggs were incubated and larvae reared at 29.5°C and 50% RH for 18 days , when the pupae were harvested, by first passing them through a series of gratings to remove large particles, and then removing lighter particles with an air current from a high-volume blower (Dayton Model 2C890). The pupae were weighed to determine the number harvested. Emergence of moths from these pupae averaged 88%.

Production of the BC required maintenance of a *Heliothis virescens* colony to obtain males for mating with BC females. These colonies were maintained in separate facilities as described by Brewer et al. (1978). After the initial sexing with the aid of a stereoscope (Butt and Cantu 1962), male *H. virescens* pupae were confirmed once more before transfer into the BC colony and a second time before setting up for moth emergence. BC pupae were sexed only once, to remove the sterile males to prevent interference in mating between BC females and *H. virescens* males. Maintenance of sterility within the BC colony was monitored twice weekly by mating male and female BC moths, collecting eggs from these ovipositing females, and observing egg hatch; fertile eggs would have signified introduction of one or more *H. virescens* females into the BC colony.

For colony maintenance and egg production, pupae were held until emergence in 3.8-liter cylindrical cardboard containers. The emerged moths were paired and held in these containers, where they oviposited on fine-weave polyester cloth (Hill and Co., Inc., P.O. Box 15159, Cincinnati, Ohio) covering the top of the container and also on a strip (about 7.5 cm wide) suspended from the container top edge to the bottom. A 7.5 cm^2 cotton pad saturated with 5% sucrose solution placed on the cloth cover served as a food and water source. Collection of moth scales was accomplished by a device similar to that described by Hartley et al. (1977). Eggs produced in these colonies were transferred to a facility described by King et al. (1979) for mass production of the BC.

Pupae were packaged and shipped using techniques similar to those reported by Raulston et al. (1976b). Two hundred pupae, based on weight, were placed in 0.47-liter cylindrical cardboard containers filled with dry vermiculite. The top of each container was perforated for ventilation and taped shut with 2.5 cm masking tape to prevent spillage of contents. The containers were shipped in corrugated cardboard boxes (24/box) with ventilation holes. Shredded paper was placed around the container in the box to further cushion the pupae during shipment. The boxes were shipped airmail through the U.S. Postal Service. Moth emergence from pupae packaged and shipped by this process averaged 85%.

Release

Four releases were made (Table 1) (Proshold, unpublished data). The first two releases were point releases and all insects were released at one site on the Federal Experiment Station. The third release (west release) was made at 10 sites in the western part of St. Croix and the fourth release (all-island release) was made at 50 sites throughout St. Croix (Figure 2). The first release was made with pupae, the second and third releases with both pupae and adults, and the fourth with pupae only. The first two releases were made during the time of year when native populations were the greatest. The third release was made into an increasing population following the onset of the rainy period, and the all-island release was made during the dry season when the native population was the lowest.

Behavior and Interaction of Released (R) with Native (N) Insects

Released males did not appear to disperse far from release point. Nearly 60% of the males recaptured were trapped within 0.8 km of the release site and another 24% were trapped from 0.8 to 1.6 km from the release site. No male was recaptured further than 16.1 km. Consequently, for the point release the ratio of R:N males dropped rapidly away from the release point, so that ratios of 1 or higher R:N were obtained only within the first 1.6 km. For the third release, ratios of 1:1 or higher were trapped throughout the western part of St. Croix and ratios of 1 R:2N were trapped in the central area. During the final release no trap was further than 1.6 km

Table 1. Dates and approximate number of backcross tobacco budworm *(Heliothis virescens*) sterile hybrids released on St.Croix, U.S. Virgin Islands, 1979-1960.[a]

Release area	No. sites	Date	Type	Number
		1979		
Station	1	19 Jan-16 Feb	Pupal	3 500 females/day 3 500 males/day
Station	1	13 Apr-27 Apr	Pupal	3 500 females/day 3 500 males/day
			Adult	5 000 males/day
West	10	1 Nov-15 Nov	Pupal and adult	3 500 females/day
		15 Nov-22 Nov	Adult	3 500 males/day
		22 Nov- 19 Dec	Pupal	20 000 females/day
		1980		
All-Island	50	27 Aug- 17 Dec	Pupal	20 000 males/day

a. The first two releases were conducted for study of behavior and interaction between released and native insects; the third release was made to study infusion of the sterility trait into the native *H. virescens* population; and the fourth release was made to demonstrate suppression of the native *H. virescens* population by infusion of sterility.

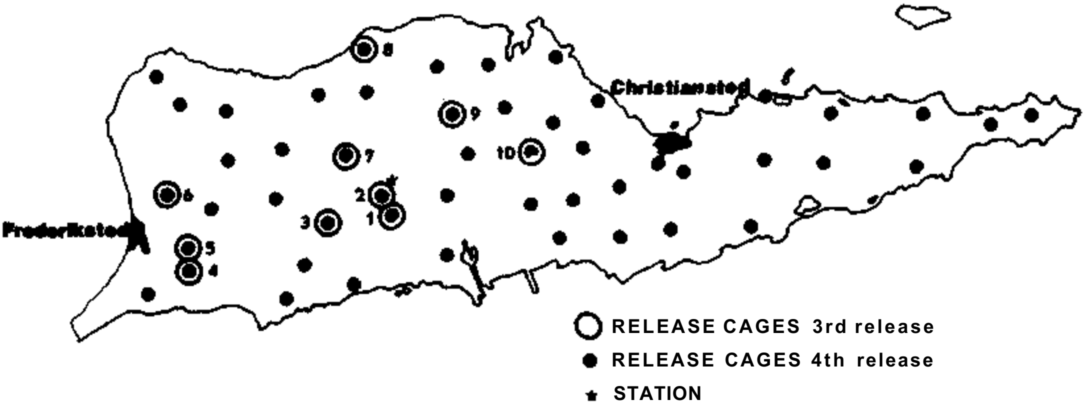

Figure 2. Sites for the third and fourth releases of the backcross tobacco budworm (Heliothis virescens; *sterile hybrid on St. Croix, U.S. Virgin Islands.*

from one of the 50 release sites. Within 61 m of release sites, R:N ratios were 10:1; from 0.4 to 0.8 km, 9:1; from 0.8 to 1.6 km, 7:1.

Activity of the insect was studied by the method of Raulston et al.(1976a) and Lingren et al. (1978). In general, released insects become active earlier than native ones. Of the 395 females collected flying, feeding, or ovipositing, three-fourths were released females. For wild females, the ratio of females flying to feeding to ovipositing was the same before 2000 AST (Atlantic Standard Time) as that after 2000 AST. About half were collected flying and one-fourth either ovipositing or feeding. Conversely, for released females, 86% were collected before 2000 AST, and of these, over half were feeding and about equal numbers flying or ovipositing. After 2000 AST, about the same numbers of released females were collected feeding, flying, or ovipositing. Comparing the numbers of females ovipositing, there was no difference in ratio of wild and released females, regardless of the collection time. Ratios of females collected ovipositing on pigeonpea and on *Bastardia* were the same.

About the same ratio of R:N males were collected either feeding or flying, but before 2000 AST a greater percentage were feeding (61%) than those collected after 2000 AST (26%).

Of females collected in copula, a larger percentage of released females were collected earlier in the mating period than were native females. Still, some released females were collected in copula as late as native females. There was no significant difference in time of mating between those females released as adults and those put in field cages as pupae. Nearly half were collected before midnight.

In contrast to ratios of R:N females, released males, regardless of whether released as adults or pupae, were collected in copula throughout the night in the same ratios as native males. Slightly more than half were picked up before midnight.

Of 1141 pairs picked up in copula, 84% were between released females and released males and 11 % were between released females and native males. When pupae were placed in cages and allowed to emerge, mating between released and native insects was random. But when adults were released, a greater than expected frequency of released pairs and native pairs were collected.

One of the most important observations made during this study was the reduction in fertility of native females during the release. Percentage mating observed in native females was nearly 80% or greater during all releases. Of a single collection of native females that were mated, during the point, west, and all-island release, 92, 81, and 25%, respectively, were fertile (contained eupyrene sperm in their spermathecae). This substantiates the high degree of mating interactions between native females and backcross males.

Infusion of Sterility into Native Populations

Since backcross insects are genetically very similar to *H. virescens,* there is no difference in external appearance of the two types. Thus ratios of field-reared backcross (BC) insects to pure *H. virescens* (V) were determined by crossing males to virgin females; males that transferred only apyrene sperm were considered BC males (Proshold and LaChance 1974). All males trapped alive were crossed. Before any backcross insect was released on St. Croix, 400 males collected in cone traps from October to December 1978 were crossed in the laboratory with virgin females to check the reliability of this method of determining BC males. Of these, 66% mated and of the females that mated, 81% contained sperm in their spermathecae. Of these, 99.5% contained eupyrene sperm. Only one female received only apyrene sperm.

During the release, 268 released males that had been recaptured in cone traps were paired with virgin females. Nearly 82% mated and of these only 12% failed to transfer apyrene sperm to the spermatheca. No female contained eupyrene sperm. Further, adult males from red eggs (eggs laid by released females) collected on host plants during the release were also crossed with virgin females. For 203 pairs 82% mated, and of those, only 13% failed to transfer sperm. Eight females did contain eupyrene sperm. However, this was probably the result of our mistaking embryonated eggs laid by native females for red eggs rather than of the BC males recovering the capacity to transfer eupyrene sperm in BC males.

Crossing virgin females with males captured in the cone traps provided the most data on BC:V frequency. Of the pairs caged, 70% or more mated, and of those, more than 90% of the females contained sperm. The percentage of BC males in the population increased with each release, but the percentage of sperm transfer remained fairly constant (Table 2).

Table 2. Percent mating, sperm transfer, and percent field-reared backcross tobacco budworm *(Heliothis* virescens sterile hybrids aa determined by crossing virgin *H. virescens* females with males trapped on St Croix, U.S. Virgin Islands, following the release of backcross Insects.

Release no.	Trapping period	No. of pairs	Mating (%)	If mated female w/sperm I%)	Backcross I%)
1	15 Jan 1979 - 30 May 1979	5075	69.8	92.4	4.6
2	30 May 1979 - 15 Dec 1979	2610	71.1	94.1	5.5
3	15 Dec 1979 - 2 Oct 1980	7810	77.1	91.0	33.9
4	2 Oct 1980 - 1 Mar 1981	3139	75.6	92.8	83.8

The first field-reared BC male was collected 6 weeks after the first pupae were placed in field cages. During the first field generation, nearly 10% of all males that were collected were BC, and at one location nearly one-third of the males from one sample period was BC. The location was within 1.6 km of the release site. Within the first 3 months, the BC frequency was greater *near the release site* than at distances of more than 4.8 km. In fact, no BC male was trapped on the east end until 2 months after the release. Considering all males trapped, the BC frequency declined at a rate of about 2% per month until June. The June population showed a significant increase in BC percentage over the May population (G=32.477, P< 0.001) but there was no difference because of distance (G=3.51,6, D.F.=4, P > 0.75) nor was there any interaction (log likelihood ratio test, Sokal and Rohlf 1969). This increase probably resulted from the second release. Thereafter, the BC frequency declined to about 3% in August and remained at that level until the west release.

The BC frequencies began to increase as a result of the west release in December. There was no significant difference between frequencies obtained at release sites and those in the west region. For January, February, and March, these frequencies were about 50%. Fewer BC males were trapped in the central and eastern regions. About three generations were required (December 1979 to April 1980) for the BC frequencies to become homogeneous throughout the western and central regions. Another generation (until June) was required for complete island-wide homogeneity, at which time the BC frequency was 23%. This frequency dropped to a low of 18% in July. Interestingly, the BC frequency in August was significantly greater (25%) than that in July (G=4.336, D.F.= 1, P < 0.05), but there was no difference among sites nor was there any interaction.

The all-island release began 27 Aug 1980. From 17 Sept 1980 to 25 Feb 1981, the rate of increase in BC frequency per week followed the quadratic curve $Y = 11.77 + 12.48x - 0.7598x^2 + 0.0164\ x^3$, where Y = expected BC frequency and x = week (Figure 3). Indeed, until the first of December, the

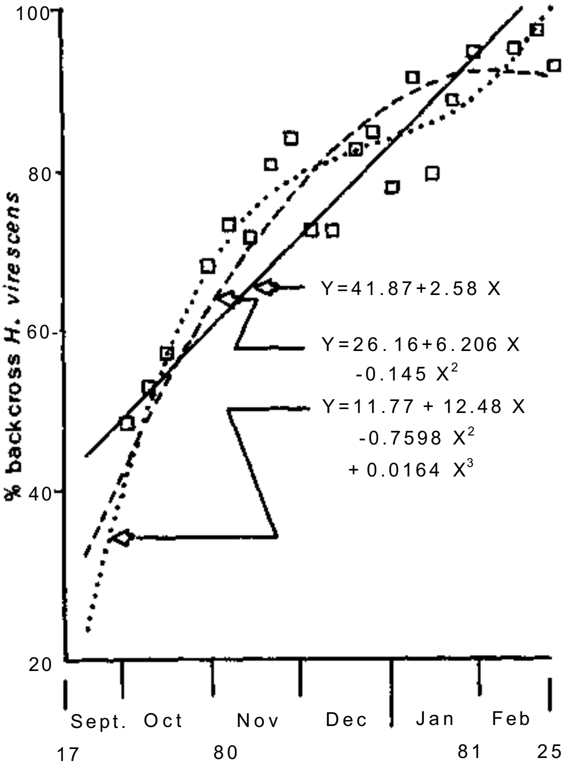

*Figure 3. The rate of increase in backcross tobacco budworm (*Heliothis virescens*; sterile hybrids within the St. Croix, U.S. Virgin Islands,* H. virescens *population followed a quadratic curve, and Initially, the Increase was linear with an increase of 4 to 5% per week.*

increase in BC frequency was linear with an increase of 4 to 5% per week. During December, increases in BC frequency leveled off somewhat, and from then on to the end of February, increased only at a rate of 2% per week. Nonetheless, for a 6-week period (17 Jan through 27 Feb 1981) the frequency of BC males in cone traps was 94.3 + 6.24%. A two-way analysis of variance indicated no significant difference among weeks or among sections for the 6-week period. A frequency of 94% would be a ratio of 17 BC to 1 V insect.

BC frequency obtained from mating tables (Snow et al. 1974) or from crossing adult males collected as eggs or larvae were similar to those obtained from traps. For example, for five consecutive weeks from 6 Mar 1980 to 1 Apr 1980, 50 females were placed on nine mating tables; 4, 3, and 2 in the west, central, and east regions.respectively. The weekly average over all tables was 43.5 ± 6.2%, with tables in the west, central, and east averaging 49, 46, and 16% BC, respectively. This compared with an average of 46% obtained for the same period with traps. Again, 50 females were placed on four tables four different weeks from 15 Jan to 27 Feb 1981. The average BC frequency was 91.5 ± 6.26%.

Similar data were obtained from males from field-collected eggs or larvae. Comparing BC frequencies of males trapped and males collected as eggs or larvae from October, November, and December 1980 and January 1981 gave no significant difference because of sampling techniques (G=2.999, D.F.=1, $P < 0.05$). For the first few generations after the point or west release, BC frequencies of males collected as eggs or larvae were generally greater than those from traps. This was probably due to sampling error, as most eggs and larvae were collected near release sites. Once the BC frequencies obtained from males collected in traps became homogeneous island-wide, there was no difference between those frequencies and those of males collected as eggs or larvae.

From February to July 1981, backcross frequency dropped from about 94% to 65%, or at a rate of 1.14% per week. At about 65%, BC frequency leveled off and has been at that level for more than 3 months. Comparing the 1981 native population on St. Croix and Vieques, a neighboring island, with that of previous years demonstrates that suppression by the release of the backcross insects has been achieved (Table 3).

Whether a mixed population of BC and pure *H. virescens* will increase or decrease the following generation depends upon the BC frequency, mating potential of the fertile males, and the reproductive potential of the females (Makela and Heuttel 1978). The latter, in part, is dependent upon the availability of suitable host plants. On St. Croix the availability of host plants is influenced by rainfall and varies markedly from year to year. The past 3 years have been increasingly favorable for *H. virescens,* as reflected in the spring trap catches on Vieques and the August (dry season) trap catches on St. Croix. Our data indicate that a BC frequency of 17:1 will maintain a static population during the population-growth phase. The fact that the BC frequency was still increasing at the end of the release indicates that ratios high enough to cause a population decline during the growth phase can be achieved simply by releasing insects for a longer period or in greater numbers.

Some researchers felt that releasing fertile BC females would cause the first field generation to be abnormally large, since *H. virescens* males can mate many times. Our data have shown this not to be true. In fact, the field increase between the August and January populations was lower in 1979-1980 and 1980-1981, following the release of BC insects, than in 1978-1979, before BC release. This probably reflects the benefit of releasing ste-

Table 3. Average number of males per trap per week during various population peaks on St. Croix for 1978-1981, compared with major spring peak on Vieques. Number in parentheses is the fold increase from the August peak on St Croix.

	St. Croix			Major spring peak, Vieques
Year	Aug peak	Jan-Feb peak	Major spring peak	
1978 - 1979	0.9	7.1 (8)	18.8 (21)	1.6
1979 - 1980	1.5	9.7 (6)	20.1 (13)	5.0
1980 - 1981	5.5	9.5 (2)	9.0 (2)	19.7

rile males and the reduced reproductive potential of females mating with these males. This reduced potential may result through replacement of eupyrene sperm from a previous mating with apyrene sperm (Pair et al. 1977b), or by preventing the female from being fertilized within the first few nights of emergence, a requirement for maximum egg production (Proshold et al. 1982).

This unique system of using inherited male sterility would seem to have several advantages over other sterility-inducing systems such as radiation or chemosterilization: (1) no treatment is necessary other than the original cross; (2) any life stage of the insect can be released; and (3) the desired BC frequency can be obtained either by release of large numbers for one generation or fewer numbers for several generations. Whether such a system can be found with other Lepidoptera remains to be determined. But the potential for population suppression by this technique would make the effort worthwhile.

Note; Trade names are used in this paper solely for the purpose of providing specific information. Mention of a trade name does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture or an endorsement by the Department over other products not mentioned.

References

BREWER, F.D., GANTT, C.W., and MARTIN, D.F. 1978. Media preparation and brood colony facility Pages 72-75 *in* Facilities for insect research and production, eds. N.C. Leppla and T.R. Ashley U.S. Department of Agriculture technical bulletin 1576, Washington, DC, USA.

BUTT, B.A., and CANTU, E. 1962. Sex determination of lepidopterous pupae. U.S. Department of Agriculture, ARS-33-75, Washington DC, USA. 7 pp.

CARPENTER, J.E., SPARKS, A.N., and RAULSTON, J.R. 1979. Competitiveness of *Heliothis* hybrids vs. *H. virescens* females for *H. virescens* males in Georgia tobacco. Journal of the Georgia Entomological Society 14: 65-69.

GOODPASTURE, C., RICHARD, R.D., MARTIN, D.F., and LASTER, M. 1980. Sperm cell abnormalities in progeny from interspecific crosses between *Heliothis virescens* and *H. subllexa.* Annals of the Entomological Society of America 73: 529-532.

HARTLEY, G.G., GANTT, C.W., KING, E.G., and **MARTIN, D.F. 1977.** Equipment for mass rearing of the greater wax moth and the parasite *Lixophaga diatraeae.* U.S. Agricultural Research Service (Report) ARS-S-164, Washington DC, USA. 4 pp.

HARTLEY, G.G., KING, E.G., BREWER, F.D., and GANTT, C.W. 1982. Rearing of the *Heliothis* sterile hybrid emphasizing a multicellular larval rearing container and pupal harvesting. Journal of Economic Entomology (in press).

HARTSTACK, A.W., WITZ, J.A., and BURK, D.R. 1979. Moth traps for the tobacco budworm. Journal of Economic Entomology 72: 519-522.

KARPENKO, C.P., and PROSHOLD, F.I. 1977. Fertility and mating performance of interspecific crosses between *Heliothis virescens* and *H. subllexa* backcrossed for three generations to H. *subllexa.* Annals of the Entomological Society of America 70: 737-740.

KING, E.G., HARTLEY, G.G., MARTIN, D.F., SMITH, J.W., and SUMMERS, T.E. 1979. Production of the tachinid *Lixophaga diatraeae* on its natural host, the sugarcane borer, and on an unnatural host, the greater wax moth. U.S. Department of Agriculture, Advances in Agricultural Technology 3, Washington DC, USA.

KNIPLING, E.F. 1960. Use of insects for their own destruction. Journal of Economic Entomology 53: 415-420.

KNIPLING, E.F., and KLASSEN, W. 1976. Relative efficiency of various genetic mechanisms for suppression of insect populations. U.S. Department of Agriculture Technical Bulletin 1533, Washington DC, USA. 56 pp.

LaCHANCE, L.E., and KARPENKO, C.P. 1981. Effect of seven antibiotics on the growth and reproduction of *Heliothis subllexa* x *H. virescens* interspecific hybrids and backcross males. Annals of the Entomological Society of America 74: 493-497.

LASTER, M.L. 1972. Interspecific hybridization of *Heliothis virescens* and *H. subllexa.* Environmental Entomology 1:682-687.

LASTER, M.L., MARTIN, D.F., and PARVIN, D.W., Jr. 1976. Potential for suppressing tobacco budworm (Lepidoptera: Noctuidae) by genetic sterilization. Mississippi Agricultural and Forestry Experiment Station technical bulletin 82, Jackson, Miss.. USA. 9 pp.

LASTER, M.L., MARTIN, D.F., and PAIR, S.D. 1977. Mating incidence of male *Heliothis virescens,* hybrid and backcross males from *H. subllexa* x *H. virescens* crosses. Annals of the Entomological Society of America 70: 293-295.

LASTER, M.L., MARTIN, D.F., and PAIR, S.D. 1978a. The attraction of wild *Heliothis virescens* males to sex pheromone traps baited with *H. virescens* and backcross females. Environmental Entomology 7: 19-20.

LASTER, M.L., MARTIN, D.F., PAIR, S.D., and FURR, R.E. 1978b. Infusion of hybrid *Heliothis* male sterility into

H. virescens populations in field cages. Environmental Entomology 7: 364-366.

LINGREN, P.D., RAULSTON, J.R., SPARKS, A.N., and PROSHOLD, F.I. 1978. Tobacco budworm: nocturnal behavior of laboratory-reared irradiated adults and native adults in small diverse cropping systems. U.S. Department of Agriculture ARS-W-1 Series, Washington DC, USA.

MAKELA, M.E., and HUETTEL, M.D. 1978. Model for genetic control of *Heliothis virescens.* Theoretical and Applied Genetics 54: 225-233.

MARTIN, D.F., PROSHOLD, F.I., and LASTER, M.L. 1981. a. Status of hybrid *Heliothis* pilot test. Pages 150-151 *in* Proceedings, Beltwide Cotton Production Research Conference (1981), 5-6 Jan 1981, New Orleans, La., USA.

MARTIN, D.F., LASTER, M.L., and PAIR, S.D. 1981b. Backcross progeny from interspecific hybrids of *Heliothis subflexa* x *H. virescens:* physiological diapause, winter survival and infusion into natural *H. virescens* populations. Environmental Entomology 10: 197-200.

MISKIMEN, G.W., and BOND, R.M. 1972. The insect fauna of St. Croix, United States Virgin Islands. New York Academy of Science Scientific Survey of Puerto Rico and the Virgin Islands, XIII. 114 pp.

PAIR, S.D., LASTER, M.L., and MARTIN, D.F. 1977a. Hybrid sterility: mating dynamics of backcross progeny from crosses of *Heliothis subtlexa* and *H. virescens.* Annals of the Entomological Society of America 70: 665-668.

PAIR, S.D., LASTER, M.L., and MARTIN, D.F. 1977b. Hybrid sterility of the tobacco budworm: effects of alternate sterile and normal matings on fecundity and fertility. Annals of the Entomological Society of America 70: 952-954.

PROSHOLD, F.I., and LaCHANCE, L.E. 1974. Analysis of sterility from interspecific crosses between *Heliothis virescens* and *H. subflexa.* Annals of the Entomological Society of America 67: 445-449.

PROSHOLD, F.I., LaCHANCE, L.E., and RICHARD, R.D. 1975. Sperm production and transfer by *Heliothis virescens, H. subflexa,* and the sterile hybrid males. Annals of the Entomological Society of America 68: 31 - 34.

PROSHOLD, F.I., KARPENKO, C.P., and GRAHAM, C. 1982. Egg production and oviposition in the tobacco budworm: effect of age at mating. Annals of the Entomological Society of America (in press).

RAULSTON, J.R., and LINGREN, P.D. 1972. Methods for large-scale rearing of the tobacco budworm. U.S. Department of Agriculture production research report 145, Washington DC, USA. 10 pp.

RAULSTON, J.R., GRAHAM, H.M., LINGREN, P.D., and SNOW, J.W. 1976a. Mating interaction of native and laboratory-reared tobacco budworms released in the field. Environmental Entomology 5:195-198.

RAULSTON, J.R., SNOW, J.W., and GRAHAM, H.M. 1976b. Large-scale shipping techniques for tobacco budworm pupae. U.S. Department of Agriculture production research report 166, Washington DC, USA. 6 pp.

RAULSTON, J.R., LINGREN, P.D., SPARKS, A.N., and MARTIN, D.F. 1979. Mating interaction between native tobacco budworms and released backcross adults. Environmental Entomology 8: 349-353.

RICHARD, R.D., LaCHANCE, L.E., and PROSHOLD, F.I. 1975. An ultrastructural study of sperm in sterile-hybrids from crosses of *Heliothis virescens* and *H. subflexa.* Annals of the Entomological Society of America 68: 35-39.

SNOW, J.W., CANTELO, W.W., BAUMHOVER, A.H., GOODENOUGH, J.L., GRAHAM, H.M., and RAULSTON, J.R. 1974. The tobacco budworm on St. Croix, U.S. Virgin Islands: Host plants, population survey and estimates. Florida Entomologist 57: 297-301.

SOKAL, R.F., and ROHLF, F.J. 1969. Biometry. San Francisco, USA: W.H. Freeman.

STADELBACHER, E.A., and MARTIN, D.F. 1981. Fall diapause and spring emergence of *Heliothis virescens, H. subflexa,* and backcrosses of their hybrid. Environmental Entomology 10: 139-142.

Discussion — Session 6

During the discussion on the use of pheromones, it was emphasized that although catches in pheromone traps may not be directly useful in estimating the size of populations in surrounding areas, they may be of use in indicating the timing of moth buildup. They are being used in Hartstack's model and give a warning of buildup 3 or 4 days in advance of light traps.

In a discussion of why pheromone-trap catches do not appear to reflect the size of populations, Sparks explained that the males differ in their response to the traps according to the abundance of virgin females in the area. Thus, a-catch of 25 males in a trap could represent either a very large population in which most females are virgin, or a very small population within which most of the females have been mated. However, it was generally agreed that pheromones would be useful when more is known of the behavior of the moths in differing circumstances. It was considered unlikely that the *Heliothis* pheromones could be usefully exploited in mass trapping as part of a management program.

Dr. Rothschild considered that two or three pheromone traps would be sufficient for monitoring *Heliothis* moths over 1 ha and that a lower density of traps might be sufficient in larger areas. In Australia, pheromone septa have remained attractive for about 14 days, but at ICRISAT Center the septa have proved to be effective for more than 28 days. The cost of the *Heliothis* pheromones in the USA are from $3 to $9/g.

In discussions of trap designs, it was noted that in the most efficient traps in the USA, the moths move upwards into the trap, but in those developed elsewhere, moths fall down a funnel into the trap. It was not considered that this was likely to indicate a behavioral pattern difference between *H. zea* and *H. armigera,* but that there was a need to test the range of trap designs at each location. As with light traps, there are many factors, including climatic ones, that influence catches in pheromone traps.

Session 7

Integration of Management

Chairman: K.S. Kushwaha
Cochairman: K. Leuschner

Rapporteurs: A.B. Mohammed
S.L. Taneja

Past and Future *Heliothis* Management in Australia

A.G.L. Wilson*

Abstract

Heliothis punctigera and H. armigera are serious pests of cash crops in Australia, particularly cotton, oilseeds, horticultural crops, and coarse grains. H. punctigera additionally occurs on pasture legumes and weeds. There is increasing evidence of migratory behavior of H. punctigera, which tends to move from vegetation of low or zero economic value to crops of high economic value, thus complicating areawide control measures. H. armigera appears somewhat more sedentary, but also shows the same crop-succession tendencies.

Heliothis management still relies predominantly on use of insecticides. With cotton, where cost of control is heaviest, economic and biological injury thresholds have been developed and are used in conjunction with regular crop scouting to minimize spray frequency. The various processes have been integrated in a computerized decision-making program, SIRATAC, to optimize spray timing. The same sequence of developments may be applied to other crops in future.

Some progress has been made towards a biologically orientated pest-management approach, including use of resistant varieties, parasites, predators, pathogens, and selective insecticides. Used singly, none of these components is very effective, and in no crop have enough components been assembled to give a commercially viable management program particularly because sudden upsurges of Heliothis can only be combated successfully with "hard" insecticides. However, some of the biological control components are compatible with insecticidal control and are being incorporated into management systems based on it.

