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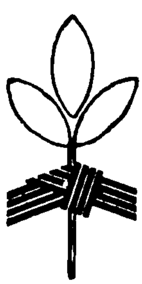

The symbol shows a traditional knot tied from kunai grass. It means "do not touch" or "keep away." If it is placed on a tree or any plant in a garden, it means "this plant is protected." Designed by Iava Greita, the symbol was first used for the South Pacific Commission third Regional Meeting on Plant Protection in Port Moresby, Papua New Guinea.

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SUB-REGIONAL TRAINING COURSE
ON
METHODS OF CONTROLLING DISEASES, INSECTS
AND
OTHER PESTS OF PLANTS IN THE SOUTH PACIFIC

OCTOBER 4-20, 1982
GOVERNMENT EXPERIMENTAL FARM, VAINI
KINGDOM OF TONGA

SPONSORED BY

GERMAN AGENCY FOR TECHNICAL CO-OPERATION
UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT
CONSORTIUM FOR INTERNATIONAL CROP PROTECTION

IN CO-OPERATION WITH

MINISTRY OF AGRICULTURE, FISHERIES AND FORESTS OF TONGA
SOUTH PACIFIC COMMISSION

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Date: Oct. 4
Time: 1400*

WELCOME ADDRESS AND OFFICIAL OPENING

His Royal Highness Prince Tu'ipelehake
Minister of Agriculture, Fisheries and Forests
Kingdom of Tonga/South Pacific

Ladies and gentlemen, I have the honor to address you this afternoon at the opening of this important meeting. It is pleasing to know that we have here with us a good number of leading scientists from both within and outside the South Pacific region for this purpose. I would like to congratulate the organizers of the Training Course for the considerable effort contributed which finally sees us here today. I am obliged to acknowledge with gratitude the financial assistance of the sponsors, the Consortium for International Crop Protection, the Agency for International Development, and the German Agency for Technical Cooperation. Without your kind assistance this occasion would not have been possible. The South Pacific Commission is also acknowledged, for assistance lent to organizing and in arranging the course.

It is noted that the some 35 participants to this course come from some 19 different countries of our region. Such interest underlines the importance to us all of the subject on which you are about to deliberate. Increased agricultural production and modernization are preconditions for future development of our nations. New crops and farming techniques are being introduced and leading toward increased productivity, and the export markets are imposing new demands in crop quality. Hence, agriculture must be increased and the crops must be protected as required to meet not only the farmers' demands but also the export demands. I believe that this Training Course and similar courses in the future will contribute significantly in allowing us to meet these demands.

Over the next three weeks, you will deal with many details of plant insect pest and disease control. It should be borne in mind, however, that control measures are tools and are not by themselves answers to all questions. You participants are charged with the responsibility of not only utilizing them but also in deciding on how and when to use these tools; for they must be used rationally and conscientiously.

*Date and time of presentation

This Plant Protection Center has only recently been opened. It is indeed fitting that a training course on the subject of plant protection be the first to be held here.

To all you distinguished scientists from far and near and participants from our neighboring countries on behalf of the Government of Tonga I extend to you all our sincere greetings. I hope that your stay with us will be a rewarding experience; we certainly look forward to sharing with you our island culture in the next few weeks. With these few comments, I have much pleasure in declaring the Sub-Regional Training Course on Methods of Controlling Diseases, Insects, and Other Pests of Plants in the South Pacific open. May God lead you in your deliberations of heart.

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To enable the GTZ to operate as flexibly as possible in fulfilling these tasks, it was given the legal status of a private enterprise working according to commercial principles.

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- optimal gearing of GTZ contributions to the local conditions; special emphasis on environment-oriented project planning, appropriate technologies and locally renewable sources of energy; 'soft' utilization of ecosystems aimed at longevity;
- maximum participation of target groups in planning and implementing the projects;
- maximum coverage of the population's basic needs for goods and services in the developing countries;
- optimal results with the lowest possible costs for client and project partner, not least with a view to foreign exchange and follow-on costs.

Flexible management, emphasis on economy and public benefit principles, supervision by the Federal German Government, with most projects anchored in bilateral government agreements - these are the major elements and specific characteristics of GTZ work as an enterprise devoted to economic and social development in the developing countries.

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CICP/USAID STATEMENT

Consortium for International Crop Protection

United States Agency for International Development

The Sub-Regional Training Course and the proceedings were sponsored in part by the Consortium for International Crop Protection (CICP) and the United States Agency for International Development (USAID) through Contract No. DSAN-C-0252 to CICP. The contents of the proceedings do not necessarily reflect the policies and techniques of CICP or USAID, nor does the mention of trade names of commercial products constitute endorsements or recommendations for use.