Résumé

*Le passé et l'avenir de la lutte contre l'*Heliothis *en Australie:* Heliothis punctigera *et* H. armigera *sont des ravageurs redoutables des cultures commerciales en Australie, surtout le coton, les cultures oléagineuses et horticoles, ainsi que les mils. En outre,* H. punctigera *se retrouve chez les légumineuses des pâturages et les mauvaises herbes. Le comportement migratoire d'*H. punctigera *est de plus en plus évident. Cet insecte tend à se déplacer d'une végétation de faible ou sans importance économique vers des cultures de grande valeur; ce qui complique les mesures de lutte sur une vaste superficie.* H. armigera *semble relativement plus sédentaire, mais présente les mêmes tendances de succession culturale.*

*La lutte contre l'*Heliothis *repose encore surtout sur les insecticides. Dans le cas du coton, où la lutte est la plus chère, des seuils de nuisibilité économique et biologique ont été établis et ils sont utilisés en association avec une surveillance régulière des cultures, afin de réduire au minimum la fréquence des pulvérisations. Les divers procédés ont été intégrés dans un programme informatique décisionnel, SIRATAC, afin d'optimiser le temps des pulvérisations. Dans l'avenir, l'on pourra appliquer la même séquence de développement à d'autres cultures.*

*Il y a eu un certain progrès dans la lutte biologique, incluant des variétés résistantes, parasites, prédateurs, agents pathogènes et insecticides sélectifs. Utilisée seule, aucune de ces composantes n'est très efficace et il n'a jamais été possible de réunir assez de composantes chez une culture pour établir un programme de lutte viable au niveau commercial. Un problème particulier est dû à une pullulation soudaine d'*Heliothis *qui ne peut être combattue efficacement que par des insecticides ''violents''. Cependant, certaines composantes de la lutte biologique sont compatibles avec la lutte insecticide et elles sont introduites dans des systèmes basés sur cette dernière.*

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International Crops Research Institute for the Semi-Arid Tropics. 1982. Proceedings of the International Workshop on *Heliothis* Management, 15-20 November 1961, Patancheru, A.P., India

To give a background for subsequent discussion of *Heliothis* management a summary is first presented of the host range, economic status, biology, and control of *Heliothis* spp in Australia.

Species and Their Distribution

Two *Heliothis* species are of economic importance in Australia: *Heliothis punctigera* Wallengren, the native budworm, and *H. armigera* (Hubner), the cotton bollworm, or corn earworm. *H. assulta* Guenee and *H. rubrescens* (Walker) also occur, but have not so far been recognized as pests (Common 1953). *H. punctigera* occurs only in Australia, where it is recorded in all states. *H. armigera,* an economic pest in many countries, is usually less abundant. It is not reported from Tasmania or South Australia and is of only minor importance in Victoria.

The period of activity and relative abundance of the two species are illustrated by graphs of light-trap catches at three locations (Fig. 1). *H. punctigera* alone is active between September and April (i.e. spring to autumn) near Adelaide, South Australia. Both species are represented at Narrabri, central northern New South Wales, but *H. punctigera* is usually the most abundant. Both species are represented all year round in the Ord Irrigation Area, northwestern Australia, but *H. armigera* was the dominant species after grain sorghum production commenced in 1969.

Pest Status

Both species attack a wide range of economically important plants. *H. armigera* tends to favor graminaceous crops, while *H. punctigera* tends to favor broad-leaved crops and weeds. However, both species attack cotton, *H. punctigera* predominating early and mid-season, while *H. armigera* may be important towards maturity (Wilson and Greenup 1977).

The major crops affected by *Heliothis* spp are shown in Table 1. To obtain an estimate of economic losses caused by *Heliothis* spp in Australia, the Queensland survey of Alcock and Twine (1980) has been expanded by consultation with entomologists in other states. Records of crop area and production during 1979-80 were obtained from the Australian Bureau of Statistics.

In terms of cost of insecticidal control, cotton, tobacco, tomato, sorghum, field peas, and sunflower are the most important crops infested. Cotton accounted for 46% of the estimated total cost of *Heliothis* control in Australia of $23.5 million. In addition to the costs of control, damage caused to unprotected crops and residual damage where protection is incomplete may approximately double the cost of *Heliothis* infestation. Besides the crops listed, fodder lucerne (alfalfa) and fruit trees may also be infested by *H. punctigera* in outbreak years at levels requiring control measures, while spraying may also be carried out on intensive horticultural crops, the area of which is small.

Secondary pest outbreaks may occur as a result of control measures for *Heliothis.* Thus severe

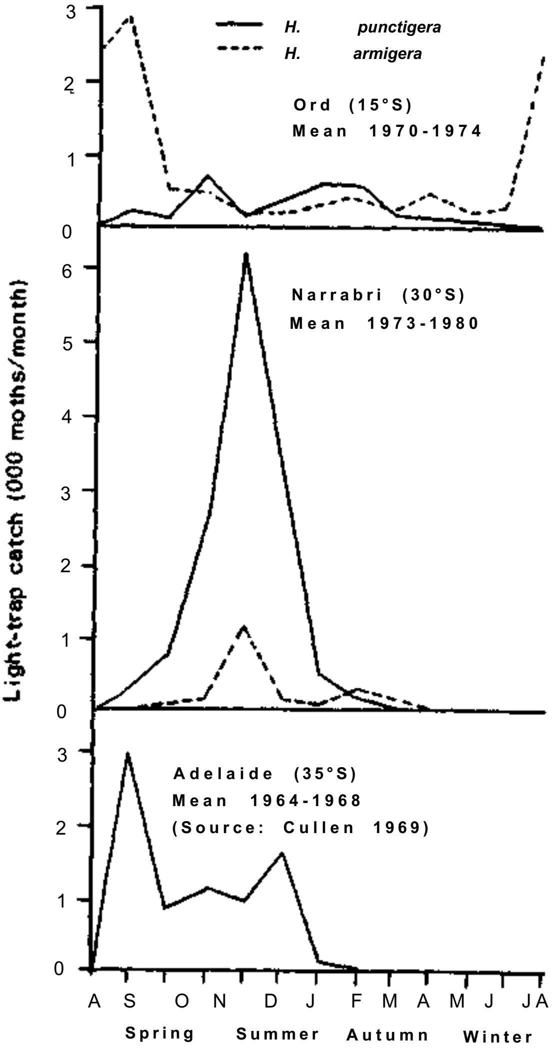

Figure 1. Mean monthly catch of H. punctigera *and* H. armigera *at three sites in Australia.*

Table 1. Statistics of crops Infested by Heliothis spp in Australia with injury thresholds, insecticide application*, and control costs.

Crop	*Heliothis* species[a]	Area grown (000 ha)	Gross Value/ha ($ A)	Larval damage threshold/ m^2	Plant	Average no. of sprays	Cost/ha of one application modal spray[c] ($ A)	Cost/ha (% of gross value)	Average cost/ha <$ A)	All-Australia cost of control ($ A million)
Tobacco	a& p	7.5	6346	0.05	0.03	7.50	23-20 (2&3)	0.4	174.00	1.3
Tomato	a& p	8.4	4507	p[b]		12.50	14.30 (1)	0.3	177.50	1.5
Cotton	a & p	75.0	1700	1-4		9.50	15.20 (1 &3)	0.9	144.00	10.8
Green bean	a& p	7.2	1068	0.3		2.25	23.20 (2)	2.2	52.20	0.4
Sweet corn	a	2.8	674	P		6.10	23.20 (2)	3.4	141.50	0.4
Lucerne seed	P	11.0	485	P		2.00	14.30 (1)	2.9	28.60	0.3
Soybean	a & p	56.0	320	0.5		1.25	14.30 (1)	4.5	17.90	1.0
Sorghum	a	518.0	200	15-30	1.0	0.25	23.20 (2)	11.6	5-80	3.0
Field pea	P	53.0	190	P		2.50	14.30 (1)	7.5	35-50	1.8
Linseed	P	17.0	190	15-20		0.50	14.30 (1)	7.5	7.20	0.1
Safflower	a & p	53.7	142	5		1.00	14.30 (1)	10.0	14.30	0.8
Rapeseed	a & p	41.6	141	15-20	0.5	0.25	14.30 (1)	10.0	3.60	0.1
Sunflower	a & p	221.0	130	15-20	2.0	0.50	14.30 (1)	11.0	7.10	1.6
Field lupine	P	105.0	130	15-20	0.5	0.25	14.30 (1)	11.0	3.60	0.4

a. a = *H. armigera;* p = *H. punctigera*

b. Protective spray

c. Modal sprays: (1) endosulfan, 735 g ai/ha; (2) methomyl, 452 g ai/ha; (3) fenvalerate, 90 g ai/ha.

tetranychid mite and aphid infestations are reported from cotton and seed lucerne following application of DDT or pyrethroids for *Heliothis* control.

Pest Biology

H. punctigera is an opportunist pest, with a high rate of reproduction under favorable conditions and strong migratory tendencies. Endemic populations are present in the higher rainfall areas of the continent, but outbreaks occur at irregular intervals (Common 1953). Then heavy spring populations are thought to develop on the western plains of New South Wales and Queensland and extend to the eastern seaboard and beyond, causing severe infestations of cultivated crops.

An example of such a migration occurred in November 1973, following the outbreak season of 1972-73. Flights of *H. punctigera* and other known migrants *Agrotis infusa* (Boisduval) and *Plusia (Chrysodeixis) argentifera* (Guenee) reached New Zealand, 2000 km to the southeast (Fox 1975). A similar eastward migration occurred in the 1980-81 season, but infestations were limited by drought in cultivated areas.

In contrast, *H. armigera* appears to be a somewhat more sedentary pest in Australia, mainly associated wth crop hosts, particularly sorghum, maize, and cotton. However, movement of moths between crops is thought to occur within regions.

Overwintering

Pupae of *H. armigera* enter a facultative diapause during the winter months, moths emerging in October-November (Wilson et al. 1979).

The proportion of pupae entering diapause is higher in the cooler (southerly) than in warmer (northerly) parts of the continent. Although both species show a similar response to temperature in terminating diapause, moths of *H. punctigera* appear about 4 weeks earlier than those of *H. armigera* in the spring in southern Australia.

The early emergence permits the former species to exploit the spring flush of growth on pastures and oilseed crops better than *H. armigera.* It may be explained either by successful establishment of a small nondiapausing segment of the population, which emerges from late winter onwards, or by migration from elsewhere.

Host-Plant Succession

During the warmer months, both species exist on a succession of hosts. In the Namoi Valley the sequence of major host plants, supporting successive generations, appeared to be:

H. armigera—wheat; preflowering cotton and sorghum; flowering cotton, sorghum, and sunflower;

H. punctigera—field lupines, rapeseed, medics; weeds and preflowering cotton; flowering cotton, sunflower, soybean, and lucerne (Wardhaugh et al. 1980; Wilson unpublished).

In the Namoi Valley, as indicated by the light-trap catches (Fig.1), populations of *H. punctigera* decline more rapidly in the autumn than those of *H. armigera,* which is thus generally more abundant in autumn. Near Adelaide, *H. punctigera* infests field peas and lucerne from early spring to summer. In the Ord Irrigation Area summer, wet-season, infestations of both species occurred on cotton. *H. armigera* alone infested the dry-season crops of wheat and sorghum, giving rise to heavy moth abundance in August-September, when these crops matured (Fig.1).

Mortality Associated with *Heliothis* spp

Natural Mortality

Parasites, predators, pathogens, and physical factors have been associated with mortality of *Heliothis* life stages in Australia. The various findings are summarized below:

Parasites

Eggs. Generally, egg parasitism by Trichogrammatidae appears higher in the north of the continent, with levels of up to 90% being reported on sorghum in the Ord Irrigation Area (Michael 1973). Lower levels are reported in southern Queensland, where the Scelionid *Telenomius* sp is more important (Twine 1981). Egg parasitism is virtually nonexistent in northern New South Wales. Paradoxically, effective parasitism of *Heliothis* on tomatoes by *Trichogramma ivelae* Pang & Chen is reported from central Victoria (McLaren 1981).

Larvae. The Braconid *Microplitis* sp is the most important parasite emerging from larvae. It is reported from all states except Victoria and Tasmania. Parasitism levels of 31 % of third- to fifth-instar larvae are reported from tobacco (Titmarsh 1981).

Several Tachinid parasites of larvae have also been identified, but their incidence is usually less than 5%; of these, *Chaetophthalmus* sp appeared the most widespread.

Pupae. Of Ichneumonidae and Tachinidae reared from pupae or prepupae, *Heteropelma scaposum* (Morley) and *Carcelia noctuae* Curran were respectively the most common. An average of 18% parasitism of overwintering pupae and prepupae was recorded in a 6-year study in the Namoi Valley, New South Wales (Wilson unpublished), while 8 to 18% were found to be parasitized during the summer in sunflower (Forrester and Kay 1981). Both species were found to overwinter within the host and emerge in the spring. The nematode *Heterorhabditis bacteriphora* has been identified from *Heliothis* pupae in south Australia.

Predators

Room (1979a) obtained evidence that 19 species of insect and five species of spider could feed on *Heliothis* spp in cotton in New South Wales.

Similar lists of predators have been produced in Queensland. When ranked according to frequency of occurrence, *Nabis capsiformis* was by far the most common in all localities in cotton crops. It is of interest that the Anthocorid, *Orius* sp, did not occur in cotton, although common on sunflower, where it was the second most common predator after *Campylomma livida.*

In spite of the range ot natural enemies present in unsprayed cotton, yields were 50 to 90% below those in otherwise comparable sprayed cotton in New South Wales. Damage was primarily due to the *Heliothis* spp, but in addition, *Earias huegeli, Anomis flava,* and *Thrips imaginis* contributed to losses (Wilson and Greenup 1977).

Natural enemies appear more effective in sunflower crops where, particularly with early crops sown in spring, heavy oviposition at flowering has been noted to produce few larvae. The predatory bugs *Campylomma livida* and *Orius* sp *are* thought to be responsible for heavy predation (Forrester 1981).

Little information is available on the effects of natural enemies on *Heliothis* in other crops.

Pathogens

Five diseases of the *Heliothis* larva have been reported from Queensland (Teakle 1977). The nuclear polyhedrosis virus disease is the most destructive; outbreaks have been recorded in lucerne, peanut, sorghum, and unsprayed cotton, where larval infestation levels were high. Outbreaks appear to be most common in moist, cloudy weather. A granulosis virus disease is also reported, but is less infective.

Two fungus diseases, *Nomuraea rileyi* and *Beauveria bassiana* also require moist conditions to be infective.

The protozoan disease *Nosema heliothidis* is debilitative to *Heliothis* larvae and may also cause mortality.

Physical Mortality

Heavy physical mortality of eggs and small larvae has been recorded in tobacco and cotton. Only 5 to 10% of eggs laid survived to produce second-instar larvae in studies conducted on tobacco in Queensland (Titmarsh 1981). Desiccation of eggs and their dislodgment by wind *or rain were* the major causes of egg loss, while small larvae disappeared without trace or were found desiccated. In cotton, less than 10% of eggs counted produced established larvae in seedling and early flowering stage of development, but the percentage rose to over 50% in later stages of crop development, when the crop canopy had closed between the rows (Wilson 1981a, 1981b).

Chemical Control

Between the 1950s and the early 1970s, control of *Heliothis* infestations was largely by DDT. Endosulfan or other alternatives were used where conservation of bees was a consideration or where use of DDT against *Heliothis* caused upsurges of secondary pests such as mites or aphids.

Insecticide resistance was first suspected in *H. armigera* in the Ord Irrigation Area in 1970 and confirmed in 1972 (Wilson 1974). In laboratory topical application tests, *H. armigera* showed a 90-fold resistance to DDT, a five-fold resistance to DDT-toxaphene and endosulfan, and a three-fold resistance to methyl parathion. No resistance was detected with DDT and endosulfan in *H. punctig-*

era, although the LD50 values obtained were somewhat higher than those obtained subsequently in New South Wales.

Resistance to DDT-toxaphene, which became the standard insecticide, increased until in 1974, 50 sprays were applied in a season, at a cost of $175/ha, without adequate control. In the absence of economically priced alternative insecticides and with other increases in production costs, cotton-growing in the Ord was abandoned in 1975.

In the Namoi Valley, over 200-fold resistance of *H. armigera* to DDT developed in 1973, and 15-fold resistance was also shown to DDT-toxaphene, compared with a susceptible strain (Table 2) (Goodyer et al. 1975). However, DDT-toxaphene continued to be effective, and in spile of its continued use, the resistance level actually fell to three-fold by 1980, when DDT was withdrawn in favor of newer, environmentally safer, insecticides. The fall in resistance level suggests dilution of resistance genes by moths produced in unsprayed crops. The most likely source of such moths was crops of sorghum and maize, which were not regularly sprayed, grown to the north and south of the heavily sprayed cotton-growing area. The synthetic pyrethroids, methomyl, and endosulfan are currently the most commonly used chemicals for *Heliothis* control in Australia.

Future Management of *Heliothis* in Australia

Reduced Pesticide Usage

Active management of *Heliothis* spp in Australia has, until now, been based largely on chemical control. However, there is potential for other elements of management (Table 3). Passive management, involving the withholding of sprays when insect abundance is low, or when natural control factors are effective, is recognized as a first step to reducing insecticide use. There is, however, still a tendency to apply routine protective sprays against *Heliothis* to medium-value crops at a stage of development when past experience has shown damage can occur. Farmers may alternatively spray at the first sign of infestation. Such measures are taken partly because of lack of information on the damaging potential of pest populations, and partly because of difficulty in controlling infestations once established in the crop canopy.

Damage Thresholds

These considerations indicate the need for improved information on the damaging ability of *Heliothis* in various crops. Such information is a prerequisite to development of integrated pest-management programs.

A simple approach to determination of economic injury thresholds involves the calculation of the marginal value of sprays in terms of crop loss. Thus, in crops of low gross value per hectare, such *as sunflower and other oilseed crops listed in Table* 1, a 10% or 11 % loss may be sustained before the cost of a spray application equals the value of the yield loss. With the more valuable crops, a loss of less than 1 % crop value may justify spraying. As Table 1 shows, this approach is either consciously or unconsciously applied in determining the average spray frequency in farming practice.

Table 2. Resistance levels of *H. armigera* to Insecticides (LD_{50} expressed as µg Insecticide *per* larval weight 35 mg).

Insecticides	Unsprayed	Ord 1972	Wee Waa 1973	Wee Waa 1980
DDT Toxaphene	0.73	10.6	11.5	4.5
DDT	0.35	80.7	>100.0	0.9
Endosulfan	0.60	3.2	6.0	0.6
Fenvalerate	0.04			0.04
Methyl Parathion	0.066	0.6	0.35	0.2

Source: 1980 data from New South Wales Department of Agriculture, Resistance Testing Section, Tamworth, Australia.

Table 3. Status of four potential[a] pest-management components on various crops In New South Wales (NSW) and Queensland QD, Australia.

	Insecticides		Host-plant resistance		Pathogens		Natural enemies	
Crop	NSW	QD	NSW	QD	NSW	QD	NSW	QD
Cotton	H	H	M	M	M	M	L	H
Sorghum	M	M	M	M	H	H	M	H
Tobacco	H	H	H	H	L	L	M	M
Tomato	H	H	L	L	L	L	L	L
Navybean. soybean	H	H	M M			H	M	M
Sunflower	M	M	L	L	M		H	H

a. H = high potential; M = moderate potential; L = low potential

Biological Injury Thresholds

Only in some of the more valuable crops have detailed experiments been done to establish injury thresholds under a range of infestation levels and stages of crop development. A tobacco pest prediction service has been developed in Queensland. Unsprayed plots are monitored for eggs and larvae, and advice given to farmers on the timing of sprays if larval survival occurs (Titmarsh 1981).

Both the biological and economic injury thresholds of larval abundance in grain sorghum have been determined in Queensland (Twine, these Proceedings).

Heliothis damage to cotton in Australia may occur at any time from cotyledon development to boll maturity, and it is difficult to assess the effect of any one infestation on final yield. In addition, the high costs of production and high potential returns make this crop very sensitive to economic loss.

Experiments were carried out in the Namoi Valley in which protection was omitted or varied in one of three stages of crop development. It was found that egg survival was lower while the tolerable larval infestation was higher to flowering. A treatment threshold (action level) of four eggs or two small larvae/m^2 was indicated at that development stage, while the threshold is subsequently reduced to one larva/m^2. Protection is not normally required before square production commences or after it ceases (Wilson 1981b).

Because of the relatively short growing season and unpredictable climatic conditions, the ability of cotton to compensate for losses cannot be exploited to an appreciable extent in the main production regions of southern Queensland and northern New South Wales (Wilson and Greenup 1977). Although compensation as a technique for minimizing spray application worked successfully in the tropical Ord Irrigation Area for a few years (Wilson et al. 1972), it became impossible to regain control following the development of resistance, while natural enemies alone did not sufficiently suppress infestations.

Crop Scouting

Improved crop scouting has in itself led to a substantial reduction in spray application. Initially carried out by farmers or chemical company representatives, the task of scouting cotton has recently been largely taken over by private consultants working on a contract basis.

This has led to improved, impartial decisions on when to spray. Although consultants charge about $20/ha per season for this service, this is easily offset by the saving of the cost of one or two sprays. With better knowledge of the damaging potential of pests, improved crop scouting, and more effective pesticides, the number of insecticide applications has fallen from 16 to 20 in 1972-73 to 8 to 11 in the 1980-81 season.

SIRATAC—Computerized Decision-Making Program

To integrate the various factors involved in minimizing pesticide applications, a computerized decision-making "package" has *been* developed by CSIRO and the New South Wales Department of Agriculture (Peacock 1980; Room and Hearn

1979). The essential components of the system are:

1. Standardized crop-sampling procedures, in which presence or absence of *Heliothis* eggs, larvae, other pests, and natural enemies are observed on 30 plants/40 ha at 3-day intervals and the observations marked on cards for computer processing.

2. Weekly counts of squares, flowers, and bolls.

3. Computer processing of the data to estimate infestation level/m^2 on that day and on the 2 following days, taking into account temperature and estimated egg and larval survival.

4. Comparison of crop development with a crop trajectory, to see whether crop development is behind or ahead of target.

5. Determination of the dominant species, *H. punctigera* or *H. armigera,* by pheromone or light-trap catches.

6. Assessment of whether the larval population is above the action level for a given phase of crop production.

7. Advice to farmer or his consultant (Table 4 and 5) on whether a spray is required.

8. Advice on sprays to be used, on a scale from "soft" (i.e. endosulfan, *Bacillus thuringiensis*-chlordimeform mixture) to "hard" insecticides (i.e. pyrethroids or organophosphates), taking into account the species represented.

The SIRATAC service has been well received by the cotton-growing community. At present it is operated from terminals connected by telephone to the central computer; however, a simplified program may be developed for cassette operation on minicomputers in the field. The program is being extended to give advice on irrigation timing, and may later cover other facets of cotton growing.

Insecticidal Control Integrated with Other Forms of Control

A second step towards minimizing insecticide application is the development of other forms of control compatible with a predominantly insecticidal approach.

Resistant Varieties

In the past 20 years, Australian plant breeders have increased efforts to identify heritable traits for resistance to *Heliothis* and other pests and to incorporate these into commercial cultivars. A problem has been the lower yields or quality often associated with resistant traits, in comparison with commercial cultivars.

Physiological, morphological, and chemical characters are being incorporated and selected. For example, in

Cotton: earliness; ability to compensate for losses; glabrous, okra leaf, frego bract, and nectariless characters; high terpenoid and tannin content (Thomson and Lee 1980).

Soybean and navy bean: antibiotic chemical characters (Rogers 1980).

Sorghum: increased grain size and ability to compensate for grain losses (Wilson 1975).

Of the various traits being investigated in cotton, combination of glabrous leaf and frego bract in a Deltapine background is farthest advanced, and lines have now been released commercially (N.J. Thomson, personal communication).

Pathogenic Microorganisms

Two commercially marketed pathogens have become available in Australia: *Bacillus thuringiensis* and the nuclear polyhedrosis virus.

B. thuringiensis has been available for 20 years, but although strains and formulations have improved over that time, it has not proved sufficiently effective to be used alone for *Heliothis* control. However, the mixture with chlordimeform has been used to a limited extent for several years and has given effective control of *Heliothis* early in the season. An advantage is the delayed buildup of tetranychid mite infestations, which tend to be heavier if broad-spectrum pesticides are used early in the season (Wilson 1981a).

The nuclear polyhedrosis virus in the commercial formulation Elcar has been assessed experimentally in cotton, sorghum, beans, and maize. Acceptable control of *Heliothis* larvae has been

Table 4. Specimen farmer output from SIRATAC computer program—crop development.

```
***********************************************************************
**** WONDERCOTT COTTON FARMS INC. ****     - REPORT FOR 03-FEB-81
***********************************************************************

SQUARES & BOLLS COUNTED, CROP DEVELOPMENT AND PROSPECTS ON 3 FEBRUARY
**********************************************************************

FRUIT PRODUCTION PLAN (YIELD DEVELOPMENT THRESHOLD)
****************************************************
                                       EFFECTIVE FLOWERS
                                         PLANNED     ACTUAL/LIKELY
TARGET YIELD     5.0 BALES/HA  FIRST   1 JANUARY   17 DECEMBER
TARGET BOLLS    80.0 PER SQ M  LAST    7 MARCH      4 MARCH
LAST EFFECTIVE FLOWER PLANNED LATER THAN LIKELY

PLANT POPULATION DENSITY 15.0 PER SQ M


NUMBERS OF FRUIT (PER METRE)
*****************************
                               LIKELY TO CONTRIBUTE TO HARVEST
                    COUNTED       WITHOUT       PLANNED
                                  DAMAGE         (YOT)

SQUARES              66.7          2.9            37.5
GREEN BOLLS         169.7         91.0            35.9
BOLLS BY 7 MARCH     94.8         94.4            80.1


TIMING OF YIELD DEVELOPMENT
****************************
SEASON (DAY DEGREES)        13 DAYS EARLY
BOLLS EXPECTED TO SURVIVE ARE LIKELY TO REACH TARGET 32 DAYS EARLY

CROP OPENING      0% AT LAST COUNT
                 60% ON 16 MARCH
                 80% ON  8 APRIL


YIELD POTENTIAL  (BALES/HA)
****************************

                          WITHOUT    WITH
                          DAMAGE    DAMAGE
FRUIT NOW ON PLANT         5.86      5.81
WITH PREDICTED SQUARES     5.90      5.87
```

Table 5. Specimen farmer output from SIRATAC computer program—pest data and pest management advice.

```
PEST STATUS
***********


                MEANS FOR WHOLE FIELD; DENSITIES IN NUMBERS PER SQ METRE
                EXCEPT FOR MITES, APHIDS 6 HONEYDEW, WHICH ARE PROPORTION
                OF PLANTS OR TERMINALS INFESTED, AND THRIPS,  WHICH ARE
                MEAN NUMBER PER PLANT.
                *******************************************************

                              HELIOTHIS     DENSITY      TODAYS    ? ABOVE
                                                      THRESHOLD  THRESHOLD

                              WHITE EGGS      9.71
                              BROWN EGGS      4.45        20.0
                              VS+S  LARVAE    3.46         2.0       YES
                              M+L   LARVE     0.00         1.0
                              TOT.  LARVAE    3.46         2.0       YES
                TOMORROWS  :  VS+S  LARVAE    4.16
                              M+L   LARVAE    0.68         1.0
                             TOTAL  LARVAE    4.83         2.0       YES
                NEXT DAYS  :  VS+S  LARVAE    3.92
                              M+L   LARVAE    1.73         1.0       YES
                             TOTAL  LARVAE    5.65         2.0       YES
                TOMORROWS  :  BROWN EGGS      9.25        20.0-
                NEXT DAYS  :  BROWN EGGS      5.83        20.0

                     OTHER PESTS            DENSITY      TODAYS    ? ABOVE
                                                      THRESHOLD  THRESHOLD

                     APHIDS                   0.00         0.9
                     MITES                    0.00         0.6
                     ROUGH BOLLWORM           0.00         3.0
                     LOOPERS                  0.00        20.0
                     GREEN VEGETABLE BUG      0.00         2.0

                     POOLED PREDATORS         0.00

HELIOTHIS AGE BREAKDOWN -       VS        S        M        L
                                2.08     1.38     0.00     0.00

PEST MANAGEMENT OPTIONS
***********************

CHOOSE ONE OF THE FOLLOWING LINES AS YOUR PEST MANAGEMENT OPTION !
OPTIONS PRECEDED BY AN "A" ARE PREFERABLE TO THOSE PRECEDED BY A "B"

TIMING OF THE SPRAY SHOULD BE BASED ON THE NATURE OF THE CHEMICAL
AND THE HeliOthiS NUMBERS THROUGH TIME IN THE ABOVE TABLE

   A   ENDOSULFAN
   B   DIPEL/CHLORDIMEFORM

IF "B" OPTION CHOSEN SPRAY WITHIN 24 HOURS
```

obtained under cloudy, humid conditions on sorghum and beans in Queensland. On cotton, although substantial mortality has been obtained in a few instances, most results have been disappointing. Further research to improve the persistence of the material on cotton and other crops is in progress.

Integrated Pest Management

A workshop on the biological control of *Heliothis* spp in Australia was held by the Queensland Department of Primary Industries in 1980 (QDPI 1981). While there was general agreement on the desirability of an integrated pest-management approach involving resistant varieties, native and introduced beneficial insects, and selective insecticides, including pathogens, it was clear that progress towards this objective has been slow. Some of the problems that have arisen are:

1. No single component of such a pest-management program is normally highly effective on its own, and it has not been possible to assemble enough components to achieve commercially acceptable control and yield in any one crop.

2. The higher value crops are often extremely sensitive to damage or the value of damage may be exaggerated by "cosmetic" effects, for example minor damage to sweet corn or tomatoes may render these crops unsalable.

3. The sudden upsurges of *Heliothis* spp arising from migration into crops from elsewhere tend to overwhelm the available natural control factors.

Areawide Control

Field observations suggest that inter- and intra-seasonal populations of *H. armigera* are partially confined to crop hosts within the Namoi Valley. This is supported by the higher level of DDT resistance originally detected within cropping areas than outside. However, the subsequent decline in resistance levels suggests that some movement into the area does occur.

The possibility that pest carryover from one season to the next could be minimized by thorough cultivation of crop residues during the winter has been discussed (Wilson unpublished). Such cultivation would destroy a high proportion of overwintering pupae. It appears possible that this action would be effective, but might require legal enforcement; the present minor status of the pest does not warrant such action. This approach may, however, have been a merit in the tropical Ord Irrigation Area, where *H. armigera* was a minor pest until irrigated crops, particularly sorghum, bridged the previously inhospitable dry-season period of May to September (Fig.1). Then a crop-free period and cultivation of crop residues may have reduced the incidence of the pest during the wet season, when cotton was grown (Wilson et al. 1972).

During the summer months in New South Wales, *Heliothis* spp show a sequence of infestation from extensive crops and pastures where the damage threshold is either very high or nonexistent, to intensive crops where the damage threshold is low (Table 1). At present it appears economically impracticable to minimize *Heliothis* in the extensive crops, other than possibly by enhancement of biological control agents.

References

ALCOCK, B., and TWINE, P.H. 1981. The cost *of Heliothis* in Queensland crops. Pages 1 -10 *in* QDPI 1981.

COMMON, I.F.B. 1953. The Australian species of *Heliothis* (Lepidoptera: Noctuidae) and their pest status. Australian Journal of Zoology: 319-344.

CULLEN, J.M. 1969. The reproduction and survival of *Heliothis punctigera* Wallengren in South Australia. Ph.D. thesis, Waite Agricultural Research Institute, University of Adelaide, NSW, Australia.

FORRESTER, N.W. 1981. Biological control agents of *Heliothis* spp. in sunflowers. Pages 49-53 *in* QDPI 1981.

FOX, K.J. 1975. Migrant Lepidoptera in New Zealand. New Zealand Entomology 6: 66-69.

GOODYER, G.J., WILSON, A.G.L., ATTIA, F.I., and CLIFT, A.D. 1975. Insecticide resistance in *Heliothis armigera* (Hubner) (Lepidoptera: Noctuidae) in the Namoi Valley of New South Wales, Australia. Journal of the Australian Entomological Society 14:171 -173.

HEARN, A.N., and ROOM, P.M. 1979. Analysis of crop development for cotton pest management. Protection Ecology 1: 265-277.

KAY, I.R. 1981. Host plant resistance. Pages 29-33 *in* QDPI 1981.

McLAREN, I.W. The use of *Trichogramma* sp. in tomatoes. Pages 54-55 *in* QDPI 1981.

MICHAEL, P.J. 1973. Natural control for insect pests on the Ord. West Australian Agricultural Journal 14:207-208.

PEACOCK, W.J. 1980. SIRATAC management system for cotton. Agricultural Gazette of New South Wales 91 (4): 7-10.

QDPI (Queensland Department of Primary Industries). 1981. Proceedings, Workshop on Biological Control of *Heliothis* spp. 23-25 Sept 1980, Toowoomba, Queensland, Australia.

ROGERS, D.J. 1981. Varietal resistance to *Heliothis armigera* in navy beans *(Phaseolus vulgaris).* Pages 36-42 *in* QDPI 1981.

ROGERS, D.J., TEAKLE, R.E., and BRIES, H.B. 1981. Evaluation of the *Heliothis* N.P.V. "Elcar" against *Heliothis armigera* in navy beans *(Phaseolus vulgaris).* Pages 101-105 *in* QDPI 1981.

ROOM, P.M. 1979a. A prototype 'on line' system for management of cotton pests in the Namoi Valley, New South Wales. Protection Ecology 1:245-264.

ROOM, P.M. 1979b. Parasites and predators of *Heliothis* in cotton in the Namoi Valley. Journal of the Australian Entomological Society 18: 223-229.

TEAKLE, R.E. 1977. Diseases of *Heliothis* caterpillar. Queensland Agriculture Journal 103: 390-391.

THOMSON, N.J., and LEE, J.A. 1980. Insect resistance in cotton. A review and prospectus for Australia. Journal of the Australian Institute of Agricultural Science 46: 75-86.

TITMARSH, I.J. 1981. Two seasons' life tables for *Heliothis* spp. on vegetative tobacco in far North Queensland. Pages 114-117 *in* QDPI 1981.

TWINE, P.H. 1981. The potential role of parasites in the biocontrol aspect of pest management of *Heliothis.* Pages 43-46 *in* QDPI 1981.

WARDHAUGH, K.G., ROOM, P.M., and GREENUP, L. 1980. The incidence of *Heliothis armiger* (Hubner) and *H. punctiger* Wallengren (Lepidoptera.Noctuidae) on cotton and other host plants in the Namoi Valley of New South Wales. Bulletin of Entomological Research 70:113-131.

WILSON, A.G.L. 1974. Resistance of *Heliothis armigera* to insecticides in the Ord Irrigation Area, North Western Australia. Journal of Economic Entomology 67:256-258.

WILSON, A.G.L. 1975. Varietal responses of grain sorghum to infestation by *Heliothis armigera.* Experimental Agriculture 12: 257-265.

WILSON, A.G.L. 1981a. Field evaluation of formamidine insecticides and *Bacillus thuringiensis* for selective control of *Heliothis* spp. on cotton. General and Applied Entomology 13:105-111.

WILSON, A.G.L. 1981b. *Heliothis* damage to cotton and concomitant action levels in the Namoi Valley, New South Wales. Protection Ecology 3: 311 -325.

WILSON, A.G.L., and GREENUP, L.R. 1977. The relative injuriousness of insect pests of cotton in the Namoi Valley, New South Wales, Australian Journal of Ecology 2: 319-328.

WILSON, A.G.L., BASINSKI, J.J., and THOMSON, N.J. 1972a. Pests, crop damage and control practices with irrigated cotton in a tropical environment. Cotton Growers Review 49: 308-340.

WILSON, A.G.L., HUGHES, R.D., and GILBERT. 1972b. The response of cotton to pest attack. Bulletin of Entomological Research 61: 405-411.

WILSON, A.G.L., LEWIS, T., and CUNNINGHAM, R.B. 1979. Overwintering and spring emergence of *Heliothis armiger* (Hubner) (Lepidoptera:Noctuidae) in the Namoi Valley, New South Wales. Bulletin of Entomological Research 69: 97-109.

Problems and Progress in *Heliothis* Management in Tanzania, with Special Reference to Cotton

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Abstract

Heliothis armigera *(H'ubner) is a major cotton pest in Tanzania. It also attacks a number of other cultivated crops, and the role of maize in the seasonal buildup of* Heliothis, *and hence the damage to cotton, has been established. In cotton, control measures include the use of insecticides and early sowing, based on the pest-avoidance principle and the ability of some varieties to compensate for the loss of early fruiting bodies.*

Despite the difficulties of weather, which have been a major constraint in the effort to introduce and select for insect-resistant characters in recent years, some progress has been made. Both frego bract and high gossypol characters have given promising results.

Résumé

*Problèmes et progrès dans la lutte contre l'*Heliothis *en Tanzanie, avec référence particulière au coton:* Heliothis armigera *(Hübner) est un ravageur important du coton en Tanzanie. Il attaque aussi plusieurs autres cultures. Le rôle du maïs, dans l'accroissement saisonnier des populations d'*Heliothis *et les dommages ultérieurs au coton, a été établi. Dans le cas du coton, les mesures de lutte comprennent l'utilisation d'insecticides et un semis hâtif, basé sur le principe d'évitement des ravageurs et la capacité de certaines variétés à compenser les pertes hâtives d'organes fructifères. Malgré les aléas du temps, qui ont été une entrave importante à l'introduction et la sélection de traits de résistance aux ravageurs au cours des dernières années, des progrès ont été réalisés. Les caractères de la bractée Frego et d'une forte teneur en ''gossypol'' ont permis d'obtenir des résultats prometteurs.*

The American bollworm, *Heliothis armigera* Hubner, is one of the major cotton pests in Tanzania. It also attacks a number of other cultivated crops, including maize, sorghum, millet, legumes, sunflower, and tomatoes, but its pest status on these crops has not been fully established.

The population buildup of *Heliothis* on cotton, and hence the damage caused, varies from season to season, and depends to a great extent on total rainfall and its distribution. Most of Tanzania's cotton is grown around the southern shores of Lake Victoria in an area known as the Western Cotton Growing Area (WCGA). In the WCGA, the rainfall pattern is bimodal, with the short rains usually falling between November and early January, and the main rains occurring from March to May.

The first generation of *Heliothis armigera* builds up on wild host plants, especially *Cleome* spp, and moves on to the November-sown maize, which makes an ideal host for the second generation (Reed 1965). The generations that build up on maize later move on to cotton at or around flowering time (usually from mid-February). Consequently, the severity of *H. armigera* infestation on cotton depends a great deal on the *Heliothis* population development on early-sown maize. As a result, in years of low rainfall, during December and January, the infestation on cotton in February and March is often very low, because of the adverse effect of drought on the maize crop. Low and erratic rainfall in December and January has been a feature in the WCGA in recent seasons, and this has resulted in low levels of *Heliothis* on cotton.

In 1964, Reed (1965) recorded an average of about 0.23 eggs and 0.15 larvae per plant on unsprayed cotton at Ukiriguru during the flowering period. During the same period in the 1979-80 and 1980-81 seasons, the average egg and larvae count per plant on unsprayed cotton at Ukiriguru was 0.015 and 0.03, respectively. Records from

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International Crops Research Institute (or the Semi-Arid Tropics. 1982. Proceedings of the International Workshop on *Heliothis* Management, 15-20 November 1981, Patancheru, A.P., India

Lubaga (an experiment station 100 km south of Ukiriguru) indicated an average of 0.003 eggs and 0.041 larvae per plant on unsprayed cotton.

Control Measures for *Heliothis*

Cultural Practices

Since the severity of *H. armigera* attack on early-sown cotton in the WCGA is determined largely by the population building up on early-sown maize, it would have been ideal to ban early-sown maize, thus interrupting the generation preceding that which attacks cotton (Reed 1965). Such a practice was successfully tried by Reed at Ukiriguru, where early *H. armigera* attack on early-sown cotton was light, and good yields were achieved without chemical control.

However, with the present cropping system, in which food crops are given priority, the recommendation is impractical. The use of maize as a trap crop has also been tried, but was abandoned because it involved sowing maize at a time when labor for weeding cotton was in high demand.

Early sowing of cotton is strongly recommended. Cotton in the WCGA should be sown between the end of November and the end of December. If the sowing dates are strictly observed, first pick should be ready in May/June. The sowing date recommendation was based on the fact that in years when *H. armigera* built up early, the early-sown cotton may lose its bottom crop but would compensate later by producing a crop during the main rains of April and May. The present varieties grown in Tanzania are particularly suited to such compensatory growth, provided soil moisture and soil nutrients are adequate. The crop would also be partly protected from further severe attacks of *H. armigera* by natural enemies, which are more abundant after a heavy *Heliothis* attack (Reed 1965). Under conditions that allow the *Heliothis* population to build up later rather than earlier, the early-sown cotton would already have set its main crop and would therefore escape serious damage.

Insecticides

In Tanzania, apart from early sowing, *H. armigera* control on cotton and some other crops is by chemical means. Insecticide-testing began in 1956, with the evaluation of DDT. To date, the list of recommended insecticides against *H. armigera* on cotton consists of DDT 40% ULV or 75% w.p. at 1000 g ai/ha; endosulfan 25% ULV at 625 g ai/ha; DDT 35% plus methidathion 15% ULV (a commercial mixture) at 875 + 375 g ai/ha; DDT 35% plus phenthoate 25% ULV at 875 + 625 g ai/ha; permethrin 5% ULV at 125 g ai/ha; and fenvalerate 4% ULV at 100 g ai/ha.

Progress

Monitoring and Forecasting

Field monitoring or scouting as practiced in Central Africa has not so far been successful in Tanzania, where a fixed spraying regime is still followed. The blanket recommendation advises farmers to apply six sprays at 2-week or 10-day intervals, beginning at first flower, 10 weeks and 8 weeks after sowing in WCGA and the ECGA (Eastern Cotton Growing Area), respectively.

The government policy of encouraging communal farming on large block farms, plus the rising costs of insecticides, made it necessary to reassess the fixed spray regime. It was considered that scouting could reduce spraying costs by withholding a spray until a given threshold is reached, and the grouping of the farmers would make the introduction and supervision of the scouting technique easier. Consequently, scouting trials were initiated during the 1971 -72 season in the hope of introducing a spraying program based on *H. armigera* egg and/or larvae thresholds.

After three seasons' evaluation in the WCGA and ECGA, it was tentatively concluded that cotton spraying could be profitable if based on 0.5 or more eggs or 0.2 or more larvae per stand. The scouting trials conducted in WCGA since the 1978-79 season have not produced clear-cut results, because the *H. armigera* infestation has remained consistently low each season, with no clearly defined peaks. Consequently, the thresholds used have been unable to trigger a spray. Even in the ECGA, where the *Heliothis* pressure is normally higher, it has not been possible to formulate a recommendation. Where some of the thresholds have triggered spraying, the net economic return has not compared favorably with the net return obtained from the blanket recommendation.

Forecasting of *H. armigera* in order to warn the farmers of a probable heavy attack has not been fully evaluated to date, though it could prove useful.

In 1964, for example, it was possible to warn extension officers of the likelihood of a severe *H. armigera* attack on cotton. This was based on light-trap catches, as well as on egg and larval counts on maize in early January.

Breeding for Plant Resistance

Ukiriguru (UK) cotton varieties have the ability to compensate for loss of fruiting bodies caused either by physiological stress or by insect attack. Brown (1962), working at Ukiriguru, showed that the removal of the early flowers from the UK varieties did not necessarily result in lower yield. Instead, flower removal induced greater structural and frame development, which could lead to yield recovery, provided soil moisture and nutrients were sufficient.

In recent work initiated in the 1972-73 season at Ukiriguru, the possibility of incorporating *Heliothis*-resistant characters into the UK varieties has been studied, with emphasis on frego bract, nectariless, high gossypol, and glabrous characters. The frego bract selections gave promising results in the 1973-74 and 1974-75 seasons (Tables 1 and 2). The study was resumed in 1978-79 at Ukiriguru and initiated at Ilonga in the ECGA during 1979-80. However, due to the low pest pressure in the WCGA, it has been difficult to draw any definite conclusions. Nevertheless, even under the low *Heliothis* pressure, frego bract and high gossypol plants have both showed reduced numbers of *Heliothis* larvae (Treen 1979, 1980, 1981) compared with present commercial varieties (Table 3). Work at Ilonga in 1979-80 (Hackett and Kabissa 1980), under higher levels of *Heliothis* infestation, also indicated that the frego bract character was promising.

Evaluation of New Insecticides

The evaluation of new insecticides and formulations in an attempt to identify a cheap, safe (in terms of mammalian toxicity), and efficient chemical to control *H. armigera* on cotton has been emphasized in our research program.

Wettable powders and emulsifiable concentrates are used in the ECGA by small holders. ULV formulations have wholly replaced these in the WCGA and on large Tanzania Cotton Authority (TCA) production farms in the country. Spraying is done solely by hand-held sprayers.

In addition to the organophosphates, organochlorines, and carbamates, the synthetic pyrethroids have also been examined, and some of them have been recommended for farmers' use.

Table 1. Bollworm damage[a] In normal, frego bract, and nectariless cotton at four sites In the Western Cotton Growing Area, Tanzania, 1973-74.

		Site and trial			
Variety	Description	Bwanga IRG (73) 1a	Mwamala IRG (73) 1c	Mwanhala IRG (73) 1d	Ukiriguru IRG (73)1e
Control (commercial cultivar)	UK68/UK69 mixture	43.3 (100.0)	11.2 (100.0)	27.4 (100.0)	24.9 (100.0)
Frego bract	Unselected F$_4$ bulks of first cross to local varieties	32.4 78.4)6	8-7 (77-7)	17.0 (62.0)	19.7 (79.1)
Nectariless		31.6 (73.0)	12.4 (110.7)	23.2 (84.7)	18.5 (74.3)
SE		±2.17	±0.97	±1.38	±1.67
Site mean		35.8	10.8	22.5	21.0
No. of weeks of counting		11	10	8	10

Source: Lee et al. 1975.

a. The values quoted are weekly flared square indices, mean of n weeks of counting, low values indicate good resistance.

b. Figures in parentheses are percentages of the control variety.

Table 2. Bollworm resistance and other characteristics of normal, nectariless, frego bract, and glandless cotton In an unsprayed trial at Ukiriguru, 1974-75.

Cultivar	Flared square index[a]		Corrected flower count[b]		Ginning percentage	Seed per boll (g)
J3 (72) 36[c]	4.33		439		37.7	7.00
J3 (72) 29[c]	5.14		399		36.3	6.63
S_1 (72) 70[d]	9.56		473		37.2	6.90
B_1 (72) 49[d]	6.73		466		38.5	7.02
UK Frego (73) 11	1.57	1.75±0.516	376	369 ± 8.7	36.7	6.78
UK Frego (73) 12	1.42		371		37.5	6.49
UK Frego (73) 13	2.56		359		39.4	8.18
UK Nec (73) 10	2.52	3.65 ± 0.516	357	386 ±8.7	43.2	7.48
UK Nec (73) 12	3.36		412		38.8	8.20
UK Nec (73) 18	5.06		390		39.0	6.78
gl UK (73) 6	6.21	6.54± 0.631	334	363 ± 10.6	36.5	6.55
gl UK (73) 12	6.86		391		37.2	7.49
Frego x local F_4 bulk	2.91		408		37.9	7.04
Nectariless x local F_4 bulk	3.37		367		40.1	7.30
UK-68 Commercial	4.12	3.7410.631	450	430 ± 10.6	36.3	6.63
UK-69 varieties	3.35		410		36.0	6.55
SE treatment mean	±0.893		±15.0		± 0.32	± 0.274

Source: Lee et al. 1975.

Correlation between flared square index and corrected flower count was + 0.52, significant at 5%.

a. Low values indicate good resistance.

b. Corrected for bollworm damage.

c. Bollworm-resistant normal variety selected from 1973-74 S.Z. Strain trial, Ukiriguru.

d. Bollworm-susceptible normal variety selected from 1973-74 S.Z. Strain trial, Ukiriguru.

Influence of Cropping Sequence on *H. armigera* Pest Status

Reed (1965) examined the role of maize in the buildup of *H. armigera* on cotton at and around Ukiriguru. Apart from this work, no effort has been made to examine the importance of the other cultivated crops in the population changes of *H. armigera.*

During the 1980-81 season, a start was made in identifying the cropping sequence at and around Ukiriguru in relation to alternative hosts *of Heliothis* and pest population changes. Crops studied included cotton, short- and long-duration maize, short-duration sorghum, chickpea, and tomatoes. The flowering pattern of these crops—i.e., the stages attractive to *Heliothis—is* shown in Figure 1.

Short-duration maize sown in October and early November started flowering mid-December and would have remained attractive until the end of February. However, a drought in January and February adversely affected maize development and therefore the buildup of *H. armigera.* Long-duration UCA maize and some local varieties are sown in December and January and begin flowering in April, which coincides with flowering in late-sown cotton.

The early-sown cotton season was prolonged in 1980-81 because of the delay in the second rainfall peak; a top crop formed after the loss of the early crop in mid-season drought.

Tomatoes are grown in backyard gardens throughout the year; however, farmers favor the dry-season crop because it is less damaged by diseases. This crop is considered a major cultivated host for *H. armigera.* Chickpea is a late-season crop, usually sown on residual moisture on heavy *(mbuga)* soils.

The level of *Heliothis* infestation on cotton was regarded as being very low in the WCGA as a

Table 3. Insect-pest resistance in cotton in Tanzania, 1978-1981.[a]

Character	American bollworm (ABW) eggs	American bollworm (ABW) larvae	Larvae: egg ratio	Spiny bollworm (SBW) larvae	American+ spiny bollworm larvae	White flowers (WF)	Flared squares (FS)	FS as percentage of WF+FS	Ratio flared squares to ABW + SBW larvae	Yield of seed cotton[b] (kg/ha)
Frego bract	0.70	0.31	0.44	0.19	0.51	50.0	9.2	15.9	18.0	947
Nectariless	1.05	2.14	2.04	0.94	3.08	48.2	9.5	16.8	3.1	1061
High gossypol	0.82	1.36	1.67	0.97	2.34	54.4	10.4	16.3	4.4	948
Glandless	0.82	2.57	3.14	1.05	3.63	47.2	12.6	21.5	3.5	810
UK-77 (commercial variety)	0.90	2.22	2.46	0.90	3.12	51.7	11.7	18.9	3.8	1268

Source: Treen 1981.

a. Means per 100 plants from totals recorded on each character over three seasons.
b. 1979-80 and 1980-81 only.

whole. However, the results of sampling the different crops twice a week gave an idea of the level of infestation on each. The average larval counts per plant on unsprayed crops at flowering were: Katumani (short-duration maize) 0.12; cotton 0.014; UCA maize 0.11; sorghum 0.083; and chickpea 0.73. The infestation on chickpea was considerable.

Role of Natural Enemies in Controlling *Heliothis*

Reed (1965) reported that at Ukiriguru, the dry-season diapause breaks the association between *Heliothis* and most of its natural enemies, so that there is an uncontrolled rapid buildup of the pest on cotton early in the season. Reed also observed heavy parasitism and predation later in the season.

However, with the changed farming system in which there is continuous cultivation of crops that have the ability to harbor *Heliothis* during the dry season, the predator-prey association may well have changed.

Examination of the activity of adult *Heliothis* moths from light-trap catches at Ukiriguru, 1973 to 1980, showed that moth activity was continuous throughout the year, with two peaks. The major moth flight takes place towards the end of the main rainfall in April-May and the lower peak is in January. These two peaks are separated by a period of low moth activity during the dry season between June and October.

To investigate pupal period and diapause, larvae collected in the field during the 1980-81 season were reared to pupal stage, and the pupal period observed (Table 4).

There is some evidence, therefore, that even with a small percentage of diapausing population, continuous *Heliothis* activity throughout the year could support a small population of its natural enemies.

Problems

Insecticidal Control

Acceptance by Farmers

About one-fifth of the cotton farmers in Tanzania spray their cotton, and about half of these apply an average of three sprays out of the six recommended. Those who spray often base their spraying on a scouting system, which is

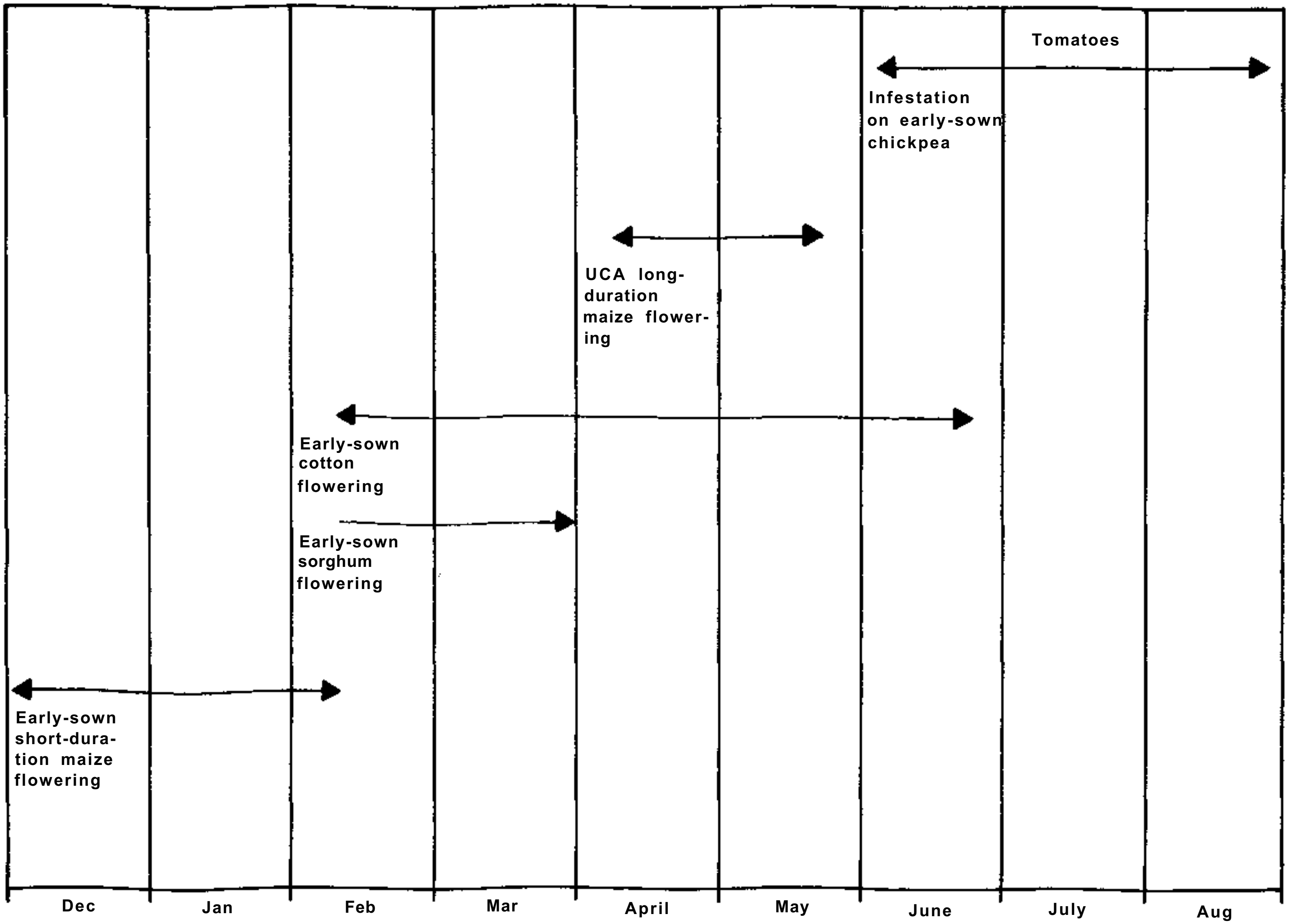

Figure 1. The flowering pattern of cotton, maize, sorghum, chickpea, and tomatoes in and around Ukiriguru, 1980-81 season. Arrows indicate period during which crop remains attractive to Heliothis.

Table 4. Pupation period of field-collected larvae from different crops at and around Ukiriguru, 1980-81 season.

Month	Number of pupae	Range of pupal duration (days)	Average duration (days)	Number in diapause more than 30 days[a]
January	72	11-17	14.5	0
February	23	14-16	15.2	0
March	53	12-25	17.6	0
April	35	15-42	16.5	1
May	44	12-19	15.2	0
June	123	12-23	16.6	0
July	168	14-32	17.7	1
August	363	12-20	16.6	0

Source: Nyambo unpublished.

a. According to Reed (1965) diapause duration in the laboratory was 30 to 171 days after pupation.

determined by the number of fully grown bollworms and/or an increase in the number of flared squares in the crop. A major disadvantage of this system is that by the time the farmer notices the bollworm larvae, the damage has already been done to the crop; additionally, larger dosages of insecticides are required to kill the full-grown larvae.

Increased Insecticide Prices

Insecticide prices are continuously rising, so that even with government subsidies, cotton spraying is becoming less economic. In the 1974-75 season, a farmer needed to produce only 100 kg of seed cotton to pay for the cost of the insecticides, whereas in the 1979-80 season, he needed 150 kg of seed cotton to pay for the same insecticide. The problem of prices is more acute with the synthetic pyrethroids. Although research has recommended some of them, it may be some time before they can be purchased cheaply enough for farmers' use. Moreover, some of the pyrethroids, particularly cypermethrin and deltamethrin (decamethrin), have been observed to induce a red spider mite, *Tetranychus* spp, outbreak on research cotton plots. This is casting a shadow on the future of the synthetic pyrethroids on cotton in Tanzania.

Effect of Insecticides on Natural Enemies

An increased reliance on insecticides could have a detrimental effect on *Heliothis armigera* natural enemies. Reed (1965) reported about 27% parasitism of larvae collected from the field between March and July 1962 at Ukiriguru. Over a similar period in 1964, after more intensive use of insecticides, he observed only 6.4% parasitism on larvae collected from the same crops. Reed expressed the fear that increasing use of insecticides at Ukiriguru might be reducing the activity of the natural enemies. This could be true for TCA cotton seed production farms and research stations, where insecticides are used intensively, but may not be the case on farmers' scattered plots.

Weather

The continuous dry weather in January and February in the WCGA, which has affected the buildup of *H. armigera* on cotton and its alternative host plants, has made the evaluation of *Heliothis*-resistant plant material and scouting-based spraying unrewarding.

Lack of Host-Crop Integration

To date, *Heliothis* management on cultivated crops has been considered in isolation on each crop. Control efforts have been concentrated on particular crops only, ignoring the fact that the different crops in the system could play an important part in increasing or decreasing *Heliothis* pressure on others. The cropping sequence could be better utilized to facilitate integrated *Heliothis* management.

Future Work

Heliothis management in Tanzania warrants more intensive research for a number of reasons. First, our farming system is being changed from small, isolated fields in scattered villages to large, organized communal villages *(ujamaa* villages) and block farms, where both food and cash crops receive equal importance. The pest pressure under such a farming system is likely to be more severe. Second, *Heliothis* control has so far been *centered* on single crops, without taking into consideration the agroecosystem as a whole. Some of the cultivated food crops will be a potential source of infestation or a reservoir of natural enemies for other crops in the cropping sequence. Third, *Heliothis* control to date has largely depended upon insecticides; in view of the problems often associated with a heavy reliance on insecticide use, there is need to search for more efficient, more reliable, and cheaper control measures.