The purpose of CICP is to aid countries requesting assistance to improve their capability for developing economically efficient and environmentally sound systems of crop protection. Thirteen universities--University of California, Cornell University, University of Florida, University of Hawaii, University of Illinois, University of Maryland, University of Miami, University of Minnesota, North Carolina State University, Oregon State University, University of Puerto Rico, Purdue University, Texas A&M University--and the United States Department of Agriculture form the CICP membership. CICP is financed in part by USAID, and it works with this agency in carrying out pest and pesticide management programs in the developing countries. One of CICP's missions is to develop short courses, seminars, and workshops on pest and pesticide problems in given regions. For more information, write: CICP, 2288 Fulton Street, Suite 310, Berkeley, California, 94704 (USA); Cable address: CONSORTICP BERKELEY.

SPC STATEMENT

The South Pacific Commission (SPC), founded in 1947, is a technical organization which provides training and assistance in social, economic, and cultural fields to 22 countries of the region it serves (American Samoa, Cook Islands, Federated States of Micronesia, Fiji, French Polynesia, Guam Kiribati, Marshall Islands, Nauru, New Caledonia, Niue, Northern Mariana Islands, Palau (Republic of Belau), Papua New Guinea, Pitcairn Islands, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, Wallis and Futuna Islands, and Western Samoa). Altogether the countries contain approximately five million people scattered over some thirty million square kilometers.

The South Pacific Commission is the executive arm of the South Pacific Conference which is composed of 27 member countries including Australia, France, New Zealand, United Kingdom, and United States of America. The Conference meets annually to examine the Commission's budget and work program, which incorporate projects covering food and materials, marine resources, rural management and technology, community services, socio-economic statistical services, education services, information services, regional consultation, awards and grants, and cultural conservation and exchange.

The principal officers of the South Pacific Commission at October 1982 were: Secretary-General, Mr. Francis Bugotu; Director of Programmes, Mr. W. T. Brown; and Deputy Director of Programmes, Mr. T. Pierre.

COURSE OUTLINE

Oct. 2 (Sat.)		Most of the participants arrived
Oct. 3 (Sun.)	1300	- Tour of Tongatapu Island (Coordinated by N. von Keyserlingk)
Oct. 4 (Mon.)	1400	- Welcome address and official opening (His Royal Highness Prince Tu'ipelehake, Minister of Agriculture, Forestry and Fisheries)
	1415	- Background and objectives of the course (N. von Keyserlingk)
	1430	- Welcome address by the representative of the South Pacific Commission (M. Lambert)
	1435	- Welcome address by the representative of the Consortium for International Crop Protection (D. G. Bottrell)
	1445	- Introduction to agriculture in the South Pacific ('Epeli Hau'ofa)
	1515	- Break and photographs of course participants
	1545	- Technical course arrangements and election of course Chairman and trainees' representatives (Coordinated by N. von Keyserlingk)
	1600	- Objectives of the course D. G. Bottrell)
	1830	- Social reception for course participants sponsored by the Government of Tonga (held at the International Dateline Hotel)
Oct. 5 (Tue.)	0840	- An overview of plant protection in the South Pacific (I. D. Firman)
	0945	- Review of major insect pests of crops in the South Pacific (P. Maddison)
	1120	- Break

Oct. 5 (cont'd)	1140 -	Review of major diseases of crops in the South Pacific (I. D. Firman)
	1250 -	Lunch
	1415 -	Tour of crops at the Government Experimental Farm at Vaini, and practical exercise in the identificaton of representative crop insect pests and diseases (Coordinated by P. Maddison and T. Holo)
	1950 -	Evening workshop emphasizing discussion of research and extension planning for pests on selected crops (Coordinated by T. Holo)
Oct. 6 (Wed.)	0905 -	Major weed problems of the South Pacific (R. K. Nishimoto)
	1040 -	Break
	1120 -	Rat damage, ecology, and control in the South Pacific (J. M. Williams)
	1250 -	Lunch
	1400 -	Practical exercise identifying weeds and training on rat control measures (Coordinated by R. K. Nishimoto and J. M. Williams)
Oct. 7 (Thur.)	0905 -	Country reports elaborated in working groups: review of major pest problems and status of crop protection in representative countries, including: 1. principal crops and major pests 2. pattern of pesticide use and development of nonchemical methods 3. institutional arrangements for developing and implementing crop protection programs:

Oct. 7 (cont'd)

a. research institutions involved, emphasis and establishment of priorities

b. extension programs and education

c. operation programs

d. pesticide and quarantine regulations

4. future aspects of plant protection

1100 - Break

1115 - Presentation of working group reports

1245 - Lunch

1400 - The influence of pests on cash crops (F. Dori)

1510 - Break

1540 - The influence of pests on traditional crops (R. Muniappan)

2020 - Evening workshop emphasizing discussions on research and extension planning for pests on selected crops (Coordinated by N. von Keyserlingk)

Oct. 8 (Fri.)