With these limitations in mind, a research program has been initiated to study the following aspects:

- The effect of the changing farming system on the occurrence of *Heliothis,* with particular reference to its abundance and the damage it can cause to cultivated crops.
- *Heliothis* key mortality factors on the major field crops.
- The establishment of a monitoring and forecasting system, including the use of simple traps.
- Chemical control of *Heliothis* with emphasis on selectivity against non-target organisms, including the evaluation of more efficient and safer insecticides.

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References

BROWN, K.J. 1962. Agronomy and crop physiology progress report, 1960-61. Experiment Stations, Empire Cotton Growing Corporation, Tanganyika Lake Province, Tanganyika. 8 pp.

HACKETT, D.S., and KABISSA, J.C.B. 1980. Pages 7-8 *in* Cotton research annual report, 1979-80. Tanzania: Agricultural Research Institute, Ukiriguru, Mwanza.

LEE, B.J.S., WALTON, I.C., JACKSON, A.C., MARANDU, W.Y.F., and KAPINGU, M.P.K. 1975. Pages 26-56 *in* Annual report, 1974-75. Tanzania: Agricultural Research Institute, Ukiriguru, Mwanza.

REED, W. 1965. *Heliothis armigera* in Western Tanganyika, Parts 1 and 2. Empire Cotton Growing Corporation research memoirs 61, Tanganyika.

TREEN, A.J. 1979. Ukiriguru cotton research. *In* Annual report 1978-79. Tanzania: Agricultural Research Institute, Ukiriguru, Mwanza.

TREEN, A.J. 1980. Entomology (WCGA). *In* Ukiriguru cotton research annual report 1979-80. Tanzania: Agricultural Research Institute, Ukiriguru, Mwanza.

TREEN, A.J. 1981. Cotton entomology (WCGA—Ukiriguru). Summary of 1980-81 results. Ukiriguru Agricultural Research Institute, Mwanza, Tanzania.

Progress in Research and Development for *Heliothis* Management in the Sudan

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Abstract

The change in the status of Heliothis armigera *from an occasional and sporadic cotton pest to a major problem under Sudan Gezira conditions is associated with changes in crop rotations and the increased area under crops that serve as host plants for the pest. Groundnut growing early in the season over a large area has provided the insect with a suitable host plant on which to develop prior to cotton infestation. Development of* Heliothis *infestation on sorghum coincides with the start of cotton infestation and therefore contributes to later attacks on cotton. Advancing the sowing date and planting of early-fruiting cotton varieties disposes the cotton to* Heliothis *attack.*

At present, *the strategy for* Heliothis management is based on *the use* of *insecticides to keep the early bollworm damage below the economic threshold. Emphasis is placed on the use of insecticides that interfere least with natural control agents. Programs tor developing pest-resistant cotton varieties are under way.*

Résumé

*Progrès de la recherche et développement de la lutte contre l'*Heliothis *au Soudan: L'évolution du statut d'*Heliothis armigera, *de ravageur occasionnel et sporadique du coton à celui de problème majeur sous les conditions de Gezira au Soudan, est associé à des changements de rotations culturales et à l'augmentation de la superficie consacrée à des cultures qui servent de plantes-hôtes à cet insecte. L'arachide, cultivée tôt dans la saison et sur une grande superficie, a fourni à ce ravageur une plante-hôte appropriée lui permettant de se développer avant d'infester le coton. Le développement de l'infestation d'*Heliothis *chez le sorgho coïncide avec le début de l'infestation chez le coton, entraînant ainsi des attaques ultérieures chez ce dernier. Un semis plus hâtif et l'utilisation de variétés de coton à fructification hâtive prédispose aux attaques d'*Heliothis.

*Actuellement, la stratégie de lutte contre l'*Heliothis *est basée sur l'utilisation d'insecticides pour contenir les dommages hâtifs sous un seuil économique. L'accent est mis sur l'utilisation d'insecticides qui interfèrent le moins avec les agents naturels de lutte. Des programmes sont réalisés pour créer des variétés de coton résistantes au ravageur.*

The American or African bollworm *(Heliothis armigera)* has been recognized as a pest of *cotton* in the Sudan since organized cotton production started in the country. Reports of the then Agricultural Research Corporation contain numerous records of this pest from different parts of the country where either rainfed or irrigated cotton was cultivated (Cowland 1931-35; Bedford 1934-38; Joyce 1949-54). *Heliothis armigera* then was a major pest in the central rainlands and the inland deltas (Tokar and Gash Deltas), but in the Gezira irrigated cotton was only occasionally and sporadically infested. Serious infestation in the Gezira was reported during the 1931-35 seasons by Cowland, and the 1951 -54 seasons by Joyce. However, in these seasons of high infestation, the distribution of the pest was not uniform, varying with locality and generally associated with the early-sown crop. In the early 1960s, however, a marked change took place and *Heliothis* established itself as a major pest. This change was at first confined to the southwest (Managil) extension but later spread to the whole Gezira. The importance of *Heliothis* has progressively increased with time and currently it constitutes, together with the cotton whitefly, *Bemisia*

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tabaci, the major hazard to the irrigated cotton crop in the Gezira. On the other hand, the pest continued to command its traditional major status in rainfed cotton.

Crops and the Cropping Systems in the Gezira

The Gezira Scheme, which was launched in 1925, has witnessed several changes in the spectrum of crops grown, the crop rotations adopted, and the total acreage sown to each crop. These changes were dictated by economic considerations, development of plant diseases, and other practical reasons. The major changes are summarized below.

Changes in Crop Rotations

The first rotation adopted in the old Gezira was: cotton - sorghum / lablab - fallow. in 1931, and in view of the spread of leaf curl and bacterial blight diseases on cotton, the legume, *Dolichos lablab* was abandoned, and the rotation changed to: cotton-fallow-sorghum-lablab-fallow-cotton-fallow-fallow.

The main feature of these early rotations is the emphasis on cotton as the major crop, and the large proportion of land left fallow to combat cotton diseases and renew soil fertility.

In the early 1960s, a new policy of crop diversification was implemented, and groundnut was introduced commercially as a second major cash crop besides cotton, after it had shown its suitability for the heavy Gezira clays. At the same time, wheat was also introduced as a cash crop. Consequently, two different rotations were followed: one for the southern Gezira where the rotation became cotton-groundnut/lablab-sorghum-fallow-fallow-cotton-fallow-fallow. In the northern Gezira, wheat was introduced, and here the rotation adopted was: cotton-lablab/fallow-sorghum-fallow-fallow-cotton-wheat-fallow. Though these newly adopted rotations had two new cash crops besides cotton, the large proportion of fallow remained. In the mid-1970s, with the launching of a policy of crop intensification, the areas left fallow were drastically reduced, and the rotation adopted in the old Gezira became cotton-wheat - groundnut / sorghum / vegetables / rice / fodder-fallow.

In the southwest (Managil) extension, which was started in 1957 and developed in phases to be completed by 1962, the plan was to implement an intensified and diversified rotation from the very beginning. So the original rotation cotton-groundnut/lablab-sorghum-fallow-cotton-fallow had both cotton and groundnut as major cash crops. In 1967, wheat was added, and the rotation was modified to: cotton-sorghum fallow-cotton-wheat-groundnut/lablab. In the mid-1970s the fallow was eliminated, and the rotation was changed to: cotton-wheat-groundnut / vegetables / sorghum / fodder.

Changes in Areas Under Different Crops

The main rotational crops that cover sizable areas are cotton, groundnut, sorghum, and wheat; the first three of these are host plants, of *Heliothis.* The cotton area increased progressively from 80000 feddans (33600 ha) in 1925 to reach about a quarter of a million (105 000 ha) by 1957-58 (Table 1). With the completion of the Managil Extension in the 1962-63 season, the total area under cotton was doubled.

Table 1. Area (ha) under cotton, sorghum, and groundnut in the Sudan Gezira over three decades—1941-42 to 1972-73.

Season	Cotton	Sorghum	Groundnut
1941-42	87 071	64 428	
1946-47	86 674	43 467	
1951-52	92 885	46 535	1 167
1956-57	103104	51 557	403
1962-63	203 571	95028	10015
1967-68	232 638	132191	42715
1972-73	247 772	123 520	74738

During the decade 1948-1958, the area annually sown to groundnut was very low. With the start of the Managil Extension this area began to expand rapidly; at present, groundnut area is over a quarter of a million feddans (105000 ha).

Few changes occurred in the sorghum areas in the Scheme during the 1940s and 1950s, but in the early 1960s, the sorghum area increased to about a quarter of a million feddans and is now approaching 300 000 feddans (126000 ha) in the 1980s.

Heliothis Infestations on the Rotational Crops

The sequence of cropping starts with groundnut, followed by sorghum, then cotton, and lastly wheat. This sequence satisfied the optimum requirements of the crops included in the rotation and avoids the overlap of the various cultural operations.

Groundnut

The cultivar grown commercially is Ashford, which takes about 140 days to mature under the Gezira conditions. The crop is sown in early June and harvested in November.

Heliothis larvae feed on groundnut leaves, young leaves being preferred to older leaves. Laboratory breeding has shown that larvae develop normally on young leaves but they suffer high mortality when bred on old leaves. Economic losses resulting from *Heliothis* feeding on groundnut are negligible.

A study of *Heliothis* infestation on groundnut in the Gezira Research Farm, showed low populations during the period August to October, with a peak (1.9 larvae/50 random plants) occurring in late August, then declining to 0.2 larvae per 50 plants by mid-September (Balla 1968). In a similar study in the Managil Extension during 1970, it was found that the infestation was higher, but again a peak of 5 larvae per 50 plants was attained towards the end of August. Topper, in an intensive study of *Heliothis* on groundnut in 1976 and 1977, found that the numbers of larvae increased from July until September, with a pronounced peak in late August-early September, after which the numbers declined in October (Topper 1978). He showed that the larval peaks correspond to adult moth peaks that later oviposit on cotton in early September to mid-October.

Sorghum (Dura)

Heliothis larvae feed on sorghum grain at the milk stage only but after that stage sorghum infestation ceases. It was observed that compact-head varieties, which predominate in the Sudan, are more heavily infested than open-headed varieties. In the Gezira, several local and improved varieties are grown under irrigation. The crop is sown in early July, and the milk stage under the Gezira conditions is attained normally during the early September to mid-October period, depending on the variety. Larval numbers per head were found to vary, but as many as 30 larvae per head or more were encountered in some seasons. Loss in grain due to *Heliothis* damage is estimated as 5 to 10%. From a study of sorghum infestation, Topper (1978) concluded that only one generation develops on the crop in the Gezira and the adults produced oviposit on cotton during the first half of October.

Cotton

The Gezira area grows predominantly long-staple cotton (*Gossypium barbadense);* however, in recent years, medium-staple cotton *(Gossypium hirsutum)* varieties traditionally grown outside the Gezira were introduced. These varieties are derivatives of the American Upland Acala and they are potentially higher yielders than the long-staple ones. The area under medium-staple cotton is about 12% of the total cotton area in the current 1981 -82 season.

Long-staple cotton used to be sown from mid-August to late-August. However, in the 1970s, the sowing date was advanced by about 2 weeks. This was made possible by the breeding of varieties resistant to the bacterial blight disease caused by *Xanthomonas malvacearum,* which was the major factor preventing earlier sowing. Early sowing leads to higher yields and better grades of cotton.

Heliothis larvae feed on the fruiting points of the cotton plant, i.e. flower buds, flowers, and bolls and the start of infestation is associated with the start of the fruiting cycle. Advancing the sowing date results in earlier fruiting and consequently earlier bollworm attack on cotton.

The growth pattern and fruit initiation vary in the two types of cotton grown in the Gezira. Given the same agronomic treatments, the long-staple cotton takes 80 days from sowing to the first flower, produced on the 15th to the 18th node. For the Acala type, the first flower is produced on the third to fourth node after 50 days from sowing (Farbrother 1973). It follows, therefore, that infestation in Acala types of cotton is earlier (early September) compared with the long-staple varieties (about mid-September).

Impact of Insecticides on Natural Control Agents

Heliothis larvae are parasitized by some ten different species in the Sudan (Table 2). The incidence

Table 2. *Heliothis* armigera parasites and predators In the Sudan.[a]

Parasites:		
Euplectrus	*laphygmae*	Ferr.
Drino	*imberbis*	Weid.
Exorista	spp.	
Isomers	*cinerascens*	Rord
Sturmia	*inconspicua*	Mgn
Hypeuchalcidia	*soudanensis*	Steff
Chelonus	*versatilis*	Wikn
Meteorus	*laphygmarum*	Brues
Elasmus	*johnstoni*	Ferr
Goniophthalmus	*halli*	
Pediobius	*furvum*	Gah
Cardiochiles	sp	
Microbracon	*kirkpatricki*	
Predators:		
Eumenes	*maxillosus*	De Geer
Chrysopa	*carnea*	Steph

a. Compiled by Balla and Ahmed (1981).

of larval parasitism in the bollworm was recorded by Cowland during the season 1933-34 before insecticide application was started in the Gezira. He found that larval parasitism, which was low in October, increased progressively reaching a peak of over 50% by February (Table 2).

Cotton spraying in the Gezira started in the 1944-45 season on a limited area, using tractor-mounted sprayers with DDT, primarily for the control of the cotton jassid *Empoasca lybica de* Berg. During the 1950s, aerial application replaced ground application, and the number of sprays increased to an average of two sprays applied in midseason, with DDT still the main insecticide in use. In the early 1960s, the American bollworm and whitefly started to increase, requiring three to five sprays. DDT and dimethoate were the main chemicals used, usually as a mixture, to control the pest complex. In the late 1960s and early 1970s, the whitefly became a more serious pest, requiring five to seven sprays annually. Several insecticides were applied, but DDT still dominated.

The adverse impact of increased spraying on parasites and predators is well established. During the 1965-66 season, Lazarevic studied the incidence of *Heliothis* parasitism in the Managil Extension and found that there was a general decline from the peak (39%) attained in March (Table 3).

Table 3. Percentage parasitism in Heliothis in the Sudan Gezira.

	Season 1933-34 (Cowland)	Season 1965-66 (Lazarevic)
October	2-4	0
November	6-12	0
December	0-5	0
January	34-37	0
February	53	1
March		39

Our continuous monitoring for parasites during the 1970s and 1980s in the Managil and Gezira has shown that the incidence has declined to almost nil.

The Strategy of *Heliothis* Control in the Sudan

At present, the use of insecticides is the only control method resorted to in combating *Heliothis.* Though other rotational crops including groundnut and sorghum are attacked and contribute to the infestation on cotton, control is confined to the cotton crop only. Several insecticides have been tested in the Sudan, approved, and registered for commercial application against the American bollworm. They are either emulsifiable concentrates, wettable powders, water-soluble concentrates for low-volume spraying, or oil-based formulations for ultralow-volume application. The American bollworm is usually found in association with other pests, particularly whitefly, and since few chemicals control the two pests when used singly, the rule is to use mixtures of chemicals (ready mixtures or tank mixtures) to combat the pest complex. These mixtures also undergo screening tests for compatibility and efficacy.

Proper timing and prompt action are critical for the control of a pest like *Heliothis.* Insecticide application when the majority of larvae are at an early stage of development ensures a good kill and prevents extensive damage. This is achieved by taking *Heliothis* egg counts on the crop. The presence of eggs is also indicative of the presence of ovipositing females, which are consequently killed by insecticide application. The economic threshold at which the spraying operation commences is 10 eggs and larvae per 100 random plants.

Research and Development in *Heliothis* Management

Though the strategy ot control developed for *Heliothis* in the Sudan proved to be effective in minimizing losses to the pest.the need arose to revise this strategy along the lines stipulated for the development of an integrated control program for the cotton-pest complex as a whole. This need has become pressing in recent years, in view of the increased importance of the cotton whitefly. *Heliothis* is the major pest attacking cotton early in the season, preceding the whitefly, and the first sprays applied are primarily directed towards it. It is believed that the aggravation of the cotton whitefly is partly due to the disruptive effect of these early sprays of persistent, broad-spectrum insecticides such as DDT on the parasites and predators of *Bemisia tabaci* (Eveleens and Abdel Rahman 1979).

Delaying the first spray so as to decrease the early insecticide pressure on the parasites and predators was found to predispose the crop to economic losses in yield as a result of *Heliothis* damage (Eveleens et al. 1981). Thus, to protect the crop from early bollworm damage, insecticide use appears indispensable at the present time. However, to minimize the adverse effect on the parasites and predators, it has become necessary to aim at selecting insecticides that interfere least with the buildup of these natural control agents. The recent stoppage of DDT, which is a broad-spectrum, persistent chemical of long standing in the Sudan, is a step taken partly to achieve this end. At present, work is in progress to evaluate the impact of other chemicals on parasites and predators. Microbial Insecticides, such as *Bacillus thuringiensis* and polyhedral viruses, which have shown some promise under Sudan conditions hitherto, are being investigated.

Breeding for bollworm resistance in cotton has long been recognized as an important approach in pest management. Earlier attempts were unsuccessful, and the efforts were consequently abandoned. Interest in this line of research has been revived lately (Balla and Khalifa 1980). More recently, the work on breeding pest-resistant cotton varieties has been expanded under the FAO/UNEP African program for the development and application of integrated pest control in cotton.

Discussion and Conclusions

Heliothis armigera is a polyphagous insect pest that feeds on several cultivated plants and weeds in the Sudan (Balla 1978). Though it is found all the year round, it is more abundant during the period August-October. Under natural conditions the buildup starts as early as June on weeds that grow with the advent of the rainy season. The fast-growing weed, *Ipomoea cordofana* (Convolvulaceae) is particularly noted for the high incidence of *Heliothis* larvae. The survival of these early populations is important for the future development of the peak populations during August-October. Since infestation on long-staple cotton starts in early or mid-September, i.e., during the peak period of the seasonal occurrence of *Heliothis,* factors affecting the survival of the early populations in turn determine cotton infestation. The major factor determining the size of these early populations is the abundance of weed host plants, which is governed by the distribution and abundance of rainfall. If the rainfall pattern is such that weed growth is abundant during June-July, the bollworm populations are large; consequently, later infestations on cotton are heavy, and vice versa. This perhaps explains the sporadic and occasional nature of the pest occurrence in the Gezira prior to the 1960s. Rainfall in this region varies from season to season; on the other hand, in the Central Rainlands, the annual rainfall is higher, and sufficient weed growth is present annually for bollworm development.

In the early 1960s, the introduction of groundnut, a host plant of *Heliothis,* under irrigation in the Gezira and the subsequent expansion in its acreage have provided the pest with the needed host plant early in the season; thus the annual fluctuations corresponding to the rainfall have been evened out. The fact that the *Heliothis* outbreak was initially experienced in the Managil Extension, where groundnut was introduced in the rotation, is perhaps further evidence for the association of *Heliothis* with groundnut. However, although the American bollworm is now an important annual pest in the Gezira, it is more serious in some seasons than in others, reflecting the variation in rainfall amount and distribution that still operates.

While groundnut provides a host plant for *Helio-*

this development prior to cotton infestation, sorghum is infested at about the same time as cotton. The single generation developing on sorghum produces adults that oviposit later on cotton. Expansion in sorghum area has thus also contributed to the increased cotton infestation.

As mentioned earlier, the bollworm is seasonally more abundant during August-October. Therefore with regard to cotton, practices like advancing the sowing date that result in exposing the crop for a prolonged time in this period, will subject it to heavy bollworm attacks. Similarly, cultivation of early-flowering varieties, such as the short- and medium-staple cottons, leads to heavier bollworm attacks.

Though the role of parasites, which appear to be the dominant natural control agents in the Gezira, is limited early in the season, they increase progressively, as shown by Cowland's studies, before the use of insecticides. The increased frequency of sprays and the use of persistent broad-spectrum chemicals have adversely affected the parasites. Attempts to use less destructive chemicals and alternative methods of control such as pest-resistant cotton varieties would lead to the restoration of these beneficials—parasites and predators not only of *Heliothis* but of other pests—and to the reduction of the number of sprays needed.

References

BALLA, A.N. 1968. Gezira Research Station and Substations Annual Report, 1967-68, Gezira, Sudan.

BALLA, A.N. 1978. Studies on the American bollworm *H. armigera* in the Sudan Gezira. Presented at the Symposium on Crop Pest Management in the Sudan, 1978.

BALLA, A.N. and KHALIFA, H. 1980. Gezira Research Station and Substations annual report, 1979-80, Gezira, Sudan.

BEDFORD, H.M. 1935-1938. Agricultural Research Division, annual reports, Wad Medani, Sudan.

COWLAND, J.W. 1931-1935. Agricultural Research Division, Sudan, annual reports, Wad Medani, Sudan.

EVELEENS, K.G., and ABDEL RAHMAN, A.A. 1980. The cotton whitefly problem: can the tide be turned? Presented at the 44th Meeting of the National Pests and Diseases Committee, Working Paper No. 5, November 1980, Wad Medani, Sudan.

EVELEENS, K.G., BALLA, A.N., and ABDEL RAHMAN, A.A. 1981. Report prepared for the 45th Meeting of the National Pests and Diseases Committee, November 1981, Wad Medani, Sudan.

FARBROTHER, H.G. 1973. Gezira Research Station and Substation annual report, 1972-73, Wad Medani, Sudan.

JOYCE, R.J.V. 1950-1954. Agricultural Research Division Sudan, Annual Reports 1949-50,1950-51,1951 -52, 1952-53,1953-54, Wad Medani, Sudan.

LAZAREVIC, B.M. 1966. Agricultural Research Division, Sudan, Annual Report 1965-66.

TOPPER, C. 1978. The incidence of *H. armigera* larvae and adults on groundnuts and sorghum and the prediction of oviposition on cotton. Presented at the Third Seminar on the Strategy for Cotton Pest Control in the Sudan, CIBA-GEIGY, Basel, Switzerland.

The Problems and Prospects of *Heliothis* Management in Southwest Asia

G. Hariri*

Abstract

The most important crops that are attacked by Heliothis *spp in southwest Asia are cotton, tomatoes, tobacco, chickpeas, and maize.* H. armigera *(Hb.) is widely distributed in the region and causes severe damage in Turkey, the northern provinces of Iran, and in some areas of other countries in the region. Second in importance is* H. viriplaca *(Hutn.). which is causing severe damage in Iran and seems to be important in Syria also.*

Résumé

*Problèmes et perspectives dans la lutte contre l'*Heliothis *au sud-ouest asiatique: Au sud-ouest asiatique, le coton, la tomate, le tabac, le pois chiche et le maïs sont les plus importantes cultures attaquées par* Heliothis spp. H. armigera *(Hb.) est très répandu dans la région et cause de graves dommages en Turquie, dans les provinces du nord de l'Iran et quelques parties dans d'autres pays de la région.* H. viriplaca *(Hufn.), deuxième ravageur en importance, cause de graves dommages en Iran et semble être aussi important en Syrie.*

The Southwest Asia region is characterized by different climatic zones. The interaction of altitude, latitude, and distance from the Mediterranean, Black, and Caspian seas and the deserts of the Arabian Peninsula has led to the evolution of different agroclimatic subregions. Accordingly, the amount and distribution of rainfall in late autumn, winter, and early spring determine the growing periods of rainfed crops in the high plateau (Turkey, northern Iran, and northern Iraq) and lowland (Syria, Lebanon, Jordan, and Palestine) areas of the region. The rainy season is followed by several months of dry summer.

There are two types of rotations under rainfed conditions; each has its winter and summer crops. Cereals (wheat and barley) and winter legumes (lentils, faba beans and vetches) are grown in winter. Sorghum, sesame, watermelon, and chickpeas are grown in spring. Summer legumes (beans, cowpeas, peas, groundnut, and soybeans), maize, cotton, tomatoes, and other crops are grown under irrigation as summer crops. Irrigated crops are grown along the riverbeds of the region; surface and artesian wells are also commonly used for irrigation of summer crops.

Status of *Heliothis* Species in the Region

Any evaluation of pest damage to crops in the region is of a temporary nature, because of the changes in the standard of living of farmers and in agricultural practices, such as crop rotation, intensity of cropping, expansion of land under irrigation, mechanization, introduction of new crops, and land reclamation. With the increase in irrigation facilities in vast areas, continuous cropping became possible during summer, and this has resulted in the buildup of populations of polyphagous insect pests.

The most important crops attacked by *Heliothis* spp in the region are cotton, tomatoes, tobacco, chickpea, and maize. The data on area and production of these crops are given in Table 1. Four *Heliothis* species are recorded in the region attacking these main and other host crops (Table 2). *H. armigera* (Hb.), *H. viriplaca* (Hufn.), *H. peltigera* (Denis & Schiff.) and *H. nubigera* H.-S. Of these, *H. armigera* is the most widely distributed in the region and is known to cause severe damage in Turkey, the northern provinces of Iran, and some areas of Syria, Lebanon, and Palestine', and moderate

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1. Israel.

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Table 1. Area (A=000 ha) and production (P=000 tonnes) of main crops subject to attack by Heliothis spp in southwest Asia.

	Tomatoes		Tobacco		Chickpeas		Maize		Cotton Lint
Country	A	P	A	P	A	P	A	P	P
Turkey	108	3500	260	230	200	250	550	1150	481
Syria	30	460	13	13	21	70	31	70	127
Lebanon	6	75	8	5	1	2	2	2	
Jordan	10	172	3	1	3	2			
Palestine	5	258	1	1	4	4	3	13	78
Saudi Arabia	16	167					3	4	
North Yemen			6	6			64	95	2
South Yemen			1	2			6	15	4
United Arab Emirates	1	23							
Bahrain		10							
Kuwait	1	11							
Iraq	41	457	12	11	15	9	35	65	7
Iran	28	326	13	15	39	43	42	60	70
Total	246	5459	317	284	283	380	736	1474	769

Source: FAO (1981)

damage in other countries of the region. Second in importance is *H. viriplaca,* which has been reported causing severe damage in Iran and seems to be important also in Syria (Table 2).

H. armigera may be a threat to cotton, which is one of the most important cash crops in some countries of the region, especially when it is grown together with tomato, maize, or chickpea regularly. The insect switches over from these crops and becomes serious on cotton. In small areas in western Syria and northern Lebanon, where cotton is grown together regularly with corn, infestation may reach 100% (Talhouk 1969). But in other major cotton-producing areas of Syria, infestations rarely reach up to 10%. Peyrelongue (1966) estimated infestation during the 1960s at 7%. Recent estimations of *H. armigera* infestation on cotton show that there is an increase in the importance of *Heliothis* as a destructive pest in some fields, which may be due to late planting or to the increase in chickpea area (Elmosa 1981).

Crop loss estimations in the region vary from year to year and are inadequate in some countries. Reports on *H. armigera* being a major pest and causing loss in many crops in Iran indicated that damage in field-grown maize ranged from 8 to 55% in 1968 and 3 to 46% in 1969, but was only 1 % in 1970-71 (Barbulescu 1973). The damage by *H. armigera* in tomato in the Aegean area (Turkey) was estimated to be as much as 36% (Ongoren et al. 1977).

Population Buildup

Three important factors are involved in *Heliothis* population buildup in the region. The first is the growing of suitable hosts, together or in sequence. Damage to cotton in Syria depends on other early crop hosts on which there is buildup of populations that move to cotton as these hosts become unattractive. *H. armigera* is more important in the areas growing chickpeas, maize, and tomatoes together regularly with cotton. The second factor in moth population buildup is related to the migratory habit of *H.armigera* as well as *H. viriplaca, H. peltigera,* and *H. nubigera* (Rivnay 1962; Wiltshire 1957). In certain instances, the moths may fly to the region from the warmer parts of Africa, thus reinforcing the resident local populations (Talhouk 1969). Crops sown in virgin lands in the semidesert of the Negev were heavily attacked by migrant *Heliothis,* which was never known there before (Rivnay 1962). Thus the invasion by *Heliothis* may occur as a result of

Table 2. Heliothis spp.[a] and host crops in some countries of southwest Asia.

Crop	Turkey	Syria	Lebanon	Jordan	Palestine	Saudi Arabia	South Yemen	Iraq	Iran
Tomato	HA***[b]	HA**[b], HN*[b]	HA*	HA**, HP*	HA**	HA*	HA**	HA*	HA*, HV**
Tobacco	HP*	HA*, HN*		HA**	HA**, HN** HP**			HP*	HA**, HP*, HV**
Eggplant									HN*
Green pepper		HA*		HA*	HA**	HA*			
Chickpea		HA**, HV**, HP*	HA**, HV**	HP*		?HA*		HP*	HV*
Pea					HA**				HV*, HA*
Lentil		HA*, HV*. HP*							HV*
Groundnut					HA**				
Alfalfa					HA", HP*, HN*	HA*			HA*, HV*
Clover					HA**				
Melon, cucumber. and squash						HA*			
Cotton	HA*** HP*	HA*			HA**, HP*		HA*	HA**, HP*	HA*",HP*,HV"
Okra									HA*
Maize		HA*	HA**		HA**				HA*. HV*
Sorghum	HP*							HP*	HV*
Flax									HV***
Beets					HA**	?HA*		HP*	HA*, HV*
Sunflower	HP*				HA*			HA*	
Safflower					HA**, HN**, HP**	HP*			
Cabbbage					HA**				
Carnation					HA**				
Citrus					HA**				
Grape									HA*

References: Turkey-Ileri 1960. Gentry 1965, Ongoren et al. 1977; Syria-Gentry 1965, Talhouk 1979, Barbandy 1973. Hariri 1972.1979; Lebanon-Gentry 1965, Talhouk 1969; Jordan-Gentry 1965, Elmosa 1979; Palestine-Bar 1979, Rivnay 1962, Gentry 1965; Saudi Arabia—Martin 1977; South Yemen—Ba-Angood 1977; Iran—Gentry 1965, Zahedi 1968, Barbulescu 1973, Moradeshagi and Poormirza 1976; Iraq-Wiltshire 1957, Gentry 1965, Selim 1977.

a. HA = *Heliothis armigera;* HN = *H. nubigera;* HP = *H. peltigera:* HV = *H. viriplaca.*

b. Infestation level: "'severe, control measures essential; "moderate, control measures needed occasionally or locally; *tow, control measures seldom needed.

the long-distance movement from one area to another as well as from one crop to another. The third factor is the introduction of new crops on a large scale, which gives excellent possibilities for mass development of *Heliothis,* which might have formerly been of minor importance (Bytinski-Salz 1965).

Other factors are also important in the buildup of moth population. A mild winter or any early spring allows the moths to emerge from diapaused pupae in February-March (Hariri 1979). Chickpea plants at seedling stage are attractive to *Heliothis* spp egg-laying moths, and so could act as an early build-up host for these pests; this is in contrast to other crops, where egg-laying is known to occur only during the flowering and fruiting periods (Sithanantham et al. 1981). In cotton fields, the moths start to appear as early as June (Barbandy 1973).

In a recent study carried out at the ICARDA site in North Syria during the 1980 and 1981 growing seasons, *H. armigera* adults were caught in chickpea and cotton fields in pheromone traps. The moth catch increased steadily from February to July in chickpea fields, while it declined from July to November in cotton fields, and few moths were caught in December. The catch in cotton was ten times greater than in chickpea fields (ICARDA, unpublished). Light traps in chickpea fields from April to June 1981 indicated that *H. viriplaca* moths were more abundant than *H. armigera* or *H. peltigera.* Moths emerged from pupae collected from chickpea and lentil fields during the 1980 and 1981 seasons showed that *H. armigera* was more abundant in the 1980 season than the other two species, whereas *H. viriplaca* was more abundant in the 1981 season (ICARDA, unpublished).

Little is known about the role of natural enemies in suppression of *Heliothis* spp populations in the Southwest Asia region. Recorded' principal parasites of *H. armigera* larvae were *Hyposoter didymator* (Thnb.) *Meteorus* sp, and *Bracon hebetor* Say. *H. didymator* was a significant limiting factor of *H. armigera* populations on cotton (Bar et al. 1979). In Turkey, *B. hebetor* was found parasitizing *H. armigera* larvae on tomatoes (Ongoren et al. 1977), while in Syria, *Habrobracon brevicornis* Wesm. was found parasitizing larvae of *H. armigera* and *Earias insulana* Boisd. on cotton (Stam and Sabek 1981). The bacteria, *Bacillus* sp and *Hafnia* sp were recorded infecting *H. armigera* larvae (Ongoren et al. 1977). The predators of eggs and larvae of *H. armigera* were *Orius* spp and *Chrysopa carnea* Steph. (Bar et al. 1979).

Monitoring and Future Needs in *Heliothis* Management Research

A review of the literature revealed a lack of basic information on the biology and ecology of *Heliothis* spp in most countries of the region. Currently there are studies in progress to determine the injury thresholds for *Heliothis* as well as other main insect pests of cotton and the role of natural enemies in controlling them (Stem and Sabek 1981; Elmosa 1981), and in chickpea fields (ICARDA, unpublished). The economic threshold of *H. armigera* on cotton in Egypt was determined as 10 young larvae/100 plants.

Due to the increase of maize cultivation in Azerbaidzhan (USSR), the economic injury threshold for *H. armigera* on cotton has been revised to 5 to 6 larvae and 10 to 12 eggs of the first generation and 10 to 12 larvae and more than 20 eggs of the second generation per 100 plants, with some differences in these figures in different areas (Mamedova 1978; Mamedova et al. 1975).

For future *Heliothis* management research in the region, the following topics are suggested:

a. Further work on the evaluation of crop loss and economic damage threshold of *Heliothis* in each country of the region.

b. Emphasis on the use of insecticides in integrated control of *Heliothis* spp and careful monitoring of the development of insecticide resistance.

c. Work on determining the role of natural enemies, such as parasites and specific diseases, and their possible use against *Heliothis* spp.

d. Further studies on the biology and population dynamics of *Heliothis* spp using an efficient trapping system.

References

BA-ANGOOD, S.A.A. 1977. Control of the tomato fruitworm, *Heliothis armigera* Hb. (Lepidoptera: Noctuidae), in People's Democratic Republic of Yemen. Journal of Horticultural Science 52: 457-459.

BAR, D., GERLING, D., and ROSSLER, Y. 1979. Bionomics of the principal natural enemies attacking *Heliothis armigera* in cotton fields. Environmental Entomology 8: 468-474.

BARBANDY, A.R. 1973. Cotton insects in Deir Elzor Governorate. Ministry of Agriculture Agrarian Reform, Syria, Leaflet 40, 32 pp. (In Arabic).

BARBULESCU, A. 1973. Some observations on the biology, ecology and attack of *Heliothiszea* Boddie (Lepidoptera) in the conditions of Rasht (Iran). Problems de Protectia Plantelor 1:311 -317. Cited in Review of Applied Entomology Series A 63: Abstract 1931.

BYTINSKI-SALZ, H. 1965. Effects of modern agrotechnical methods on the agricultural insect pest population. *In* Proceedings, 12th International Congress of Entomology, 1964, London, UK.

ELMOSA, H. 1979. Insect species belonging to Lepidoptera in Jordan. Dirasat 6: 7-16.

ELMOSA, H. 1981. FAO/UNEP Near East Inter-Country Program for the Development and Application of Integrated Pest Control in Cotton Growing. 1980 report. 44 pp.

FAO (Food and Agriculture Organization). 1981. Production yearbook 1981, vol. 34. Rome, Italy: FAO.

GENTRY, J.W. 1965. Crop insects of Northeast Africa-Southwest Asia. U.S. Department of Agriculture Handbook No.273, Washington DC, USA.

HARIRI, G. 1972. The economic insects of Syria and neighbouring countries, Part 1. University of Aleppo, Syria, 465 pp.

HARIRI, G. 1979. Insect pests of chickpea and lentils in the countries of the Eastern Mediterranean: A review. Pages 120-123 *in* Food legume improvement and development (eds. G.C. Hawtin and G.J. Chancellor). ICARDA-IDRC publication, Aleppo, Syria. 216 pp.

ILERI, M. 1960. Cukurova Pmnklarinda Zarali Yesil Kurt *(Heliothis obsoleta* F.) nin Yasayisi Salgin iasmasi ve onlenme earlleri uzerinde ara. Stir malar Ankara Ziraat Mucadele Muderrade. Ankara, Turkey 16:64. (In Turkish).

MAMEDOVA, S.R. 1978. Ways of improving the method of protecting cotton. Review of Applied Entomology Series A 68: 1180.

MAMEDOVA, S.R., GUSEINOV, D.G., and ISMAILOV, F. Yu. 1975. The tactics of control of the cotton bollworm in Azerbaidzhan. Review of Applied Entomology Series A 65: 334.

MARTIN, H.E. 1971. List of plant pests and diseases in Saudi Arabia. Near East Plant Protection Committee, FAO, Cairo, Egypt. 55 pp.

MORADESHAGI, J., and POORMIRZA, A.A. 1976. Laboratory studies on host preference and insecticide resistance of the cotton bollworm, *Heliothis obsoleta.* F. Bull. Org. Europ. Med. Prot. Pl. 6: 315-321.

ONGOREN, K., KAYA, N., and TORKMEN, S. 1977. Investigations on the morphology, bio-ecology and control methods of the tomato fruitworm *(Heliothis armigera* Hb.) harmful on tomatoes in Aegean region. Bitki Horuma Bulteni 17: 3-28.

PEYRELONGUE, J.Y. 1966. Rapport de mission en Syrie. Cotonnier entomologie. Internationale Recherche Cotonnier Tropicale, Paris, France. 71 pp.

RIVNAY, E. 1962. Field crop pests in the Near East. The Hague, Netherlands: Junk Publishers. 450 pp.

SELIM, A.A. 1977. Insect pests of safflower (*Carthamus tinctorius)* in Mosul, Northern Iraq. Mesopotamia Journal of Agriculture 12: 75-78.

SITHANANTHAM, S., TAHHAN, O., HARIRI, G., and REED, W. 1981. The impact of winter sown chickpeas on insect pests and their management. Presented at the Workshop on *Ascochyta* Blight and Winter Sowing of Chickpeas. ICARDA, May 1981, Aleppo, Syria. 12 pp.

STAM, P.A., and SABEK, S. 1981. Bio-control and the importance of some insect pests on cotton in Syria. Report for 1980 Near East Regional Programme, Integrated Pest Control, FAO/UNEP/0108/76/03. 55 pp.

TALHOUK, A.A. 1969. Insects and mites injurious to crops in Middle Eastern countries. Hamburg: Verlag Paul Parey. 239 pp.

WILTSHIRE, E.P. 1957. The Lepidoptera of Iraq. Ministry of Agriculture, Baghdad, Iraq. 162 pp.

ZAHEDI, K. 1968. Lotta antiparasitaria della piante orteusi nell. Iran Faculty of Agriculture, University of Teheran Publication 102, Teheran, Iran.

Progress and Problems in *Heliothis* Management in Tropical Southern Africa

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Abstract

Heliothis armigera *in southern Africa occurs on a wide variety of wild hosts and is a damaging pest of many crops, of which cotton is the most important in terms of control costs. Although predominantly a summer pest.* H. armigera *is recorded as damaging on both summer and winter crops, and is of economic importance throughout the year in some part of the region.*

Ten years' records show that the timing of attack on any particular cotton crop is not predictable within useful limits, and the efficiency of control measures therefore depends upon field scouting to assess pest incidence and the need for insecticidal applications. The economic threshold for action to control H. armigera *attack is also variable, and is affected by climatic factors and farming practices as well as crop variety.*

Low-level insecticide resistance in H. armigera *populations has been recorded in both Zimbabwe and South Africa in recent years, though the problem has not yet caused serious economic losses. However, with the planned intensification of agricultural production and expected* extension of double-cropping irrigation schemes, *the probability of the induction of resistance is steadily increasing.*

The general introduction of crop scouting to limit insecticide usage to essential periods, together with the development of biologically selective control measures and the improvement of pesticide application methods are suggested as priorities in the development of sound management practices for Heliothis.

Résumé

*Progrès et problèmes dans la lutte contre l'***Heliothis** *dans les régions tropicales d'Afrique australe: En Afrique australe,* **Heliothis armigera** *se retrouve dans un grand éventail d'hôtes sauvages et c'est un ravageur de plusieurs cultures, dont le coton, la plus importante au niveau du coût de la lutte. Bien qu'***H. armigera** *soit surtout un ravageur en été, on a vu cet insecte s'attaquer aux cultures d'été et d'hiver et il est économiquement important tout au cours de l'année dans certaines parties de la région.*

*Des données couvrant une période de dix ans montrent que le temps de l'attaque sur les cultures cotonnières n'est pas prévisible dans des limites utiles et, par conséquent, l'efficacité des mesures de lutte dépend de la surveillance sur le terrain afin d'évaluer l'incidence du ravageur et le besoin de traitements insecticides. Les seuils économiques justifiant des mesures de lutte contre les attaques d'***H. armigera** *sont aussi variables et dépendent des facteurs climatiques, des pratiques agricoles, ainsi que des variétés.*

*De faibles niveaux de résistance aux insecticides chez les populations d'***H. armigera** *ont été signalés au Zimbabwe et en Afrique du Sud au cours des dernières années, mais jusqu'ici ce problème n'a pas causé de pertes économiques importantes. Cependant, la probabilité d'induction de la résistance s'accroît progressivement suite à l'intensification planifiée de la production agricole et l'extension prévue des projets d'irrigation pour la production de deux cultures annuellement.*

*L'introduction généralisée de la surveillance des cultures pour limiter l'utilisation des insecticides aux périodes essentielles et le développement de mesures de lutte biologiquement sélectives, ainsi que l'amélioration des modes d'application des insecticides sont recommandés comme priorités dans la mise au point de mesures de lutte efficaces contre l'***Heliothis.**

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Heliothis armigera is a pest of economic importance on a very wide range of crops in southern Africa, principally cotton, but including various beans, castor, carnations, chickpea, citrus, coffee (young leaves), groundnut, maize, peas, sorghum, stocks, sunflower, sunnhemp, tobacco, tomato, and wheat (PPRI 1980). In the Republic of South Africa additional crop hosts recorded are apples, boysenberries, cherries, cruciferae, cucurbits, lucerne, lupines, ornamentals, peaches, pears, plums, quinces, vines, and youngberries (Bot et al. 1980). *H. armigera* also occurs on a wide range of wild hosts, including some flowering trees and shrubs such as *Cassia* spp. An *H. armigera* larva was recovered from a wild winter-flowering *Cassia* at Gatooma during bush surveys carried out in 1970, but there are no other records of *Heliothis* on wild trees. Laboratory feeding tests in September at Gatooma have indicated that *Brachystegia spiciformis, Schotia brachypetala,* and *Erythrina abyssinica* flowering heads are readily taken by all stages of *H. armigera* larvae. Larval development was almost identical for *Brachystegia, Schotia,* and the standard bean and maize meal *Heliothis* diet, but was slower for larvae feeding on *Erythrina.*

In considering the problems and possibilities connected with *Heliothis* management in this region, it must be recognized that besides the wide range of potential hosts, there is also a wide range of climatic and environmental conditions under which the hosts may occur. There is also a wide range of farming practices and levels of agricultural inputs applied in different cropping systems, having differing impacts on the stability or instability of *Heliothis* populations through the seasons.

The cost of *Heliothis* control is greater for cotton than for any other crop in the region; this paper will therefore deal basically with the problems of *H. armigera* in cotton and some recent developments in its control and management, while introducing other crops where appropriate.

The Seasonal Incidence of *Heliothis*

Heliothis armigera has been recorded attacking different crops at all seasons of the year in Zimbabwe, but is predominantly a pest during the summer rainy season. In the winter months it is more prevalent in the warmer environments, with monthly mean temperatures about 15°C, than in the cooler uplands. It can be damaging on tomatoes and other irrigated vegetable crops during the winter season, from May to September. On citrus it is recorded (Pearson 1958) from the end of August to October and it can cause damage to irrigated winter wheat during the soft dough stage over a similar period.

Heliothis armigera damage to Virginia tobacco (Tobacco Research Board 1980) is most likely to occur between October and December, within 8 weeks of transplanting. On cotton it has been recorded from October to June, virtually throughout the legal cotton period, and also on out-of-season experimental crops at Gatooma and in the Zambesi Valley between May and September. Although the pupal diapause (Pearson 1958) may facilitate population carryover under the normally dry winter conditions, it seems probable that the increasing winter irrigation is providing opportunities for a continuous progression of nondiapause generations to persist all year round.

The incidence of damaging levels of H. *armigera* on cotton, as indeed on other crops, is highly variable. Table 1 summarizes ten years of cotton pest research records of the periods during which pesticide spray control of *Heliothis* was required (Gatooma Research Station 1969, 1970, 1971, 1972, 1973; Brettell et al. 1974-1981) at (a) Gatooma Research Institute on raingrown cotton germinated between 5 November and 10 December and (b) Chiredzi Research Station on irrigated cotton germinated about the first week of November.

It must be emphasized that these examples apply to well-managed trial crops on research stations. Much greater variations occur under farm conditions ranging from some very long-season irrigated crops to some very short-season rainfed crops in the warmer and drier areas.

At Gatooma the incidence of *H. armigera* has also been monitored by a Robinson light trap for the past 10 years, and graphical comparisons of light-trap records of *H. armigera* moth catches and contemporaneous weekly records of egg counts from field trials are shown in Figure 1. This figure gives:

1 The weekly totals of *H. armigera* moths caught by the light trap during each cotton cropping season from 1971 -72 to 1980-81. The numbers are graphed on a logarithmic scale against weeks and for the week of full moon, moth numbers are corrected upwards, where necessary, to the geometric mean between the preceding and succeeding weekly moth

Table 1. Duration of damaging Heliothis attack in cotton trials 1070/71-1980/81.

	Gatooma (1157m) Jan Feb Mar Apr May	Chiredzi (430m) Nov Dec Jan Feb Mar Apr
Earliest and latest dates of attack over 10 years	18 weeks x------------------x	17 weeks x------------------x
Longest seasonal attack	11.5 weeks x-------------x	11 weeks x-------------x
Shortest seasonal attack	3 weeks x---x	3 weeks x---x
Common attack period over 10 years	2 weeks x--x	3 weeks x---x
Common attack period 4 years in 5	6 weeks x----x	6 weeks x----x

catches. Light-trap moth catches are almost always reduced during full moon.

2 The mean weekly *H. armigera* egg counts per 100 plants, recorded from the weekly scouting of 420 to 600 randomly selected plants in the *Heliothis* insecticides trial at Gatooma, which is conducted annually.

3. The weekly rainfall total (mm) recorded at the Cotton Research Institute.

4. The recommended timing of insecticide spraying for *H. armigera* control, based upon an action threshold (A/T_E) of 50 eggs per 100 plants (12/24 plants), or a cumulative count exceeding the A/T_E over 2 or 3 consecutive unsprayed weeks, or a rising count the projection of which would exceed A/T_E by the next week. Late-season sprays due according to the A/TE after the cotton had reached maturity are marked as cancelled.

During the main cotton flowering and fruit-formation period, mid-February to mid-April, the correlation between moth catches and *Heliothis* egg counts is often quite good, but discrepancies between the two may be large at the start of many seasons and also during the course of some seasons such as 1972-73, which was a drought year: 1975-76, when cotton germination was very late; and 1980-81, which was unusually wet.

In view of the unpredictability of the time of *Heliothis* attack on cotton crops in different places in the same season, or the same place in different seasons, or on adjoining crops of different ages in the same season, the efficient timing of *Heliothis* control measures is completely dependent upon crop inspection and scouting for pest incidence if unnecessary insecticide applications are to be avoided.

General Considerations for *Heliothis* Control

For cotton, scouting procedures are needed to assess the incidence of at least five key pests, including *Heliothis.* For this reason sequential sampling has not been developed for farm use, since the full sample size is virtually always required.

Standard practice is to scout weekly 24 plants (Gledhill et al. 1972) per field of up to 20 ha on a stratified sampling pattern. Where pest levels are close to the prescribed action threshold, an additional check count is recommended to verify the results; other factors related to yield potential may also be used in deciding whether or not to spray a broad-spectrum insecticide.

Chemical pest-control trials in Zimbabwe are aimed at establishing minimal effective field dosage rates for *Heliothis* pesticides, assessed on the basis of 7-day intervals between spray applications, when egg incidence is above the action threshold.

Minimal effective dosage rates on full-grown cotton for recommended *Heliothis* insecticides assessed at two research station sites in Zimbabwe over the past 12 years are given in Table 2.

Carbaryl 85% WP at 1000 g ai and endosulfan at 300 g ai with 10% to 25% molasses as diluent are also recommended for *Heliothis* control but are not quite as active as the other chemicals listed.

Concurrent research is conducted on scouting

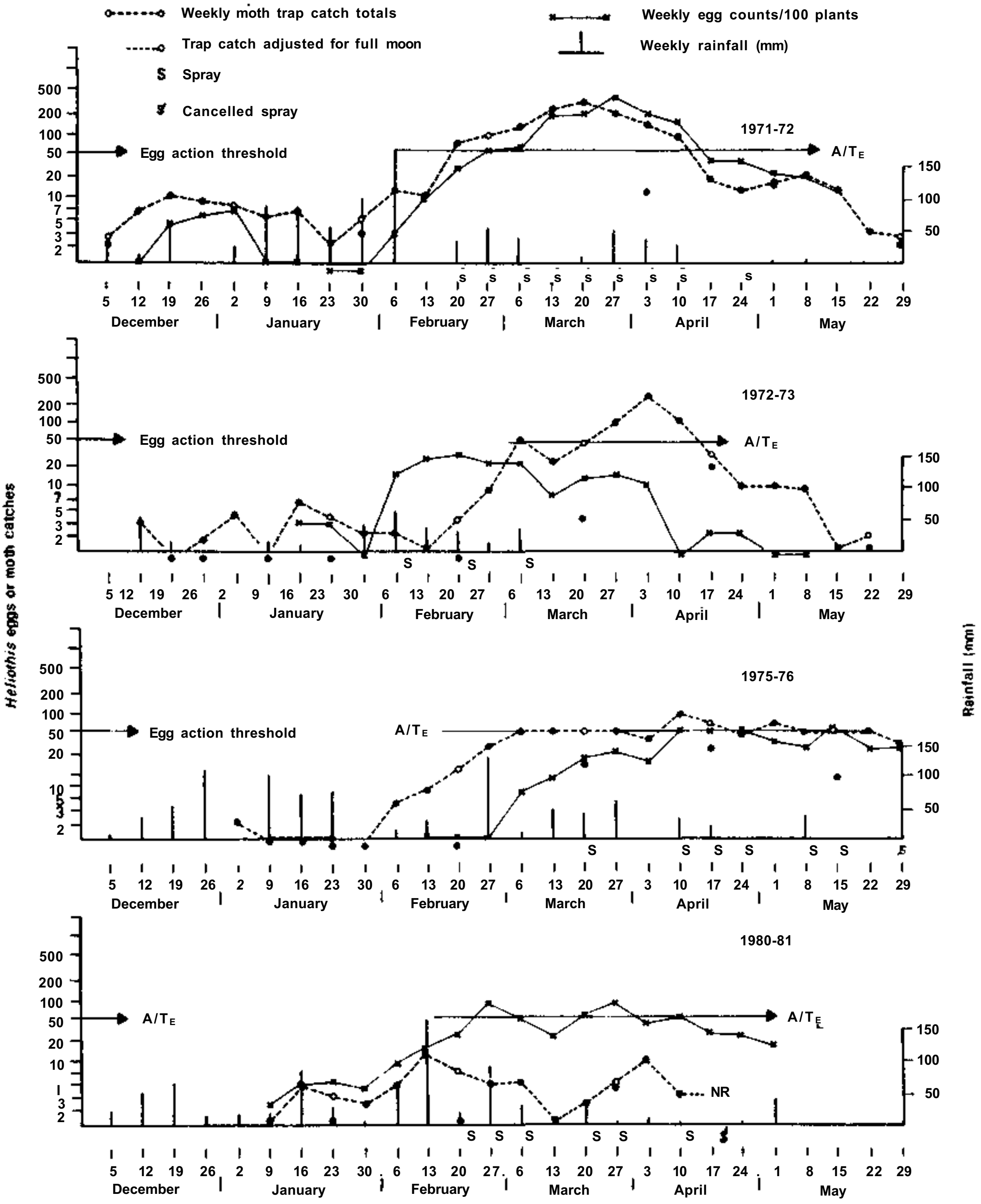

Figure 1. Light-trap and insecticide trials for Heliothis armigera *control, field records, Gatooma Research Station, Zimbabwe: 1971-72, a normal year; 1972-73, a drought year; 1975-76, cotton germination unusually late; 1980-81, an unusually wet year.*

Table 2. Relative field activity of recommended Insecticides against Heliothis armigera In Zimbabwe.

Insecticide	Formulation	Rate of application/ ha
DDT (limited recommendation)	75% WP	1000 g ai
Endosulfan	35% MO	500 g ai
Cypermethrin	20% EC	30 g ai
Deltamethrin	2.5% EC	6.25 g ai
Fenvalerate	20% EC	40 g ai

methods and the practical determination of spray timing, using action thresholds applicable in the existing wide range of farming conditions.

Action Thresholds and Spray Timing for Chemical Control of *Heliothis* on Cotton

The optimum timing of insecticide applications is subject to a range of factors, some of which, like weather, can alter crop potential within wide limits, and are beyond major remedy, but must be taken into account. Others, such as levels of pest incidence, produce fairly predictable short-term effects that are amenable to corrective action. Practical recommendations on spray timing (Gledhill 1977) that will avoid the use of potentially wasteful calendar spraying have to be tailored to meet the different users' resources and requirements. This calls for a gradation of recommendations from the most simple to the most sophisticated, suited to the different farming practices and conditions.

Given the ability to recognize and count *Heliothis* eggs, the simplest set of recommendations relate to late-germinated rainfed cotton with a strictly limited growing season. In such cases, any *Heliothis* attack above a given action threshold based on egg counts (normally 12 eggs per 24 plants) would justify a spray application. A simple yes or no spray decision is required weekly.

At the other end of the scale is the detailed procedure needed for deciding optimum pest-management practices in cotton crops with a long dependable growing season when water and temperature are not normally limiting. Under effective and flexible management with the implementation of weekly or twice-weekly crop scouting and cross checking, the season can be divided into four periods, during which different criteria for timing of chemical spray applications against *Heliothis* are appropriate.

1. Early growth period: prior to the formation of potentially productive squares (time of first effective squares) (Heam and Room 1979), spray decision is made on weekly larval counts, with an action threshold of up to 18 larvae on 24 plants. The aim is to limit the use of broad-spectrum pesticides during this period, and biological control agents or selective chemical insecticides would be most useful here.
2. Early squaring and fruiting period: from first productive square formation to about the second week (depending on climate) of productive flower formation. Spray decision is made on weekly egg and larval counts, with an action threshold of 12 eggs (or 6 larvae) on 24 plants.
3. Main fruiting period: from period 2 until 2 weeks after estimated date of last productive flower. This should not be longer than about 8 weeks. Spraying decision is made on weekly action threshold of: (a) counts of 8 eggs per 24 plants, or (b) cumulative counts of 8 eggs per 24 plants from 2 or 3 consecutive weeks without spray applications, or (c) rising egg counts, the projection of which would exceed 8 per 24 plants by the next week.
4. Crop maturing period: spray decision is made on 10- to 14-day action threshold of 12 eggs per 24 plants until all productive bolls have reached the fibrous stage; thereafter *Heliothis* control is not required

Where crop scouting is conducted twice weekly, spray action on egg thresholds can be delayed by 3 or 4 days if pest control, as indicated by low larval counts, retains effectiveness for more than a week. This allows the spray interval to be extended to 10 days or 2 weeks where justified by insecticidal persistence or any other cause of high pest mortality.

Many larger farms and estates in Zimbabwe pay a hectarage fee to participate in an external check scouting scheme, which operates to supplement their farm scouts. The check scouting scheme is organized by the Commercial Cotton Growers

Association and provides for weekly checks as well as monthly, or more frequent, group discussions with extension specialists.

Heliothis Resistance to Insecticides

In Zimbabwe, despite fairly intensive insecticidal treatments against *Heliothis* on about 100 000 ha of cotton annually, in rather widely dispersed areas, there has only been one established instance (in 1978) over the past 10 years of insecticide resistance in a *Heliothis* population. Although it was not possible to carry out a full-scale comparative bioassay between the field strain from Chisumbanje Estate and the laboratory standard culture, the limited tests that were completed with insecticide concentrations close to the normal LC50s showed tolerance levels for both endosulfan and DDT that were from 1.6 to over 2.5 times higher in the field strain (Madende and Brettell 1978).

In South Africa, tolerance of *Heliothis armigera* to endosulfan (3 times) and parathion (5 times) was reported by Whitlock in 1973. More recently, Basson (1980) investigated reports of unsatisfactory control of *H. armigera* by endosulfan in some cotton-producing areas in the northern and eastern Transvaal. On bioassay, he found resistance factors of 2.1 and 0.7 over the laboratory standard in larvae from Komatipoort in the 1976-77 and 1977-78 seasons. Subsequently, endosulfan had been replaced by synthetic pyrethroids for *Heliothis* control in these areas, with satisfactory results, but Basson advised continued monitoring to check for *Heliothis* resistance to the insecticide currently in use.

In the case of resistance at Chisumbanje in Southeastern Zimbabwe, the estate management decided to adopt a new pest-control program in 1978-79, following research recommendations (Gledhill 1980) aimed at reducing the risk of building up insecticide resistance in *Heliothis.* Chisumbanje is a fully irrigated estate of over 2000 ha growing summer cotton and winter wheat. *Heliothis* populations persist throughout the year, and heavy attack usually develops on seedling cotton in October and November during which period there are virtually no other green plants, either cultivated or wild, available to egg-laying moths. For a number of years previously, the pest spraying program had been based upon the simple premise that high input equals high production; this approach resulted in the heavy use of pesticide mixtures at all stages of cotton crop development. Cotton plantings had been made from early October to mid-December, and the resultant spraying program on successive fields continued from mid-October to May or June.

Under the revised spraying program, minimal insecticide sprays were applied against *Heliothis* (spray threshold of 18 larvae per 24 plants or 25000 larvae/ha) during the period from germination up to 27 December (period P1, Fig. 2). Thereafter, during the main crop-formation period through crop maturity, (period P2, Fig. 2) *Heliothis* control sprays were applied at the standard spray threshold of 12 eggs or 6 larvae per 24 plants, and a synthetic pyrethroid was introduced into the spray program for the first time.

In the 1978-79 season, cotton germination on the estate extended over 10 weeks. For the purpose of analysis, scouting records from all fields (total area of 2295 ha) were assembled into 10 groups. Mean egg and larval counts from cotton fields with the same week of germination were computed separately for period P1 and period P2. These are shown in Figure 2, together with the main yields for each group.

The marked differences in the intensity of *Heliothis* attack on cotton fields of different ages is noteworthy, and emphasizes the importance of field scouting for the determination of pest threshold levels rather than dependence upon nonspecific assessments of pest incidence.

It appears unlikely that the high *Heliothis* larval populations during period 1 on the earlier planted fields had any appreciable adverse effects upon yield. The highest single yield of the season was from a field that germinated in the week ending 21 October; and this yielded 3716 kg/ha seed cotton despite mean larval counts of more than 45 per 100 plants over 8 weeks in period P1. Factors other than early *Heliothis* attack were obviously important in determining yield.