0900 - Analysis of the economic status of diseases, insects, and other pests in question (D. G. Bottrell)

1030 - Break

1055 - The concept of economic injury level and economic threshold level in view of economics in crop production (R. Rathey)

1225 - Lunch

1325 - Examples of case history studies involving the analysis of the economic status and determining the need for control (D. G. Bottrell)

Oct. 8 (cont'd)	1425 - Break
	1500 - Field demonstration of research to establish economic thresholds for taro insect pests and research on chemical control of sweet potato disease organisms (Coordinated by K. Englberger and P. Vi)
Oct. 9 (Sat.)	Free day - boat trip to Fafa Island
Oct. 10 (Sun.)	Free day - Bus tour of Tongatapu Island and lunch at the Good Samaritan Restaurant
Oct. 11 (Mon.)	0905 - Summary of first week (I. D. Firman)
	0945 - Cultural control in modern practice (D. G. Bottrell)
	1030 - Continuation of cultural control in modern practice (D. G. Bottrell)
	1230 - Lunch
	1330 - Use of disease resistant varieties (P. van Wijmeersch)
	1420 - Break
	1500 - Working groups to review traditional crop protection techniques in taro and coconut in the South Pacific
Oct. 12 (Tue.)	0900 - Announcements (N. von Keyserlingk)
	0919 - Summary of previous day's activities (I. D. Firman)
	0920 - Factors that merit attention in biological control programs (D. F. Waterhouse)
	1030 - Break

Oct. 12 (cont'd)	1050 -	Review of existing pest control methods using biological agents (M. K. Kamath)
	1230 -	Lunch
	1335 -	The giant African snail with special reference to its biological control (R. Muniappan)
	1440 -	Break
	1500 -	Integrated control of the rhinoceros beetle (C. Pertzsch)
	2010 -	Showing of the films "Insect Alternative" and "Biological Control"
Oct. 13 (Wed.)	0900 -	Announcements (N. von Keyserlingk)
	0910 -	Summary of previous day's activities (D. G. Bottrell)
	0925 -	Reports of working groups to reveiw traditional crop protection techniques in taro and coconut in the South Pacific
	0945 -	Legislative and regulatory methods in the Pacific (I. D. Firman)
	1035 -	Break
	1100 -	Pesticide legislation: rationale and status (I. D. Firman and D. G. Bottrell)
	1125 -	Panel discussion of on-going efforts and needs in pesticide and quarantine regulations in the South Pacific (T. Simiki, I. D. Firman, E. C. Pickop, N. von Keyserlingk, and D. G. Bottrell)
	1230 -	Lunch
	1335 -	Pheromones, hormones, and genetic methods of insect control (D. F. Waterhouse)

Oct. 13 (cont'd)	1430 -	Break
	1450 -	Environmental diversity and insect pest abundance with reference to the Pacific (J. A. Litsinger)
	1900 -	Dinner sponsored by course participants for Tongan representatives held at Akiko's Restaurant (Coordinated by E. C. Pickop)
Oct. 14 (Thur.)	0900 -	Announcements (N. von Keyserlingk)
	0915 -	Summary of previous day's activities (I. D. Firman)
	0930 -	Chemical control: principles and techniques (N. von Keyserlingk)
	1030 -	Break
	1045 -	Chemical control: use in IPM programs (D. G. Bottrell)
	1230 -	Lunch
	1330 -	Practical exercises in using and testing pesticides (Coordinated by K. Englberger and H. Stier)
		Methods of calibration and application (K. Englberger)
		Field experiments for research and extension (H. Stier)
	2000 -	Evening workshop: discussion with a representative of the pesticide industry (F. Sumich)
Oct. 15 (Fri.)	0900 -	Announcements (N. von Keyserlingk)
	0925 -	Resistance testing in insects, ticks, and mites (L. O. Brun)
	1045 -	Report of the trainees' review of the course (Presented by E. C. Pickop)

Oct.15 (cont'd)

1145 - Showing of the films: "The Rhinoceros Beetle Control Program in Western Samoa" and "Pesticides and Pills--for Export Only" (Part I)

1800 - Tongan feast and floor show at Oholei Beach (Sponsored by the German Agency for Technical Cooperation, GTZ)

Oct. 16 (Sat.)