The number of *Heliothis* control sprays applied to each group of fields in periods P1 and P2 are shown in Table 3, together with the number of carbaryl sprays applied for *Diparopsis castanea* (red bollworm) control. These carbaryl sprays would also have provided some degree of control of *Heliothis.*

Heliothis larvae were collected from the Chisumbanje Estate in February 1979 and used to initiate a separate laboratory culture at the Cotton Research Institute in Gatooma. This was subsequently compared with the standard Gatooma laboratory strain

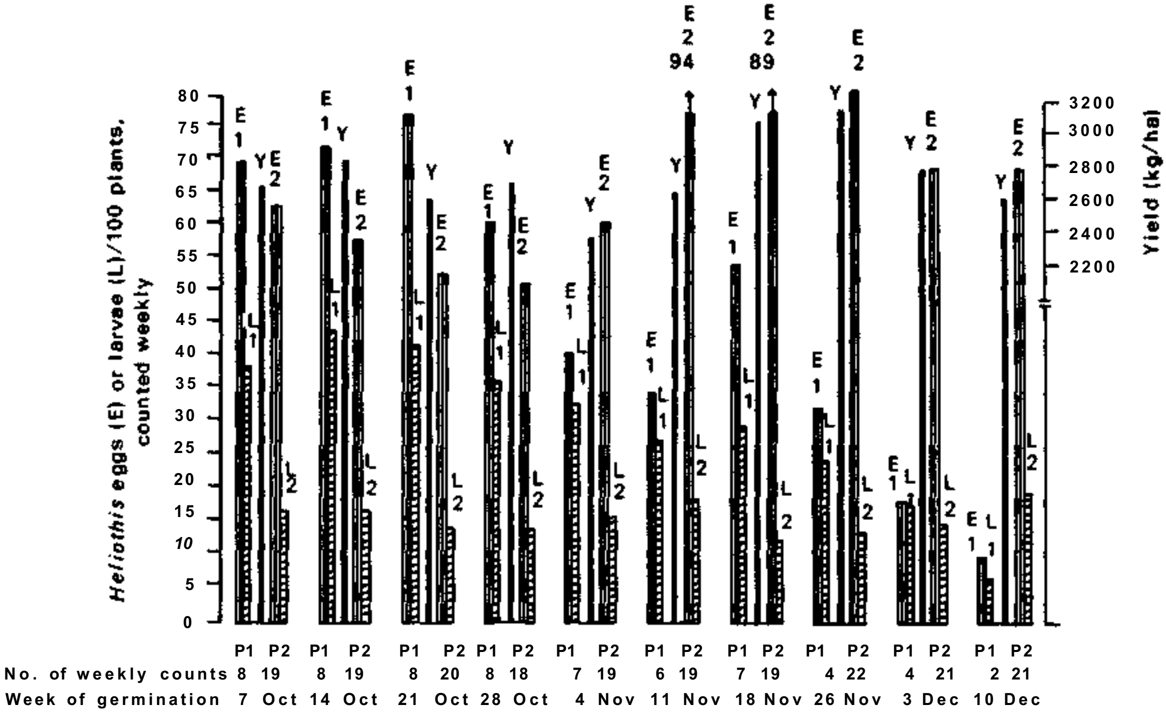

Figure 2. **Heliothis armigera** *egg and larval counts from weekly scouting records, Chisumbanje Estate, Southeastern Zimbabwe, 1978-79 season. P1 = period 1, before 28 December; P2 = Period 2, after 28 December; E1 and L1 = egg and larval counts in Period 1; E2 and L2 = egg and larval counts in period 2; Y = yield of seed cotton.*

Table 3. Mean number of bollworm sprays applied to cotton on Chisumbanje Estate, southeastern Zimbabwe.

Group No.	Week of germination 1978	Total area (ha)	Period 1 (Germination to 27 Dec)		Period 2 (27 Dec to maturity)	Yield (kg/ha)
			Diparopsis	*Heliothis*	*Heliothis*	
1	7.10	64	2.5	1.5	8.0	2619
2	14.10	32	2.3	1.6	8.1	2796
3	21.10	317	1.5	1.9	6.8	2564
4	28.10	285	1.1	1.4	7.0	2661
5	4.11	321	1.0	0.9	7.3	2338
6	11.11	326	0.4	0.8	7.6	2609
7	18.11	90	0	0.5	8.5	3051
8	26.11	149	0	0.4	9.2	3122
9	3.12	604	0	0.3	8.3	2757
10	10.12	106	0	0	6.8	2610

for susceptibility to endosulfan. Replicated bioassays testing mortality rates of second-instar larvae exposed to cotton leaf discs treated with a series of concentrations of endosulfan gave almost identical LC50s for both strains (Madende and Brettell 1979).

Biological Control of *Heliothis armigera*

Investigations into numerous aspects of biological control of the cotton bollworm by predators, parasites, pathogens, trap crops, and crop breeding were instituted in southern Africa by the Empire Cotton Growing Corporation Research Stations at Barberton and Gatooma, starting in the late 1920s. After the introduction of the broad-spectrum chlorinated hydrocarbons, organophosphates, and carbamates in the 1950s, the relative amount of research applied to biological control diminished, but the field has still continued to receive attention, even from research stations basically concerned with cotton production research.

McKinley (1971) in Rhodesia and Roome (1975a, 1975b) in Botswana investigated the use of nuclear polyhedrosis virus and *Bacillus thuringiensis* preparations against *H. armigera* in cotton or sorghum. Roome found that the use of a local virus for *Heliothis* control on sorghum offered definite promise. Later trials with pathogens on cotton in Zimbabwe have confirmed McKinley's findings and have given disappointing results except in cases where the *B. thuringiensis* preparation Dipel was used with chlordimeform, (Brettell et al. 1974-1979) but its field effectiveness was inconsistent.

Brettell (1979) in Zimbabwe, investigating the tolerance to insecticide of some larval Chrysopidae predatory upon *H. armigera,* has found that a common species in cotton fields, *Chrysopa boninensis,* shows remarkably low susceptibility to many *Heliothis* insecticides.

Some work has also been done on the incidence and use of *Trichogrammatoidea* sp egg parasites for *Heliothis* control in cotton. The natural incidence of the parasites has proved to be very sporadic, but apparently unaffected by insecticide spraying programs in the cotton fields sampled.

Another biological control aid under investigation in Zimbabwe is the use of dolichos bean (Peat and Prentice 1938) as a diversionary trap crop against *H. armigera* attack on preflowering cotton (Gledhill 1980a, 1980b). *Dolichos* does not flower until March-April, but if planted a month or more before the cotton crop, it has been found to be much more attractive in its vegetative phase than is preflowering cotton. Under special conditions of exceptionally early *H. armigera* attack upon young cotton (as at Chisumbanje, see Figure 2) this might very well reduce the attack on cotton to nondamaging levels. In addition, it appears that vegetative dolichos bean is not suitable for the complete development of *H. armigera* larvae and may therefore act as a true trap crop in its vegetative phase.

Reducing the Risk of *Heliothis* Resistance

Current registrations and recommendations for insecticides used against *H. armigera* in Zimbabwe take account of the desirability of limiting the intensity of insecticide usage to reduce the chances of selecting for resistance. The need to formulate a definite policy in this regard was sharpened by the advent of the synthetic pyrethroids, the properties of which increased the likelihood of indiscriminate and thoughtless prophylactic insecticide application.

Thus, pyrethroids are not registered for use in winter (irrigated) crops or on summer crops for which economically effective alternatives are readily available. Recommendations are aimed at limiting the period of exposure to pesticides of any given pest species, and at discouraging blanket spray usage.

Pyrethroids are registered only for cutworm control on tobacco, involving one spray at transplanting or soon afterwards. Single applications only are recommended on some other summer crops for the control of *Heliothis.*

for cotton, recommended practices in Zimbabwe include:

1. Use of selective aphicides where necessary for early aphid attack, thus permitting natural predator and parasite buildup.
2. Caution in the early use of broad-spectrum insecticides.
3. Use of'conventional" endosulfan, carbaryl, or (in some cases) DDT sprays for bollworm control, if needed, until the end of January in most cotton-growing areas (late December in the warmer irrigated areas).
4. Limitation in the subsequent use of synthetic pyrethroids on cotton to a period of not more than 9 weeks in any one season.

5. The use of minimal dosage rates of all insecticides, applied only when economically necessary.

The fact that in this region large populations of *Heliothis* on wild hosts and on many summer crops, such as maize, sorghum, and sunflower, do not receive any insecticidal spray treatments provides a large buffer population that should be fully susceptible to insecticides, and should be capable of diluting pockets of incipient resistance, provided adequate mobility and population mixing occurs. This is currently presumed to be the case in most areas, although it is not factually established. However, with the prospect of increasingly intensive crop production, this apparently favorable situation cannot be expected to continue indefinitely.

It is suggested that in regard to the short- and medium-term development of *Heliothis* management in this area, priority should be given to the following aspects:

1. Establishing the use of practical action thresholds for *Heliothis* insecticide applications that can be understood and applied by all the farmers concerned. Acceptable usage of all insecticides should eventually become conditional upon prior crop inspection and scouting.
2. Developing biologically selective methods for *Heliothis* control. Such methods would not have to possess particularly high levels of efficacy in order to be of value. The immediate need is for treatments that can be used safely when larval thresholds of economic damage on crops are relatively high, with the aim of containing *Heliothis* populations without disrupting natural control processes.
3. Reducing spray application costs and simplifying methods available for effective pesticide application. This would increase the relative cost of chemicals against the costs of application and would diminish the attractiveness of high dosage rates intended to provide longer persistence and fewer spray applications. Such practices often result in heavy overdosing and unnecessary pesticide presence, causing ecological damage.

The simplification of application methods would make it easier to promote the use of biological insecticides and the use of lower chemical insecticide dosage rates, giving shorter persistence and providing for more frequent application intervals only if required by actual pest-control requirements.

Acknowledgments

I wish to record my appreciation of assistance received from Dr. J.H. Brettell, who provided the Gatooma light-trap records on *Heliothis* moth catches that have been used in this paper, and gave ready help with the extraction of other station records and in reading and commenting upon the manuscript. Authority from the Director, Department Research and Specialist Services, to present this paper is also gratefully acknowledged.

References

BASSON, N.C.J. 1981. A survey of the possible development of resistance to endosulfan by the American bollworm, *H. armigera* on cotton. *In* Proceedings, Union Carbide Workshop on Cotton Pest Control, March 1980, Nelspruit, S. Africa. In press.

BOT, J., VERMEULEN, J.E., and HOLLINGS, N. 1980. A guide to the use of pesticides and fungicides in the Republic of South Africa. Department of Agricultural Technical Services, Pretoria, South Africa.

BRETTELL, J.H., BEMONT, M.J.L., and DURURU, PC. 1974-1979. Biological control trials. *In* Cotton Research Institute Annual Reports: Pages 102-105 *in* 1974/75; pages 167-170 *in* 1975/76; pages 158-160 *in* 1977/78; pages 158-161 *in* 1978/79, annual reports, Gatooma, Zimbabwe.

BRETTELL, J.H., AND ASSOCIATES. 1974-1981. Bollworm insecticides trials. *In* Cotton Research Institute Annual Reports: Pages 87-90 *in* 1973/74; pages 122-126 *in* 1974/75; pages 141-150 *in* 1975/76; pages 180-184 *in* 1976/77; pages 145-149 *in* 1977/78; and pages 147-151 *in* 1978/79 annual reports. 1979/80 and 1980/81 annual reports in press. Gatooma, Zimbabwe.

BRETTELL, J.H. 1979. Green lacewings (Neuroptera: Chrysopidae) of cotton fields in central Rhodesia. 1. Biology of *Chrysopa boninensis* Okamoto and toxicity of certain insecticides to the larva. Rhodesian Journal of Agricultural Research 17: 141-150.

GATOOMA RESEARCH STATION. 1969, 1972, and 1973. Bollworm insecticide trials. Pages 27-35 *in* 1968/69; pages 59-61 *in* 1971 /72; and pages 68-71 *in* 1972/73 Annual reports, Gatooma Research Station, Zimbabwe.

GLEDHILL, J.A., ET AL. 1972. Bollworm scouting trials, pages 84-85 *in* Gatooma Research Station annual report and pages 136-139 in 1974/75 Cotton Research Institute annual report, Gatooma, Rhodesia.

GLEDHILL, J.A. 1977. Crop losses in cotton caused by *Heliothis* and *Diparopsis* bollworm. Rhodesia Agricultural Journal 73: 135-138.

GLEDHILL, J.A. 1981a. Measures taken against pesticide resistant *Heliothis* population in the Rhodesian lowveld. *In* Proceedings, Union Carbide Workshop on Cotton Pest Control, March 1980, Nelspruit, S. Africa. In press.

GLEDHILL, J.A. 1981b. Dolichos trap cropping trial for *Heliothis. In* Cotton Research Institute annual report 1979/80, Gatooma, Zimbabwe.

HEARN, A.B., and ROOM, P.M. 1979. Analysis of crop development for cotton pest management. Protection Ecology 1:265-277.

McKINLEY, D.J. 1971. Nuclear polyhedrosis virus of the cotton bollworm in Central Africa. Cotton Growers Review 48: 297-303.

MADENDE, M., and BRETTELL, J.H. 1978. Laboratory screening of insecticides. Pages 178-179 *in* Cotton Research Institute annual report 1977/78, Gatooma, Rhodesia.

MADENDE, M., and BRETTELL, J.H. 1979. Laboratory screening of insecticides. Pages 172-173 *in* Cotton Research Institute annual report 1978/79, Gatooma, Zimbabwe.

PPRI (Plant Protection Research Institute). 1970, 1971. Bollworm insecticide trials. Pages 30-37 *in* 1969/70 Annual report and pages 21-25 *in* 1970/71 Annual report. PPRI, Rhodesia.

PPRI (Plant Protection Research Institute). 1981. Departmental records 1980/81. Plant Protection Research Institute and Cotton Research Institute, Department of Research and Specialist Services, Zimbabwe.

PEARSON, E.C. 1958. The insect pests of cotton in tropical Africa. London, UK: Commonwealth Institute of Entomology.

PEAT, J.E., and PRENTICE, A.N. 1938. Cotton Station progress report, Gatooma, Southern Rhodesia. Pages 71 - 72 *in* Empire Cotton Growing Corporation Report, Gatooma, Rhodesia.

ROOME, R.E. 1975a. Fixed trials with a nuclear polyhedrosis virus and *Bacillus thuringiensis* against larvae of *Heliothis armigera* on sorghum and cotton in Botswana. Bulletin of Entomological Research 65: 507-514.

ROOME, R.E. 1975b. Activity of adult *Heliothis armigera* with reference to the flowering of sorghum and maize in Botswana. Bulletin of Entomological Research 65: 523-530.

TOBACCO RESEARCH BOARD. 1980. Tobacco Research Board Recommendations, 1980. TRB, Kutsaga, Zimbabwe.

WHITLOCK, V.H. 1973. Studies on insecticidal resistance in the bollworm *H. armigera.* Phytophylactica 5: 71-74.

Research on *Heliothis* at ICRISAT

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Abstract

The International Crops Research Institute tor the Semi-Arid Tropics (ICRISAT) has a mandate to improve the production of sorghum, pearl millet, groundnut, pigeonpea, and chickpea. All of these crops are susceptible to Heliothis *spp. and survey data show that both pigeonpea and chickpea suffer crop loss to these pests in almost all the areas of the world where they are grown. The recent progress in research on various aspects of the ecology and management of* Heliothis armigera *at the ICRISAT Center in India is reviewed: population studies using light and pheromone traps; pesticide use; natural control elements, including parasites, predators, and diseases; cultural and cropping practices, including mono- and inter-crop comparisons; and host-plant resistance screening and breeding, including mechanisms of resistance. The potential tor the development of integrated pest management that will be of practical benefit in farmers' fields is also discussed.*

Résumé

*Recherche sur l'*Heliothis *faite à l'ICRISAT: L'Institut international de recherche sur les cultures des zones tropicales semi-arides (ICRISAT) a pour mandat d'augmenter la production de sorgho, de petit mil, d'arachide, de pois d'Angole et de pois chiche. Toutes ces cultures sont sensibles à* Heliothis *spp. Des données d'enquêtes montrent qu'il y a chez le pois d'Angole et le pois chiche des pertes culturales imputables à ces ravageurs dans presque toutes les parties du monde où ces plantes sont cultivées. Les progrès récents de la recherche faite au Centre ICRISAT, en Inde, sur les divers aspects de l'écologie et de la lutte contre* **Heliothis armigera** *sont présentés: études des populations à l'aide de pièges lumineux et à phéromone; utilisation d'insecticides; éléments de lutte naturelle, dont les parasites, les prédateurs et les maladies; pratiques culturales, dont une comparaison entre les cultures pures et associées; criblage et amélioration de la résistance de la plante-hôte, incluant les mécanismes de résistance. Le potentiel de développement d'une lutte intégrée, offrant des avantages pratiques en champs paysans, est également discuté.*

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has the mandate to improve the production of five crops: sorghum, pearl millet, groundnut, pigeonpea, and chickpea. The small farmers with very limited resources, who form the great majority of the farmers in the semi-arid tropics, are our special target. Our clients are the agricultural research and development workers of the national and regional programs, to whom we supply information and materials, particularly new germplasm, which can be locally adapted and developed for the benefit of the farmers.

All five of ICRISAT's mandate crops are susceptible to *Heliothis* spp. At ICRISAT Center, *Heliothis armigera* damages all of these crops and has also been recorded on more than 100 other plant species in this area. This pest causes greatest losses on pigeonpea and chickpea, so our major efforts in *Heliothis* research have been concentrated upon these two crops.

Although chickpea and pigeonpea are not very well known in the world's food markets, they are of enormous importance in some parts of the semi-arid tropics, particularly In the Indian subcontinent, where 80% of the world's chickpea and 90% of the world's pigeonpea crops are grown. They are the two major pulse crops of the region, providing a valuable protein supplement to the diets of the predominantly vegetarian human population.

On pigeonpea, as on most other hosts, *Heliothis* spp larvae are mainly pests of the flowering and fruiting stages of the crop. On chickpea, however, the plants are attractive to egg laying by *Heliothis*

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International Crops Research Institute tor the Semi-Arid Tropics. 1982. Proceedings of the International Workshop on *Heliothis* Management, 15-20 November 1981, Patancheru, A.P., India

spp from the seedling stage and substantial damage can be caused throughout the vegetative and podding stages of this crop.

Surveys of Pest Damage in Chickpea and Pigeonpea

Crop Damage in India

As there were no wide-scale survey data of losses caused by pests in farmers' crops of pigeonpea and chickpea, ICRISAT embarked upon one, starting in 1975, in cooperation with national entomologists. This survey has been particularly active in India, where we have visited and assessed the pest damage in 1297 fields of pigeonpea and 645 fields of chickpea in the major producing areas of the country.

Pigeonpea suffers damage from a large complex of insect pests including several species of lepidopteran larvae, which feed upon the flowers and pods, but *H. armigera* is by far the most important of these. Our surveys are timed to collect samples of pods from the crop at the maturity stage. These samples are brought to our laboratory, where a skilled team assesses the percentage of pods that have been damaged by the various pest groups. The data that were recorded from these surveys across India are shown in Table 1.

It can be seen that damage caused by lepidopteran larvae (mostly *H. armigera)* tends to decrease in the north where the crop matures after the winter, at a time when these pests have had insufficient time to build up to large populations. In the northwest, however, there is substantial cropping of early-maturing pigeonpeas, which are harvested before the winter, and these are often severely damaged by *Heliothis.* The second most damaging pest of pigeonpea in India is the podfly, *Melanagromyza obtusa,* which tends to be of most importance in the central and northern areas in the late-maturing crops.

In southern India, more than one-third of the pods on average, but much more in some areas and years, are damaged by *H. armigera*. Further, we are aware that *H. armigera* not only damages the large pods, which are retained on the plant and so can be counted in our survey samples, but it also destroys large numbers of buds, flowers, and young pods, which are shed, so our survey data can grossly underestimate the damage caused by this pest.

Chickpea has a relatively small number of insect pests of which *Heliothis* spp are dominant in all the major production areas of the world. In India we have collected pod samples from more than 600 farmers' fields and found an average of 7.5% of pods damaged by *H. armigera.* Here again, this grossly underestimates the actual losses caused, for there can be severe vegetative and flower feeding, particularly in central and southern India. This crop grows through the winter, and in most years in northern India it is harvested before *H. armigera* populations build up to damaging levels. In some years and areas, however, the crop is hit by mas-

Table 1. Pigeonpea pod damage by insects in samples from farmer' fields In India, 1975-1981.

	Northwest zone Early-maturing	North zone Late-maturing	Central zone Mid- and late maturing	South zone Early- and mid maturing
Fields sampled (no.)	49	359	446	443
Pods damaged by lepidopteran borers (%)	29.7	13.2	24.3	36.4
Pods damaged by podfly (%)	14.5	20.8	22.3	11.1
Total pods damaged by insect pests (%)	44.0	33.8	48.0	49.9

sive populations of this pest, perhaps as a result of migration, and the crop can be completely destroyed.

Crop Damage in Other Countries

In line with our international mandate, we also take every opportunity to collect data on the pests and the losses that they cause in other countries where these crops are of importance. We collect such data by visits and through correspondence with local entomologists. In all areas of the world where pigeonpea is of importance, *Heliothis* spp are the dominant pests. In eastern Africa, *H. armigera* severely damages the crop. In the Caribbean, both *H. zea* and *H. virescens are* common pests of pigeonpea pods. In our cooperative studies with ICARDA on the pests of chickpea in Syria, we have found that *H. armigera* and *H. viriplaca* (syn *H. dipsacea)* cause major damage, in addition to the leaf miner, *Liriomyza cicerina,* which can cause crop loss in most of the Mediterranean and west Asian chickpea-producing countries. In Mexico and other American countries, both *H. zea* and *H. virescens* are known to cause substantial crop loss in chickpea.

Monitoring and Forecasting *Heliothis* Populations

We are now monitoring the populations of *H. armigera* across areas and seasons in the hope that we will eventually understand the major factors influencing these populations and so be able to forecast the incidence of damaging populations in any area.

Egg and Larvae Counts

The polyphagous habit of *Heliothis* spp complicates the estimation of populations by direct counts of eggs and larvae, for there are so many hosts. At ICRISAT Center our pest surveillance team counts *H. armigera* eggs and larvae on sample areas of all our crops on the pesticide-treated areas. The summarized data from these counts are illustrated in Figure 1. Here it can be seen that our crops provide food for *Heliothis* from late July until April, when a closed season of 2 months, during which no crops may be grown, begins. We adopted this closed season in an attempt to reduce our pest problems, which had become particularly severe, partly because there was continuous availability of crops at all stages of growth throughout the year. In the past 2 years we have reduced *H. armigera* populations within the ICRISAT boundaries virtually to nil during this closed season. Outside our boundaries however, *H. armigera* can be found through the hot and dry April to June period in reduced but substantial populations on a variety of weed hosts and on irrigated tomatoes.

Light- and Pheromone-Trap Catches

We also monitor *H. armigera* populations through catches of moths in light and pheromone traps.

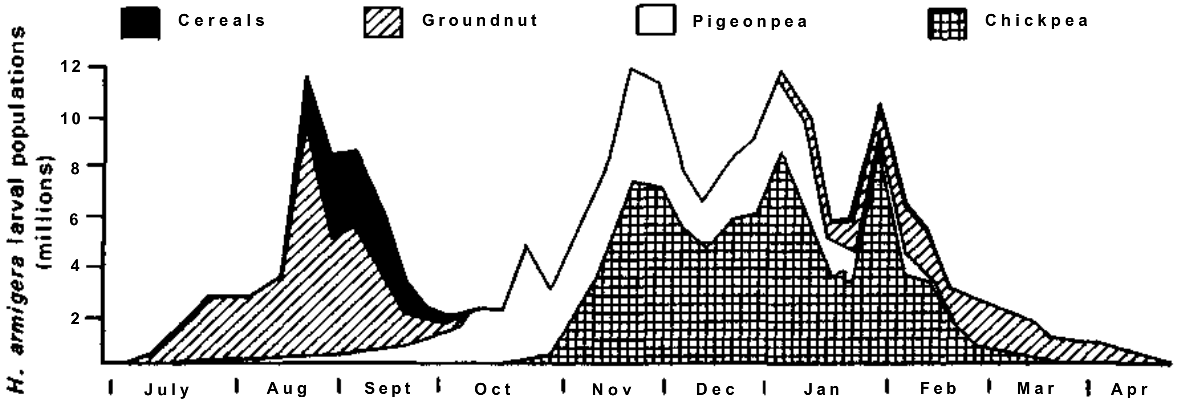

Figure 1. Populations of Heliothis armigera *larvae on crops in the pesticide-treated areas of ICRISAT Center, mean data of 1979-80 and 1980-81 seasons.*

Three light traps have been operated at ICRISAT Center since 1977, the first having been commissioned in 1975. We intend to analyze the catch data in combination with climatic data in an attempt to determine the factors that are of importance in inducing the large fluctuations in populations. We think that there is a probability that there are large-scale migrations of *H. armigera* moths across India. To gain evidence for this, we have joined the Indian Council of Agricultural Research in a project in which light traps have been set up to monitor *H. armigera* in several centers throughout the country. Some centers have found the maintenance of light traps difficult or impossible where no electric power is available, and sorting light-trap catches is a skilled and time-consuming process. We have also initiated a network of pheromone traps, baited with rubber septa impregnated with the synthetic *H. armigera* pheromone, developed and supplied by the Tropical Products Institute (Nesbitt et al. 1979, 1980) with whom we are in active cooperation. These pheromone traps have obvious advantages over light traps for they are relatively cheap, require no power source, and almost all catches are of *H. armigera* male moths, so little time is wasted in sorting the catches.

We are now well into a project comparing the two types of trap catches with each other and with counts of eggs and larvae from the plant hosts across ICRISAT Center. If we find that the trap catches can give reasonable estimates of pest populations we should be able to help the Indian national entomologists who are participating in the trap network to identify the factors, including migration, that determine the populations of this pest in their areas. Pheromone traps may also be of use as indicators of the need for pesticide use against *H. armigera* on crops in a district. We also intend to investigate the possible role of pheromones in reducing *H. armigera* populations in an area using either a mass trapping or a confusion technique.

Work on *Heliothis* Control

Pesticide Use

Our surveys of farmers' fields revealed that only 5.9% of pigeonpea fields and 7.3% of chickpea fields were treated with pesticides. Intensive work by the All India Coordinated Pulse Improvement Project has shown that several pesticides can give adequate control of *H. armigera* and good profits. Endosulfan sprayed at 0.07% concentration in 600 liters of spray liquid per hectare is the most widespread recommendation. In our surveys, however, we found that of the few farmers who used pesticides, almost all used DDT and/or BHC, usually as dusts.

The failure to utilize the widely recommended endosulfan sprays can be largely attributed to the cost and nonavailability of this pesticide and a shortage of water during the flowering and podding period. Moreover, most genotypes of pigeonpeas that are grown by farmers reach a height of more than 1.5 m at the time of flowering, and the application of pesticides to such crops is difficult, particularly with the applicators that are available to farmers in India at this time. There appear to be two ways of dealing with this problem: to reduce crop height or to develop spraying methods with machinery that can give adequate coverage to tall, dense crops. Our breeders are now attempting to develop genotypes that are small but productive. We are also looking at alternative methods of pesticide application, including the use of controlled droplet applicators (CDA) and have found marked improvement in pest control by using these sprayers. At present neither the CDA equipment nor the low volatile pesticide formulations required for this method are readily obtainable in India.

The application of pesticides to chickpea is relatively easy, but the profits from pesticide use in most areas and years appear to be much lower than those from pesticide use in pigeonpea. Replicated comparisons of pesticide-protected and pesticide-free chickpea plots from 1977 to 1981 showed yield increases ranging from 8.7% to 50%, with a mean increase of 28%. This is in sharp contrast to the benefits obtainable from the use of pesticide on pigeonea, on which we often record gains of more than 200%. The average yield increase produced by pesticide use on pigeonpea at ICRISAT over all seasons, maturities, and fields has been more than 100%.

Natural Control Elements

We have been monitoring the natural control elements of *H. armigera* and other pests on pigeonpea, chickpea, and other crops and plants throughout each year, both at ICRISAT Center and in farmers' fields. Although no virus particles could be detected in samples of dead larvae collected from our fields and sent to the Boyce Thompson Institute (BTI) for analysis, we are frequently troubled by nuclear polyhedrosis virus (NPV) epidemics in our laboratory cultures of *Heliothis* spp. In 1977-78, in collaboration with BTI, we undertook preliminary field tests of sprays containing NPV, originating from a culture supplied by the Tamil Nadu Agricultural University. These tests showed that we could achieve considerable mortality (up to 60%) of *H. armigera* larvae on chickpea, using high dosages of the virus. Since then we have made no further attempt to develop this approach, for we can see no practical future for the use of microorganisms in pest control until the national regulatory bodies develop a defined practical attitude to their development and utilization.

Mermithid nematodes *are* very common parasites of *Heliothis* spp larvae collected early in each season, particularly from weed hosts in uncultivated grazing areas on Alfisols within 50 km of ICRISAT Center. In one case, 93% of 302 *Heliothis* spp larvae collected in August were parasitized by nematodes. This parasite, which has been identified as *Ovomermis albicans,* has been found in larvae of *H. armigera, H. peltigera,* and *H. assulta.* Unfortunately, it does not persist through the season, for few are found after September, which is the month when *H. armigera* starts to attack our pulse crops.

Our surveys of the natural enemies of *H. armigera* in south-central India have so far revealed 27 species of insect parasites (Table 2).

In addition, we have also recorded at least eight hyperparasites from cocoons of the *Campoletis / Diadegma* parasite complex that are commonly found on *H. armigera.*

We have made a few observations on the predators of *H. armigera* and have now decided that this aspect requires increased attention. We have recorded 19 species of insects preying upon eggs and larvae of *H. armigera* and suspect there are many more. We also consider that other groups of predators, particularly birds and spiders, can be of importance in reducing *H. armigera* populations.

Our studies of the natural enemies of *H. armigera* have revealed a complexity of species-crop-season interactions that must be understood, or at least recognized, for such knowledge is essential before we embark upon attempts to augment the natural control of this pest. For example, of nearly 12 000 eggs of *H. armigera* collected from sorghum from August to October, 1978 to 1980, more than 25% were parasitized, but of more than 9000 eggs collected from pigeonpea from September to February, 1978 to 1981, less than 0.1 % were parasitized. We have also found that most parasites recovered from *H. armigera* larvae on sorghum are Hymenoptera, while those collected from larvae on pigeonpea are predominantly Diptera (Table 3).

The identification and quantification of the natu-

Table 2. Parasites that have emerged from eggs, larvae, and pupae of Heliothis *armigera* collected from Andhra Pradesh, Maharashtra, and Karnataka states In India.

Diptera	Hymenoptera	
Tachinidae	Braconidae	Bethylidae
Carcelia illota	*Apanteles* sp[c]	*Gomozus* sp[c]
Exoristis xanthaspis	*Bracon* sp[c]	Ichneumonidae
Goniophthalmus halli[d]	*Chelonus* sp[b]	*Barichneumon* sp[d]
Palexorista laxa[a]	*Microchelonus*	*Campoletis chlorideae*[c]
Palexorista solennis[c]	*curvimaculatus*[b]	*Diadegma* sp[c]
Palexorista sp[c]	*Rogas* sp	*Enicospilus shinkanus*[d]
Sturmiopsis inferens[c]	Trichogrammatidae	*Eriborus argenteopilosus*
	Trichogramma chilonis[a]	*Eriborus trochanteratus*[c]
	Trichogramma sp[a]	*Ichenumon* sp[c]
	Trichogrammatoidea sp[a]	*Metopius rufus*[c]
	Trichogrammatoidea	*Temelucha* sp
	bactrae sp *fumata* [a]	*Xanthopimpla stemmator*[c]

a = parasite of egg; *b* = egg-larva; *c* = larva; *d* = larva ex-pupa

Table 3. Parasitism levels recorded from eggs and larvae of Heliothis *armigera* on sorghum (CSH-6) and pigeonpea (ICP-1) in cropping systems trials at ICRISAT, 1978-81.

Pest stage	Collection periods	Crop	No. of *H. armigera* examined	Parasitism (%)	
				Diptera	Hymenoptera
Eggs	Aug-Oct	Sorghum	11846	0.0	26.4
	Sept-Feb	Pigeonpea	9250	0.0	0.1
Larvae	Aug-Oct	Sorghum	6098	2.1	24.9
	Sept-Feb	Pigeonpea	14052	10.2	1.1

ral control elements of *H. armigera,* at and around ICRISAT, has been an interesting exercise. However, it is of no direct value in furthering our aim of enabling the small farmer of limited means to produce more food from his land. But we regard such surveys as prerequisites to augmenting natural control levels and to minimizing damage to natural control agents where pesticides are used.

Effect of Pesticides on *Heliothis* and on Natural Control Elements

At ICRISAT Center we normally use endosulfan to reduce *H. armigera* populations, for this pesticide is generally considered to be less damaging to the Diptera and Hymenoptera, which form the bulk of the natural enemy complex. In comparisons of *H. armigera* collected from pigeonpea and chickpea from the pesticide-free area of ICRISAT Center and those from pesticide-protected fields, we have found no great or consistent effects on the percentages of larvae containing parasites. However, collections of *H. armigera* larvae from farmers' pigeonpea in the Tandoor region of Andhra Pradesh, where farmers have used pesticides, particularly DDT, for several years on this crop, revealed a very low incidence of parasitism. In addition, there are complaints that such pesticides no longer give adequate control of the *H. armigera* larvae. There are suspicions that populations of this pest may have developed resistance to some pesticides in some areas, but there appears to be no recorded evidence to support this. We are hoping to cooperate with the Indian Agricultural Research Institute in Delhi in a study of the susceptibility of *H. armigera* larvae, collected from various areas, to pesticides. This project could also give evidence to confirm or deny the importance of migration in this species.

Augmentation of Natural Control

Our research on augmentation of natural enemies is still in its preliminary stages. We will examine the potential for augmentation of the natural control elements both native and exotic. From 1979 we have been gaining experience in the handling, breeding, and release of the tachinid fly, *Eucelatoria* sp, which was imported from the United States by the Plant Protection Directorate of the Government of India. We have found that the laboratory breeding of this parasite, using both laboratory-bred and field-collected *H. armigera* as hosts, has been relatively easy. Field-cage releases have shown that it parasitizes *H. armigera* larvae feeding on pigeonpea more readily than those on chickpea. We suspect, however, that this parasite might not be able to survive the hot dry season at ICRISAT, when maximum shade temperatures exceed 40°C and unshaded soil surface temperatures exceed 50°C, for this fly has not survived temperatures exceeding 35°C in our laboratory tests. We are now examining the potential of selecting for temperature tolerance in this insect. We also expect to examine the potential of other exotic parasites in cooperation with scientists within the national programs and with the Commonwealth Institute of Biological Control. We will also be looking for natural enemies of this pest in India that may be of value if introduced into other areas, such as eastern Africa. The economics of laboratory or "factory" production of parasites that may be candidates for inundative release projects will have to be carefully assessed. In most developing countries the labor costs are relatively low compared with the USA and Australia, so this may benefit such projects.

Cropping and Cultural Practices

Our surveys revealed that more than 70% of pigeonpea is grown as an intercrop, the major companion crops being sorghum, millet, cotton, and other legumes. The main reason for this practice appears to be that pigeonpea grows very slowly for the first 2 months after sowing, thus leaving bare ground and an opportunity for weeds to thrive in the early stages of the monocrop situation. A faster growing intercrop will help cover the ground quickly and smother the weeds. Many farmers intercrop sorghum with pigeonpea. Studies of this combination by the Farming Systems Program of ICRISAT have shown that, given the right plant populations, a crop of sorghum almost equal in yield to a monocrop can be harvested in October, leaving the intercropped pigeonpea to grow and spread into the space vacated by the harvested sorghum and so produce a substantial yield of pigeonpea from December onwards, according to the maturity of the genotype. In this system, land equivalent ratio (LER) yields of greater than 1.4 have been commonly recorded (in comparison with sole crops).

It is commonly considered (van Emden and Williams 1974) that systems with species diversity will tend to have more stable and robust ecological systems than monocrops. It has been generally assumed that intercropping, particularly where a major pest and its natural enemies can thrive on both the crops in sequence, in a system such as that provided by the sorghum pigeonpea intercrop, should give benefit to the buildup of natural enemies and consequently to suppression of the pest in the later crop. However, intensive research on this system over the past few years has failed to establish such a benefit. If anything, pigeonpea in sorghum intercrops appears to suffer greater percentage damage than is recorded in pigeonpea sole crops. Data from a series of trials comparing sole crops of sorghum and pigeonpea with intercrops involving two spacing levels of the two crops are summarized in Table 4.

We consider that these data can largely be explained by the failure of most of the natural enemies of *H. armigera* on sorghum to transfer to the pigeonpea. We have already shown in Table 3 that the majority of parasites from *H. armigera* collected from sorghum are Hymenoptera, while most of those from pigeonpea are Diptera. There also appears to be an almost complete absence of parasites in eggs collected from pigeonpea; yet egg parasites are common and may play an important role on sorghum. Thus, the sorghum/pigeonpea intercrop appears to be an unfortunate combination, where the pest transfers from the earlier to the later crop, but its major natural enemies do not. This may be in sharp contrast to other intercrops, such as cotton/pigeonpea, for surveys of this system in some states showed high levels of dipteran parasites in *H. armigera* larvae collected from both cotton and pigeonpea, so that there the parasites may transfer with the pest. Such interactions are a complex of plant-insect-seasonal effects and deserve further research. Some details of this work have been published by Bhatnagar and Davies (1980), and more complete data are provided in ICRISAT Annual Reports and in departmental progress

Table 4. Counts of Heliothis armigera, percentage yield loss, and yields of pigeonpea grown as monocrop and Intercropped with sorghum at two spacings (mean data from trials at ICRISAT Center, 1978-81).

Crop	*Heliothis*/100 terminals at peak activity Eggs	Larvae	Yield loss (%)	Grain yields (kg/ha) Pigeonpea	Sorghum	LER[a]
Sorghum monocrop					2544	1.0
Pigeonpea monocrop	85	44	35.9	1043		1.0
Intercrops wide spaced	111	41	36.6	541	2005	1.4
Intercrops close spaced	110	46	39.3	575	1800	1.4
SE (m)±	7.0	3.7	2.33	73.9	181.1	0.11

a. LER = Land Equivalent Ratio.

reports distributed by the Cropping Entomology unit of the Farming Systems Research Program at ICRISAT.

In addition to the intercropping studies, we have also experimented with cultural practices in monocrop pigeonpea and chickpea by varying spacings and times of sowings, with cultivars of differing maturities. All of these studies indicate greater populations of *H. armigera* larvae per unit area with greater plant densities in both crops, but with no obvious increase in the percentage damage in the pods. Typical data are shown in Table 5.

Our physiologists find marked yield advantages in close spacing for both these crops, but their results are from pesticide-protected trials. Our spacing trials in the pesticide-free areas often show a reduction of yield when pigeonpea is planted closer than five plants/m^2 and chickpea is planted closer than 16 plants/m^2.

We have found that sowing dates and/or the use of genotypes with differing maturities can have a major effect on the *H. armigera* infestations attacking any particular pigeonpea plot. Here at ICRISAT, pigeonpea flowering in November has a severe infestation of *H. armigera* larvae in most years. Pigeonpea flowering in February has relatively little attack by *H. armigera,* but other pests, including the podfly and a plume moth larva, *Exelastis atomosa are* more damaging at that time.

Screening for Resistance

For both pigeonpea and chickpea, which are still grown without pesticide use in most farmers' fields, the development of selections with reduced susceptibility or tolerance to attacks by *Heliothis* spp could lead to enormous benefits. ICRISAT is ideally situated for open-field screening of genotypes against *H. armigera,* for in recent years this pest has appeared in sufficient numbers for screening, during the pigeonpea and chickpea seasons. We also have unique advantages in this work, for ICRISAT has the responsibility of maintaining the world's germplasm of both crops and has been provided with sufficient funds and staffing to carry out intensive and sustained screening programs.

The problems of screening for resistance to *Heliothis* spp are obvious. The pest itself is polyphagous and so is unlikely to be susceptible to small changes in the chemical or physical composition of any particular host. Plants are not normally attacked until the flowering or fruiting stage so the screening of large numbers of seedlings, which has provided quick results in many other pest- and disease-screening programs, is of little or no utility for *H. armigera.* We entered into our screening programs with a full awareness of the problems involved and a knowledge that the search for resistance to *Heliothis* spp in other crops had met with only limited success. However, we are also aware that most breeding and improvement programs involving these crops are carried out in environments where pesticides are used to protect the trials. Such programs are likely to produce materials that will be of no use in the real world, where few farmers protect their crops with pesticides.

Pigeonpea and chickpea are markedly different in many aspects, and these differences have affected the progress in screening for resistance. Pigeonpea is a slow-growing but large plant that is susceptible to many pests and can have a high percentage of outcrossing. Thus, relatively few plants can be grown per unit area and no more than one generation of the mid- and late-maturity types can be grown per year. In open-field screening we

Table 5. *Heliothis* armigera larvae recorded per m^2 and percent pod damage In plant-density trials at ICRISAT Cantar, 1978-1979.

Pigeonpea			Chickpea		
Plants/m^2	Mean no. *H. armigera*/m^2	Pods damaged (%)	Plants/m^2	Mean total *H. armigera*/m^2	Pods damaged (%)
1.4	2.6	24	3.3	13.5	18
4.4	4.0	30	8.0	20.3	19
10.7	5.2	25	33.0	48.7	19
			67.0	51.4	24
SE (m)	±0.17	± 1.2		± 0.98	± 0.3

cannot determine whether any line or plant has any resistance until the podding stage, and even then resistance to *H. armigera* may be masked by the damage caused by other pests. The seed from selected plants is likely to have been outcrossed, so that we are dealing with a segregating mess in subsequent generations. Attempts to utilize field cages in which the infestations of *Heliolhis* can be controlled, as used by Lukefahr et al. (1975), have not been successful at ICRISAT.

In spite of all these problems, we have made some progress in screening for resistance within the available germplasm. We have developed a methodology (Lateef and Reed 1980) that first rejects the most obviously susceptible materials in unreplicated screening and then progresses to replicated testing of materials, against appropriate checks, within trials that each contain a narrow range of maturities. This is essential, for the inclusion of plants with differing maturities in any trial will simply result in the selection of plants that happen to flower and pod during a dip in the pest population pressure!

We have tested over 10 000 germplasm accessions and breeding lines and have selected materials in each maturity group that have shown more, and less, resistance, and also those that are tolerant to *H. armigera* and other pests. Some pigoenpea plants have an outstanding ability to compensate for losses to pests; all of the first flush of flowers or pods may be lost, but the plant can quickly replace these with a second flush that can give an equal or greater yield. This complicates our testing, for we now routinely record both the first- and second-flush yields, and the pod damage in these, from each of our many trials. Data from one such trial are shown in Table 6.

In this trial we used balanced lattice squares, a design that we have found to give substantial advantage in efficiency for such testing, when compared with randomized block designs. We have found several lines that show consistent differences in their susceptibility to pest attacks and some that consistently give reasonable yields in spite of heavy pest attacks. However, we have not yet selected any plants that are outstandingly resistant to *H. armigera* attacks, and two or three pesticide sprays during the flowering period will usually result in very large increases in yield from all of our early and mid-maturity selections.

We have found that some of the *Atylosia* spp, which are close relatives of pigeonpea, have considerable resistance to *H. armigera* and other pests. Feeding tests have shown that *A.scarabaeoides* has marked antibiosis, for *H. armigera* reared on this plant show increased mortality, prolonged larval periods, low pupal weights, and reduced fecundity. This plant can be crossed with pigeonpea, and, in cooperation with our breeders, we now have several selections from the derivatives of such crosses that are of some interest, including entries 6 and 7 in Table 6.

Table 6. Percentage of pods bored (mainly by *H. armigera)* and yields from a balanced lattice-square design trial of pigeonpea selections In the pesticide-free area of ICRISAT Center, 1980-81.

		First pick		Second pick		Total
Entry	Genotype	Bored pods(%)	Plot[a] yield(g)	Bored pods (%)	Plot yield(g)	yield (kg/ha)
1	PPE-45-E2	17.2	551	14.2	115	800
2	Sehore 197	29.1	858	35.0	109	1160
3	T-21 (Check)	33.7	706	18.9	122	993
4	ICP-7349-1-S4	30.1	697	17.5	145	1011
5	ICP-7203-E1	26.9	941	18.7	258	1438
6	1914(IG)-E2	15.5	607	20.6	150	909
7	1925(IG)-E2	26.6	817	10.1	155	1166
8	ICPL-100	22.0	585	22.4	164	900
9	ICP-1903-E1	13.0	802	14.9	156	1150
	SE(m) ±	3.0	48.2	4.25	29.3	92.1
	CV (%)	25.6	13.2	42.5	38.5	17.2

a. Net plot harvested = 8.33 m^2.

In cooperation with our biochemistry unit and with the Max-Planck Institute for Biochemistry in Munich, we have initiated studies of the factors involved in resistance or susceptibility to pests in this crop. This work is in an early stage, but several interesting chemical and physical differences have been observed.

Chickpea is a rapidly growing, but small, plant that is almost invariably self-pollinated and has a remarkably restricted range of insect pests. However, this crop is particularly attractive to *H. armigera* from the seedling stage. This is illustrated in Table 7, which summarizes the egg laying on both chickpea and pigeonpea grown in pots and exposed to *H. armigera* moths in field cages. These data show that although pigeonpea is more attractive from the flowering stage, chickpea is outstandingly attractive to egg laying during the vegetative stage.

Chickpea can be eaten down to bare stalks by *H. armigera* larvae during the vegetative stage, but will usually recover to give a crop, provided there is sufficient moisture in the soil and the temperatures are not too high.

Although the chickpea plant differs considerably from pigeonpea, we have found that the general methodology developed for the field screening of the latter is equally effective for the former. On chickpea we record the damage at the seedling stage, the percentage pod damage, and the yields, and use all three criteria in our selection.

Our initial screening is in unreplicated small plots. Here the major problem is with uneven distribution of populations of *H. armigera larvae* in space and time, which allows chance escapes from damage. In this initial screening we discard the entries that appear to be very susceptible. Subsequent tests are with increasing replication of the entries, which are grouped into narrow maturity categories, with appropriate checks. In this way we have screened all of the available germplasm and the breeders' and pathologists' materials, making a total tested of more than 12 000 lines.

Table 7. Mean numbers of eggs laid on chickpea and pigeonpea plants grown In pots and exposed to *H.* armigera moths in field cages at ICRISAT, 1978-79.

Stage	Mean no. of eggs laid/plant	
	Chickpea	Pigeonpea
Seedling	12.5(120)[a]	2.3(134)
Flowering	1.2(113)	18.5(105)

a. Figures in parentheses are number of plants examined.

Early-maturing chickpeas yield better than those of later maturity at ICRISAT Center but generally suffer from the heaviest H. *armigera* attacks, particularly at the podding stage. It is within this group that we have had our greatest success, for we have been able to select lines that are consistently less attacked than the commonly grown cultivars, and also yield more in pesticide-free conditions. Data from a 1980-81 balanced lattice square design trial, which was carried out in cooperation with our breeders, are shown in Table 8.

Here we grew four of our best selections together with four entries that the breeders had selected in their pesticide-protected trials, and a well-known cultivar as a check. It can be seen that the entries previously selected as being less susceptible to *H. armigera* showed less damage and greater yields than the other entries. There was a similar trial under pesticide protection, but there we had a heavy incidence of fusarium wilt, and the best of our selections were susceptible to this disease. Our breeders have been crossing our selections with wilt-resistant materials and the progenies of these are being selected in wilt-sick plots in this season. The seed of our best selections has been made available to the national scientists, and the preliminary results from tests in southern India are promising.

We have not been so successful in selecting for resistance to *H. armigera in* the later maturing chickpeas which yield well in the major chickpea-growing tracts of northern India. We have recently transferred much of our selection and testing of this group to the farm of the Haryana Agricultural University at Hissar, where the later maturing chickpeas yield well and are also subject to heavy *H. armigera* attacks.

Mechanisms of Resistance

In cooperation with our biochemistry unit and with the Max-Planck Institute of Biochemistry in Munich, we are studying the mechanisms of resistance or susceptibility of pigeonpeas and chickpeas to *H. armigera* attacks. The green tissues of chickpea plants are densely covered with glandular hairs that exude very acidic (pH 1.3) droplets; this very acid exudate is probably what deters most

Table 8. Comparison of entomologists' and breeders' selections of early-maturing chickpeas in pesticide-free conditions at ICRISAT Cantor, 1980-81.

Genotype	Selected	Mean pod damage (%)	Yield (kg/ha)
IC-7394-18-12-1P	Ent[a]	14.6	2223
ICC-506	Ent	5.1	2001
IC-738-8-1-1P	Ent	9.9	1963
IC-73103-10-2-1P	Ent	14.9	1900
ICCCC-9	Br[b]	18.0	1876
Annigeri-1 (check)	-	20.0	1828
ICCC-6	Br	17.8	1726
ICCC-8	Br	14.9	1685
ICCC-1	Br	28.0	1297
SE (m) ±		1.70	47.0
CV %		21.3	5.1

a. Ent = Selected by entomologists in pesticide-free fields in previous seasons.

b. Br = Selected by breeders in pesticide-treated fields in previous seasons.

insect pests from feeding upon this crop. It has been shown that some of our more resistant selections tend to have greater concentrations of malic acid in their exudates (Rembold and Winter, these Proceedings). In addition, the seed of ICC-506, one of the most resistant selections, has a higher concentration of polyphenols in its seed coat than has any other seed so far tested (Umaid Singh, unpublished). There is a possibility that some of our selections may have differing mechanisms of resistance; our breeders have been crossing the selections, hoping to produce progeny that have multifactor and increased resistance.

We are particularly interested in finding out what stimulates *H. armigera* to lay eggs on chickpea during the seedling stage, for on most other hosts egg laying is mainly restricted to the flowering stage. One possibility is that the moths are primarily attracted to plants to feed, usually upon nectar. This would explain why there is some egg laying on cotton before flowering, for on that crop the extrafloral nectaries on the leaves could provide food. On chickpea there is a possibility that the moths can feed upon the acid exudate. We have been conducting laboratory tests comparing the oviposition of moths that are allowed access to honey, differing concentrations of malic acid, and water. These tests have given variable results, but it does appear that the moths can feed upon malic acid solutions.

Integrated Management

Trials combining some of the elements of integrated management of *H. armigera* are already being field tested at ICRISAT Center. For example, we are testing the utility of the more and less susceptible chickpea selections in pesticide-protected and pesticide-free plots, and include parasite release and protection from predators in some of these. However, the major elements of any pest management program cannot be adequately tested at a center such as ICRISAT, where combinations of crops, sowing dates, and pesticide use all result in an atypical pest situation. We must carry our experimentation to farmers' fields where we can encourage the synchronous sowing of crops that will limit the buildup of *H. armigera* in the area and also dilute the populations that will occur. The use of pesticides and natural enemy augmentation will also be controlled over the area. We anticipate that we will be in a position to suggest such experimentation within the next 3 years, in cooperation with national agencies.

Summary

Research towards the effective and economic management of insect pests, but particularly *H. armigera,* has been in progress at ICRISAT for the last 7 years. Our early work was largely concerned with determining the basic data of the incidence of the pests and their natural enemies on the crops, with investigating the biology and ecology of the insects, and with developing the methodology of sampling and screening for resistance to the pests in pigeonpea and chickpea. We are now well into the action phase of our research, where we are investigating the possibility of improving the elements of pest management on these crops, including economic pesticide use, natural enemy augmentation, and the use of less susceptible and more tolerant plants. We soon hope to test our findings in farmers' fields, through the national agencies.

References

BHATNAGAR, V.S., and DAVIES, J.C. 1980. Entomological studies in intercropped pigeonpea systems at ICRISAT Center: future developments and collaborative research needs. Pages 341 -347 *in* Proceedings, International Workshop on Pigeonpeas, Vol. 2. ICRISAT/ICAR, 15-19 Dec 1980, Patancheru, A.P., India.

LATEEF, S.S. and REED, W. 1980. Development of a methodology for open field screening for insect pest resistance in pigeonpeas. Pages 315-322 *in* Proceedings, International Workshop on Pigeonpea, Vol. 2. ICRISAT/ICAR, 15-19 Dec 1980, Patancheru, A.P., India.

LUKEFAHR, M.J., HOUGHTALING, J.E., and GRUHM, D.G. 1975. Suppression of *Heliothis* spp. with cottons containing combinations of resistant characters. Journal of Economic Entomology 68(6): 743-746.

NESBITT, B.F., BEEVOR, PS., HALL, DR., and LESTER, R. 1979. Female sex pheromone components of the cotton bollworm, *Heliothis armigera.* Journal of Insect Physiology 25:535-541.

NESBITT, B.F., BEEVOR, P.S., HALL, D.R., and LESTER, R. 1980. Hexadecenal: a minor component of the female sex pheromone of *Heliothis armigera* (Hubner) (Lepidoptera, Noctuidae). Entomologia Experimentalis et Applicata 27:306-308.

REMBOLD, H., and WINTER E. 1981. The chemists role in host-plant resistance studies. Session 5, these Proceedings.

VAN EMDEN, H.F., and WILLIAMS, GF. 1974. Insect stability and diversity in agro-ecosystems. Annual Review of Entomology 19:455-475.

Discussion—Session 7

This discussion concentrated upon three aspects of *Heliothis* management.

1. The pest status of *Heliothis* spp on different crops, particularly, of the increased activity of these pests with changes in cropping patterns and practices.
2. The current advances in management of these pests with improved technology.
3. The problem of insecticide resistance and the prospects for new pesticides. There is great concern that *Heliothis* spp may quickly build up resistance to new insecticides as a result of cross resistance resulting from the older insecticides.

NPV and *Bacillus thuringiensis* have not been utilized by most farmers in Australia or the USA, but there is a market for these. Although the use of parasites and predators does not appear to be an active component in many *Heliothis* management schemes, the records of natural enemy abundance are often taken into account when taking decisions on pesticide use.

The Chairman closed the discussion with the remark that the integrated package still appears to be a limping package in most areas. We have a long way to go before we replace the total reliance upon chemical pesticides with a realistic integrated management approach in most areas.

Session 8

Prospects for Future International Cooperation

Chairman: J.C. Davies

Cochairman: G. Hariri

Rapporteurs: P.W. Amin

S. Sithanantham

Prospects for Future International Cooperation

This session consisted of a series of discussions concerning the subjects covered in the previous sessions. Discussion leaders reviewed each of those sessions, introduced the potential areas of cooperation for general discussion, and subsequently formulated recommendations for future action and cooperation. A summary of these discussons and recommendations follows.

Session 1: Biology, Behavior, and Ecology of *Heliothis*

Discussion leader: P. D. Lingren

Subspecies Identification

It has been generally agreed that *H. armigera* is a single, polyphagous species extending over much of the tropical and temperate areas of the world, with the exception of the Americas, where *H. zea* replaces it. However, it is probable that there are differences between the *H. armigera* populations of different areas that merit race or subspecific rank. Such differences are of importance where they involve the host range, aestivation-hibernation-diapause abilities, other biological factors, and susceptibility to pesticides. At this time there appears to be little well-documented knowledge of such differences.

It was suggested that the identification of subspecies of *H. armigera* and the geographical range of these might be partially accomplished by the use of electrophoresis. Although this technique is fairly expensive, it is simple and straightforward. It was suggested that either the live insects or acetone-extracted materials should be sent to a central laboratory for testing. The advantage of sending live insects to a central laboratory would be that comparative biological tests could also be done. For quarantine reasons, such a central testing laboratory would have to be situated in a country where *Heliothis* spp are not a threat to the local agriculture. The United Kingdom was suggested as a suitable location.

Behavior Studies

It was agreed that practicable pest-management strategies must be based upon an adequate knowledge of behavior of the pests, and that the present availability of such knowledge was inadequate for the *Heliothis* spp, particularly for *H. armigera.* Studies of moth behavior in the field have been very few and far between, largely because *Heliothis* moths are nocturnal but man is notl Recent nocturnal studies of both *H. virescens* and *H. zea* in the USA have been extremely productive, and it was suggested that ICRISAT should now embark upon similar studies for *H. armigera.* The availability of image intensifiers in night-vision equipment has given some impetus to the nocturnal studies. However, a great deal of information on emergence patterns, population aging, feeding, mating, and trivial movement of moths can be obtained by using head lamps. The belief that all *Heliothis* nocturnal behavior is so disrupted by artificial illumination that observations using artificial lights are useless, is not justified, for when a moth enters a particular behavioral activity it is not readily diverted from that activity by a head lamp that is just powerful enough to permit easy observation.

There is also a need for further studies of the behavior of the *Heliothis* spp larvae during both the day and the night. Such studies would provide useful information for the improvement of most elements of control strategies, but particularly for host-plant resistance and pesticide use.

Aestivation and Diapause

Studies of *H. virescens* and the sterile hybrid in Arizona have revealed that it is fairly easy to induce a period of aestivation with high temperatures. In Australia and the Sudan there is also some evidence for the occurrence of aestivation in the prepupa but more commonly in the pupal stage. It was suggested that some of the observed anomalies of the occurrence of *H. armigera* moth populations in peaks might be explained by the presence of aestivating pupae that emerge in synchrony when conditions are favorable after a hot period or a drought.

The occurrence of diapause in *H. armigera,* particularly of diapause in Asia, does not appear to be well documented or understood. There is a need for laboratory and field observation of the occurrence of diapause and of the factors that induce and break it. The ability of individuals from differing geographical populations to enter diapause is well worth studying, for it would help to determine the existence of races and the importance of migration. If, for example, diapause could be induced in a population from one area but not from another, this may be good evidence that migration plays a relatively minor role in the population dynamics of this pest across those areas. Such a conclusion was reached regarding the pink bollworm when individuals derived from populations of that pest in southern India could not be induced to enter diapause but those from northern India could readily be induced to enter diapause.

Effects of Host Plants

It was agreed that, although there were extensive reports of the effects of various host plants on the biology of *H. armigera,* there was a need for further studies of food utilization, host preferences, and effects of larval diet on the fecundity and oviposition preferences of the moths. Studies are also required on the feeding of moths on different hosts and the effect of such feeding upon fecundity.

Recommendations

1. Population-management strategies must be based on an adequate understanding of the behavior of the larvae and adults of the *Heliothis* spp. There is a conspicuous lack of information concerning the behavior of *H. armigera.* ICRISAT, in cooperation with scientists from other institutions, should gather information on the behavior of the moths and larvae of this species and determine how external factors, such as the weather, influence such behavior. This work will require extensive nocturnal observations in fields, using white light. Some studies may, however, require specialized night-vision equipment.
2. Much more information should be gathered concerning the diapause and aestivation of the *Heliothis* spp, particularly in Asia and Africa.
3. Electrophoresis should be used on extracts of adults and larvae from various areas in an attempt to distinguish races and subspecies of the *Heliothis* spp that cannot be distinguished by morphological characters. This could be in conjunction with, or followed by, cross-breeding experiments in an institution in a country that is not threatened by *Heliothis* spp.
4. The effect of adult and larval food sources on the dynamics of *Heliothis* populations requires more research.

Session 2: Surveillance, Forecasting, and Modeling of *Heliothis* Populations

Discussion leader: J.R. Raulston

The discussions during this session revealed that we do not have the capability of predicting the size of *Heliothis* populations. However, some progress has been made in predicting the timing of *Heliothis* attacks, particularly in the USA. There is a clear need to assemble the available information, if only to reveal the gaps in our knowledge and hence the priorities for future research.

Surveillance

The polyphagous nature of the major pest species of *Heliothis* gives special problems in surveying populations in alt but monocropped areas. Counts of eggs and larvae on a wide range of crop and wild hosts in an area are very expensive in terms of recording time and are seldom considered to be worthwhile. Counts on the individual crops are often undertaken for pesticide use decision making, but such counts are seldom useful, or used, for population dynamics studies. We can count moths in light and pheromone traps but we must then determine the relationship of these catches to the actual field populations. It is already obvious that the relationship between the catches in *Heliothis* pheromone traps and field populations is not simple and direct.

There is a primary need to standardize traps and then to use these in fields over a long period, recording data not only from the traps but also from the crops. It should then be possible to compare these data, together with climatic records, to determine the utility of the traps in the quantitative surveillance of populations. The current ICRISAT studies, in which data from light traps, pheromone traps, and populations of larvae on all known hosts throughout the year are considered, will be particularly useful.

Movement of Moths

The movement of moths plays an important and complicating role in the population dynamics of *Heliothis.* Such movement can be at several levels, ranging from trivial movements within a crop, through movement from crop to crop, to the long-range migration from one area to another. Studies in the USA have already revealed that *Heliothis* spp are highly mobile and that there is long-range migration of populations in each year. There appears to be less evidence of long-range migration in *H. armigera* and there is a need to determine whether migration is of importance in the population dynamics of this species.

Networks of light traps and pheromone traps may provide some evidence of migration. In East Africa a network of light traps has been used both to elucidate migration patterns and to provide an early warning system for control *of Spodoptera exempts,* an armyworm. That same network also appears to have provided some evidence that *H. armigera* is a migrant, and it may be worthwhile to examine closely the data from those traps where *H. armigera* moths have been recorded.

Radar has been successfully used to track moths in several studies, and this technique is expected to be of increasing use. It was emphasized, however, that such improved technical aids will only be of use if we ensure that our knowledge of the behavior of the insects is also developed simultaneously. We should try to determine not only if, when, and how much migration occurs, but also why it occurs. The physiologial status of the host plants as well as climatic factors are likely to be of importance in stimulating moth movement. However, we need more information on the physiological status of the moths that determines the extent of moth movement. The studies using flight mills may be particularly useful in gathering such information. Already available information on other, well-researched migrant insects, including locusts and armyworms, should also be of utility in *Heliothis* studies.

Genetic markers may be of use in *Heliothis*-movement studies. The difficulties encountered in using dyes and other chemicals to mark moths were noted, and it was considered that readily identifiable variants of *Heliothis* spp moths should be sought and carefully maintained, when found, for possible use in migration and other studies.

Weather Conditions and Pest Outbreaks

Weather conditions obviously play a key role in the population dynamics of *Heliothis* spp, but the individual and combined effects of temperature, rainfall, humidity, and winds on populations have not been adequately studied. On-site ground-weather observations are important for the understanding of when an insect does what, but we also require a knowledge of upper air conditions and movements to help us understand the distribution of the moths. Site meteorological observations need to be put into a synoptic context, and the local insect populations must be related to those of much wider areas in biogeographic studies.

Ultimately we should endeavour to be able to accurately predict the occurrence of damaging *Heliothis* populations in time and space, through the use of models that include weather inputs.

Models

Many people have been disappointed with models intended to simulate the population dynamics of insects because the predicted values often differ greatly from the observed real-world data. The time and effort spent in collecting masses of data and feeding these into a carefully designed program may yield results that are less accurate than a well-informed guess. However, this is not a good reason to give up modeling; it is simply evidence that there is a need to improve on the model. Usually data are collected first and the modeling is the last stage in the exercise. There is a good case for reversing this procedure. Why not build the model first and so determine what data are required to drive the model?

The polyphagous nature of *Heliothis,* its wide geographical range, its movements and its wide range of natural enemies make the modeling of the population dynamics of this pest far from simple. However, the models already developed in the southern USA have shown considerable promise. It was pointed out that we are automatically modeling mentally whenever we consider populations of *Heliothis* spp, and the factors that affect these. With the ready availability of computers we now have an opportunity to make greater use of the mass of data being collected. One major objective of modeling *Heliothis* populations is to allow the accurate forecasting of damaging populations on a crop in an area, so that provision for the best strategy of management for that infestation can be planned. For such a purpose, very accurate predictions of the size of any population may not be necessary but an accurate forecast of the timing of the infestation may be of real value. Models already available in the USA, utilizing data from pheromone traps, appear to fufil this requirement. The more sophisticated use of models, including studies of the effects of various management practices on population dynamics, may require models of greater refinement, but these should not be beyond our capabilities within the next few years if adequate manpower and technical equipment can be allocated.

Recommendations

1. Available information on monitoring systems should be assembled, light and pheromone traps standardized, and the data from the traps compared with data gathered from scouting for eggs and larvae on the host plants in the areas surrounding the traps. Such work should be done at ICRISAT for *H. armigera.*
2. Simple models should be developed, based upon these inputs, to structure thinking and to help indicate what other inputs are needed to increase the accuracy of the models, with the eventual aim of sophisticated predictive modeling.
3. Radar technology should be utilized, coupled with nocturnal behavior studies of moths and physiological studies of the host plants, to elucidate the occurrence and cause of both trivial and long-range movement of moths.
4. Concomitantly, laboratory studies, including flight mill experiments, should be conducted to elucidate the physiological status of the moths that triggers such movement.
5. The possibilities of establishing a central forecasting system utilizing all the available data and predictive models, should be explored. The need for adequate meteorological data is stressed.
6. A system should be developed for interchange and preservation of genetic markers of *Heliothis* spp, that may be of utility in population dynamics and other studies.

Session 3: Natural and Biological Control Elements

Discussion Leader: D.J. Greathead

In discussing biological control of *Heliothis* spp it was generally agreed that these pests present special difficulties because of their polyphagous and mobile habits. The population dynamics of these major pest species have not received adequate attention; consequently, the quantitative role of the natural control elements has seldom been determined satisfactorily. Records showing that X% of the *Heliothis* eggs or larvae, taken at a certain time from a plant host, were parasitized or diseased can be useful, but we have to determine the effects of such levels of parasitism—and of changes in those levels—on the overall populations of the pest in the same and subsequent generations.

Parasitoids and Predators

There are numerous natural enemies of the *Heliothis* spp. In the absence of pesticides, these, in combination with the other natural control elements, often maintain *Heliothis* populations at subeconomic levels in crops. However, there is potential for the importation and establishment of more effective natural enemies, particularly to fill vacant ecological niches. There is a primary need to accumulate the available natural enemy data, both qualitative and quantitative, and to analyze these to determine the vacant niches and the importations that might be useful in filling them. There have been some transfers of *Heliothis* parasitoids between continents, but without major benefits. This should not discourage us from making further introduction attempts, but these should be planned carefully. All too often, introductions and augmentation efforts have been made using parasitoids that are chosen simply because they are easily reared and maintained in the laboratory.

Attempts to augment selected natural enemies (e.g. *Trichogramma* spp, *Chrysopa* spp, and *Eucelatoria bryani)* should be based upon comprehensive technical and economic feasibility studies. In particular, the maintenance of adequate populations through periods when the *Heliothis* populations fall to very low levels must be considered. It is already clear that there are strong pest-parasitoid-host plant interactions, so there is a need for entomologists to extend their studies to the full range of plant hosts rather than to confine themselves to a single target crop.

The host-finding activity of most parasitoids/predators is affected by the host population density. Chemicals emanating from the host insect and/or its products often serve as cues that aid the natural enemy in host finding and host acceptance. When the host insect density is low, released parasitoids/predators often leave the target area and do not actively seek the host. This leads to inconsistent results from natural-enemy releases. To overcome this problem we need to analyze critically the host-seeking sequence of the selected natural enemy and to identify the chemicals that arrest, retain, and stimulate it to seek the host. We may then be able to synthesize these chemicals and evaluate them for use in managing natural enemy populations. The economic feasibility of augmenting the natural enemies of *Heliothis* may well depend on our ability to mass produce them. It was stressed that vigor and essential behavioral characteristics must be maintained during mass production.

Although the introduction of exotic natural enemies and the augmentation of populations with mass-reared insects appear to be attractive possibilities, the protection of the existing natural enemies in the ecosystem and the maximization of their utility should be our first concern. The natural enemies of *Heliothis* are often referred to in insect control guides, but explicit instructions for conserving these or for making insecticide spraying decisions based on their relative abundance are seldom provided.

In general, the parasitoids of *Heliothis* spp have been more extensively recorded and studied than the predators, largely because parasitism can be recorded by simple collection of the hosts and subsequent laboratory observation, whereas predator studies require relatively long observations in the field for very few recorded incidents. In particular, there have been very few studies of the nocturnal predation of *Heliothis* eggs, larvae, and moths, and observations on the behavior of the predators during the night and day have been inadequate. While it is generally considered that spiders may play an important role in *Heliothis* population reduction, there have been few quantitative reports of predation. Birds are also considered to be important *Heliothis* predators, but here again quantitative records are scanty. Most of the needs for more research on the parasitoids that were discussed are also applicable to the predators.

Pathogens

The use of pathogens for the reduction of *Heliothis* populations was considered to be an attractive and exciting prospect. There is already some commercial utilization of *Bacillus thuringiensis* and of a nuclear polyhedrosis virus for *Heliothis* control in the USA and Australia, but the cost: benefit ratios are not yet very favorable when compared with chemical pesticide use. Sales rely heavily on the nonpolluting reputation of these pathogens and also perhaps on their novelty. From other countries, including China, there are several reports of the successful utilization of insect pathogens, generally in noncommercial formulations. These formulations often use the diseased insect cadavers with little or no purification of the pathogen.

The use of sprays containing the mashed bodies of insects that were killed by pathogens may well be cheap and possibly effective, but it was generally considered that such a practice is unlikely to be recommended by most national authorities because of the health risks to man and other mammals. Although the common insect viruses appear to be nontoxic to mammals, there is no certainty that other organisms present in dead insects, including the bacteria, are equally safe.

In some countries the existence of an important sericulture industry also presents a barrier to the ready acceptance of insect pathogens in pest control.

The major barrier to the greater utilization of NPV and of some other pathogens is the relatively short viability period in field use. The degradation of NPV by ultraviolet radiation is well known, and there are adjuvants that will extend the infective period of the virus in sprays. However, there is a need for further improvement. The alternatives to spraying include the use of semisolid baits containing the virus and autodissemination through the release of infected larvae (and/or moths) in fields. Some research on these alternatives is required.

The NPV of the *Heliothis* spp appears to be endemic in most areas where these pests are found, so there may be no advantage in transferring viruses from one country to another unless large differences in the virulence of the geographical strains are reported. In countries such as India, the importation of viruses is not encouraged. The mass culturing of the viruses and other pathogens will usually require an efficient means of mass culturing the *Heliothis* spp. Methods for efficient mass culture of this insect are now well established and were reported at this workshop. The purification of the pathogens to locally required standards and the quality control of the final product will require some experimentation, but methodologies and experience are already available.

It was considered that the pathogens are unlikely to become the sole means of *Heliothis* control but will be of use in combination with other elements, particularly with some degree of host-plant resistance, natural-enemy augmentation, and possibly with chemical pesticides.

Recommendations

1. The potential should be examined for setting up an informal international working group that will consider the biological control of *Heliothis* spp on an international basis, exchange and accumulate natural enemy data, consider the need for the exchange of natural enemies between countries and continents, and disseminate information.
2. The identification, quantification and ecological study of the natural enemies of *Heliothis* spp should be expanded, and the data summarized on a global basis. The quantitative effect of the natural enemies on the population dynamics of *Heliothis* spp needs to be determined.
3. Importations of exotic natural enemies should be carefully planned, using the following criteria; the imported natural enemy should (a) occupy a vacant niche, (b) be adapted to the target field crop or to important alternative hosts, (c) possess tolerance to the commonly used pesticides. Other criteria normally used for selection, such as adaptation to the climatic conditions should, of course, also be considered.
4. The quantitative effects of specified levels of natural enemy abundance on *Heliothis* populations should be determined and these data then be utilized in pest-control decision making. Techniques should be developed for the rapid assessment of natural enemy populations in selected crops. Control guides should consider the natural enemy populations, as well as pest density, indecision making for pesticide use.
5. *Heliothis* spp are often maintained at subeconomic levels by the natural enemies in most crops. Where this does not happen, the augmentation of the natural control using periodic releases of native or introduced biological control elements should be carefully researched and, if feasible, be implemented.
6. Mass-rearing techniques for natural enemies should be developed for use in augmentation programs. For this, the development of artificial diets and in vitro rearing may be required to ensure economic returns.
7. The behavior and host-seeking sequence of selected natural enemies should be critically analyzed, and chemicals that arrest, retain, and stimulate host-seeking should be isolated and identified. These chemicals should then be synthesized and evaluated for their potential in managing natural enemy populations.
8. Information on the safety of microbials, both to mammals and to beneficial insects including silkworms, should be accumulated and be supplemented by further research where needed. National authorities should be encouraged to take decisions on utilization of microbials in pest management, based upon the safety precautions found necessary and the potential economic feasibility of their use.
9. Further research is required on the evaluation of factors that cause the inactivation of microbials in field use and the means of overcoming these.
10. Where a microbial appears to offer safe, economic potential for *Heliothis* management, an experimental pilot plant for its production should be set up. There would appear to be economic advantages in developing countries, where labor is relatively cheap. Subsequent studies should involve application techniques, with careful monitoring of effectiveness, particularly on the overall *Heliothis* populations in an area.
11. Since microbial use is most likely to be effective when combined with other elements of pest management, studies of interactions, for example with resistant crop cultivars and differing cultural practices, should be given priority.

Session 4: Chemical Pesticides—Their Uses and Abuses

Discussion Leader: P.H. Twine

This discussion inevitably revealed a divergence of opinion on the role of pesticide use in *Heliothis* management. While it was agreed that there have been several cases where the use, or perhaps misuse, of chemical pesticides has resulted in the increase of *Heliothis* and other problems in the longer term, there are also many examples where the careful use of pesticides has resulted in economic returns without obvious problems. The worry that resistance of *Heliothis* to pesticides would create a major problem in many areas has been alleviated, temporarily, by the production of new effective insecticides, including the synthetic pyrethroids, which give highly effective *Heliothis* control. However, the need to combat the resistance menace remains a top priority.

The need for establishing economic threshold levels for pesticide use, based upon scouting and other methods of pest population detection, was accepted as a priority. On many crops the threshold turns out to be unexpectedly high, particularly in crops that can compensate by further growth. It was also agreed that the populations of the natural enemies need to be considered in the decision making.

It was agreed that pesticide use should be considered as one element of a pest-management program and not as the sole response to *Heliothis* and other pest infestations. However, in many of today's agricultural systems, *Heliothis* populations regularly exceed established thresholds in crops. In such circumstances few farmers see any alternative to chemical pesticide use, particularly in the less developed countries.

The inefficiency of the present means of covering plants with pesticide to kill the pests, rather than using a much smaller amount of pesticide directed at the pest as a target, was appreciated. It was agreed that the possibility of treating the *Heliothis* moth as a target is worth further experimentation. The treatment of individual fields, rather than synchronized efforts to reduce the *Heliothis* population of an area, was also recognized as a constraint that needs to be overcome.

There is still a great need to improve application techniques, whether the target be the crop or the insect. The development of controlled-droplet application machinery and techniques is regarded as a significant advance that is particularly relevant to the semi-arid areas, where the nonavailability of water often precludes conventional spraying. The increasing use of spraying at night was also noted with favor. (The need for moth behavioral studies to help to improve the efficiency of such spraying was commented upon in an earlier session.)

Because of the wide array of social and agricultural systems for which pesticide use is applicable, it is necessary to evolve programs of pest management, including pesticide use, that are specific to each circumstance. It was in the appreciation of this diversity that the following recommendations were made.

Recommendations

1. The development and refinement of scientifically based threshold/action levels for each crop situation is of immediate priority in helping to minimize the reliance on chemical pesticides.
2. In order to improve the contribution of chemical pesticides to *Heliothis* management, more efficient methods of pesticide application, for both aerial and ground-based systems, should be developed and research in this area encouraged.
3. Reducing potentially damaging populations by aiming the chemical pesticide at the life stage of the pest that results in the most efficient use of the chemical and the least effect on nontarget organisms is a strategy that should be further investigated.
4. The full spectrum of chemical pesticides available for *Heliothis* control in each crop should be evaluated in terms of the lowest effective rates, their influence on beneficial species, and the pesticide resistance buildup, in order to recommend the most appropriate management strategy.
5. Because of the continuing threat of pesticide resistance in areas where pesticides are used intensively, it is suggested that resistance-testing programs be set up to monitor changes in susceptibility values.
6. Farmer education programs should be encouraged to facilitate the acceptance of the pest-management approach and the associated use of chemical pesticides within this system.
7. The implementation of other pest-management elements can usually be most profitably and practicably considered as adjuncts to insecticide use rather than as total replacements.

Session 5: Host-Plant x *Heliothis* Interactions and Resistance Screening

Discussion Leader: A.C. Waiss

In these discussions it was agreed that the development of plant resistance to *Heliothis* spp is one of the most attractive management options, but there were widely varying degrees of optimism concerning the potential for this approach. In cash crops the relatively easy and profitable chemical pesticide option has tended to relegate plant resistance to a relatively minor position. There may be a greater potential for the utilization of resistance/tolerance in low-value crops where pesticide use does not provide an easy and profitable means of pest control. The development of a two-path approach, as followed at ICRISAT, was commended. Here, the effort is, on the one hand, to produce plants that yield particularly well when given purchased inputs, including protection from pests; on the other, to select plants that are resistant or tolerant to the constraints, including pests, that are present in most farmers' fields.

There was a debate on the relative merits of closed-system and open-field screening. The available evidence indicated that both methods have advantages and disadvantages, depending upon the crop and other factors. Methods of screening will vary from crop to crop and according to the facilities and manpower available. It is important, however, to develop screening methods that can be relied upon to discriminate between more and less susceptible plants and then to utilize these in a sustained effort to produce resistant/tolerant materials, first from germplasm in the preliminary stages of the program and then from the crossed materials produced by the breeders using the original selections. Far too many resistance-selection programs are half-hearted efforts that stumble into oblivion after 3 or 4 years with the erroneous conclusion that there is no worthwhile level of resistance to *Heliothis* in the crop.

The need for an interdisciplinary approach to plant resistance was stressed. The entomologists and plant breeders will, of course, be the primary participants, but there is usually a need for scientists of other disciplines, including chemists and plant physiologists. While it may not be essential to determine the mechanism of resistance, in some cases such a determination can accelerate progress, for it is often much easier to screen directly for the mechanism rather than to rely upon the insect as a bioassay indicator, particularly for single-plant selections in segregating populations.

The importance of behavioral and biological studies of the pest in plant-resistance programs was stressed. Such studies may initially help to determine the stage of the insect that is vulnerable to the available variability in the host-plant germplasm and perhaps help to identify the mechanism of resistance. In general, behavioral and biological studies will precede genetic and biochemical studies.

The need for efficient mass-rearing facilities for *Heliothis* spp was stressed. Although there has been some success in open-field screening, using the available natural *Heliothis* populations, the general finding has been that the great variability in such populations, in both time and space, has greatly hindered the screening programs. A facility to inoculate the plants in fields, screenhouses, and laboratories may lead to accelerated progress.

Although the polyphagous nature of *Heliothis* spp would appear to limit the potential for finding crop plants that have substantial resistance to this pest—for it can obviously cope with a wide range of physical and chemical differences in its host plants—there is a positive aspect to this. For oligophagous pests the detection of preferences is of little utility under the no-choice situation, but for *Heliothis* there is usually a choice, often of noncrop hosts, so the development of even slightly less preferred crops may divert a substantial portion of the *Heliothis* population to plants where their feeding is of no concern.

It was also pointed out that the utilization of crops with quite low levels of resistance may be of major value when combined with other elements of control. Resistant or tolerant cultivars will require different economic thresholds; this will be of particular importance where a tolerant cultivar replaces a susceptible one.

There should be a free exchange of information and materials between scientists and countries. Although the species of *Heliothis* in the USA differ from those in Asia and Africa, it is probable that plants found resistant to one species will have at least some resistance to the other. A good start has been made in the case of groundnut, where selections found resistant to *H. zea* in North Carolina, USA, are now being tested against *H. armigera* and other pests at ICRISAT Center in India.

Of other plant-pest interactions, most discussion centered around the use of neem extracts. Several scientists in many countries are now investigating the use of azadirachtin against several pests, including *Heliothis* spp. As this chemical has such a complex molecule, it is unlikely that it will be synthesized cheaply, if at all, so the botanical source will have to suffice. The economics of the use of this material do not appear to have been thoroughly researched.

Recommendations

1. International pest resistance nurseries should be established and encouraged.
2. The exchange of germplasm and progress reports between scientists working on plant resistance to *Heliothis* should be encouraged.
3. Standardized screening techniques and mass-rearing methods should be established and publicized.
4. There should be a multidisciplinary approach to the studies of the genetics and mechanisms of host-plant resistance.
5. The use of insect repellents, including neem and other plant extracts, should receive some attention in pest-management studies.

Session 6: Novel Methods of *Heliothis* Management

Discussion Leader: G.H.L. Rothschild

The discussion in this session concentrated upon the potential use of pheromones and sterile hybrids of *Heliothis.*

Pheromones

There has been a considerable improvement in the analysis and synthesis of the pheromones of *Heliothis* spp in recent years, but we must now determine whether the synthetic pheromone mixtures are going to be of practical value in *Heliothis* management. Considerable numbers of male moths can be caught in a variety of traps baited with various substrates that allow the evaporation of the synthetic pheromones.

The most probable practical use of the synthetic pheromones lies in monitoring populations. Forthis there is first a need to standardize trap design, pheromone dosage and release rates from the chosen substrate, and siting of the traps. Catches in these traps have to be compared with other measures of *Heliothis* populations, including light traps and actual counts of *Heliothis* eggs and larvae, on the host plants in the area of the traps. Preliminary studies have already indicated that the catches in pheromone traps do not correlate very well with light-trap catches and field counts of the pest in all circumstances. However, data from pheromone traps have already been shown to be of value in some studies in the USA, where the data have been used in prediction models and have given useful information on the timing of infestations.

Pheromone traps have many advantages over light traps, particularly in areas where electricity is not readily available or the supply is erratic. If the catches are found to have a recognizable relationship to moth populations, pheromone traps will form a relatively cheap and simple basis for networks or grids of traps over regions, the data from which may be of use in determining the extent of migration and the relationship of populations to cropping patterns and climates. Such networks may also provide us with useful predictive data, while arrays of traps within individual crops might be of value in indicating thresholds for pesticide use.

The duration of the period of attraction of synthetic pheromones has been found to vary considerably. Some have been recorded to lose much of their attraction within a few hours, but rubber septa impregnated with synthetic pheromone of *H. armigera,* formulated by the Tropical Products Institute of London, have exhibited considerable attraction for up to 3 months of exposure in traps at ICRISAT, with little or no reduction of catches discernible over the first month of exposure. Attractants of such longevity are of obvious utility in trap networks.

The use of pheromones for *Heliothis* population suppression does not look very promising at this time. Attempts to disrupt mating using the pheromones have not yet produced very encouraging results. The prospects for the utility of mass trapping appear to be even more discouraging, partly because of the considerable mobility of the moths, but also because some studies have indicated large numbers of male moths are trapped only several days after peak moth emergence and peak mating have occurred. Additionally, even the most efficient traps apparently catch less than 50% of the males attracted to within a meter of the trap. However, some success in population suppression using mass trapping has been reported from Israel.

The identification of other attractants was briefly discussed. Some chemicals are known to attract both male and female *Heliothis* moths, but the attraction is weak, and catches in traps baited with these substances are low. However, the enormous payoff that would result from the identification of a chemical mixture that is very attractive to the female moths should ensourage further research.

Sterile Hybrids

The encouraging results obtained on St. Croix Island, using the *H, virescens* x *H. subflexa* hybrid for population suppression, stimulated discussion on the future of such initiatives. This test should now be repeated over a larger area. Additionally, the possibility of producing similar sterile hybrids using other species and *H. zea* and *H. armigera* as parents should be investigated. Biosystematic and crossing studies might best be conducted in laboratories in countries such as UK, where *Heliothis* is unlikely to become a pest. Backcrossed progeny from promising species combinations can then be transferred to the target areas for behavioral studies and eventual evaluation.

Recommendations

1. Monitoring *Heliothis* abundance with pheromone-baited traps appears to be a most promising area for research in developing countries. Traps and baits should be standardized as far as possible, at least on a regional basis. Trap-catch data should be related to information from other monitoring devices such as light traps, to estimates of numbers of eggs and larvae in the crop, crop damage, crop phenology, and weather. The development of a central repository for such information should be encouraged and analysis of results should be undertaken on a collaborative basis with organizations having expertise in this area, e.g. the Centre for Overseas Pest Research (UK) and the modeling units of the United States Department of Agriculture.
2. The research on mating disruption of *Heliothis* is still at a relatively early stage in developed countries, and it is recommended that organizations in developing countries should remain informed of this work without initiating programs of their own— at least until the merits of mating disruption of *Heliothis* are obvious.
3. Mass trapping does not appear, at present, to be a feasible control strategy for *Heliothis* spp. Any new initiatives in this area should be carefully assessed.
4. It is recommended that a central location, perhaps in the UK, be established for biosystematic studies of *Heliothis* spp. This initiative should be extended to work on the development of appropriate sterile *Heliothis* hybrids when it is considered that sufficient progress has been made in the pilot programs such as those in the USA.

Session 7: Integration of Management

Discussion Leader: M.J. Lukefahr

The current status of knowledge on various management components was discussed with particular reference to their utility in an integrated pest-management system. It became evident that much more information was needed on economic thresholds, crop loss estimates, scouting methods, insect behavior, population dynamics, and the diapause/aestivation of *Heliothis* on a regional basis. In the case of economic threshold levels, differences in costs and economic returns from different crops and areas will ensure that these have to be researched and calculated for each crop on a national or even area basis.

From the available information on several management components, including host-plant resistance and the use of microbials, it would appear that, in most areas, these are still a long way from implementation in farmers' fields.

Development of crop loss assessment methodology and studies of cultural practices such as crop rotations and closed seasons, of sources of pest populations, and of the use of selective pesticides for the conservation of biocontrol agents may all produce worthwhile data that could have an impact in the near future on the management of *Heliothis* spp, particularly in the semi-arid areas of developing countries.

Although we are still a long way from being able to formulate integrated pest-management strategies that are anywhere near ideal for most farmers and areas, we have certainly progressed beyond the stage where the only advice that we can give the farmer is to spray pesticides whenever he sees *Heliothis* eggs or larvae in his crop. There is already an abundance of evidence to show that total reliance upon pesticides for *Heliothis* management is doomed to failure, with consequent major problems. It is obvious that there is unlikely to be a panacea for *Heliothis* management in the near future. Management strategies are likely to remain relatively specific to a site, or at least a region.

Recommendations

1. Economic injury levels for the major crops should be established.
2. Methods of monitoring populations should be developed.

3. The use of pheromones should be studied, particularly in relation to monitoring populations. Additional studies of the long-range movement of *Heliothis* spp moths are required in most regions.
4. Many potential elements of *Heliothis* management were presented at this workshop, but most are not yet sufficiently advanced to be of practicable use in any generally applicable pest-management strategy.
5. Additional studies need to be made on closed seasons, sowing dates, crop rotations, and other cultural practices that are components of pest management systems.

Appendix 1

Participants

International Workshop on *Heliothis* Management

Rear row (standing): H. Rembold, D.S. Hackett. A.G.L. Wilson, G.H.L. Rothschild, T.J. Lawson, A. Kohli, R.J.V. Joyce, D.J. Rogers, P.D. Lingren, Galal El Din Hamid Osman, D.J. Greathead, J.A. Gledhill, W.V. Campbell.

Second row (standing): P.H. Twine, K.S. Kushwaha, A.K. Karel, A.N. Balla, HP. Saxena, K.S. Chhabra, Zile Singh, T.S. Thontadarya, M. Jacobson, D.J. McKinley, E.G. King, A.C. Bartlett, N. Ramakrishnan, J.C. Davies.

Third row (sitting): K.D. Paharia, M.J. Haggis, Sudha Nagarkatti, R.C. Patel, S. Jayaraj, J.S. Kanwar (Director of Research, ICRISAT), L.D. Swindale (Director General, ICRISAT), J.R. McLaughlin, M.R. Bell, A.C. Waiss, Jr., B.R. Wiseman, A.N. Sparks, B. Nyambo.

Front row (sitting): S. Sithanantham, W. Reed, E. Winter, C.S. Pawar, A.B. Mohammed, P.W. Amin, H.C. Sharma, S.S. Lateef.

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