1400 - Tour of Tongatapu Island with demonstration of diseases, insects and other pests in crops (Coordinated by K. Englberger)

Oct. 17 (Sun.)

Free day

Oct. 18 (Mon.)

0900 - Announcements (N. von Keyserlingk)

0915 - Definition objectives, and features of integrated pest management (W. C. Mitchell)

1030 - Break

1100 - Sampling in integrated pest management (R. Daxl)

1230 - Lunch

1330 - IPM implementation: case history examples and guidelines for development

A case history study from Nicaragua
(R. Daxl)

Guidelines for development based on existing chemical control techniques
(J. A. Litsinger)

1450 - Break

1505 - Practical field exercise in assessing the pest problems and needs for IPM implementation in cabbage, capsicum, peanut, and paper mulberry (Coordinated by J. A. Litsinger)

Oct. 19 (Tue.)	0900 -	Summary of previous day's activities (I. D. Firman)
	0915 -	Reports of working groups on the practical field exercise in assessing the pest problems and needs for IPM implementation in cabbage, capsicum, peanut, and paper mulberry (Coordinated by N. von Keyserlingk)
	1020 -	Break
	1045 -	Working group sessions on requirements for integrated pest management in banana, tomato, coconut, and taro
	1230 -	Lunch
	1330 -	Reports of working group sessions on requirements for integrated pest management in banana, tomato, coconut, and taro (Moderated by I. D. Firman)
	1445 -	Break
	1500 -	Continuation: open discussion of reports of the working group sessions (Moderated by I D. Firman)
	1800 -	Tongan feast and floor show at the Government Experimental Farm at Vaini (Sponsored by the Consortium for International Crop Protection)
Oct. 20 (Wed.)	0900 -	Announcements (N. von Keyserlingk)
	0910 -	The future of integrated pest management in the island countries of the South Pacific--open discussion (W. C. Mitchell, Chairman)
	1040 -	Break
	1140 -	Trainees' recommendations: future needs in IPM training, research, and coordination in the island countries of the South Pacific (Presented by E. C. Pickop)

Oct. 20 (cont'd)	1155 -	Closing comments by course implementors (M. Lambert, D. G. Bottrell, and N. von Keyserlingk)
	1220 -	Closing ceremony by MAFF representative, S. Sefanaia

COURSE IMPLEMENTORS' ACKNOWLEDGEMENTS

The Sub-Regional Training Course and these proceedings are the fruits of the labors of many individuals and organizations to whom we extend our sincere thanks. We especially want to acknowledge the contributions of the following:

- The Government of the Kingdom of Tonga, for hosting the course, for publishing the proceedings, and for the fine hospitality throughout all of the course;

- The German Agency for Technical Cooperation (GTZ), United States Agency for International Development (USAID), and Consortium for International Crop Protection (CICP), for serving as financial sponsors;

- The South Pacific Commission (SPC), for getting the trainees and regional consultants safely to the course and back to their homes, and for serving as an effective course implementor;

- The personnel of the Tonga-German Plant Protection Project and the Government Experimental Farm, Vaini, for their many contributions as support staff;

- Eileen Bell, Cathy Cline, Alison Harolde, Sara Homewood, Patricia La Force, Tela Long, Pua Mitchell, Helen Petit, Sabrina Snyder, and Julie Thomas for their work in typing the proceedings' manuscript;

- The course lecturers and resource persons, for their outstanding contributions in training; and, most importantly,

- The course trainees, for exhibiting diligence, patience, and interest in the subject matter.

A very special thanks goes to two trainees, Osasa Aukuso of Western Samoa and Michel Hoatau of Wallis and Futuna, elected by the other trainees to represent them in organizing meetings called by the course implementors. Messrs. Aukuso and Hoatau worked very diligently as trainee representatives and offered many useful suggestions to the implementors.

Plant protection is a very large and diverse subject, a subject that cannot be covered adequately in a document of this size. The proceedings hopefully will prove useful in future

training activities in plant protection in the South Pacific. We especially hope that it will serve to make governments and other organizations in this region more cognizant of the important role of economically efficient and environmentally sound plant protection.

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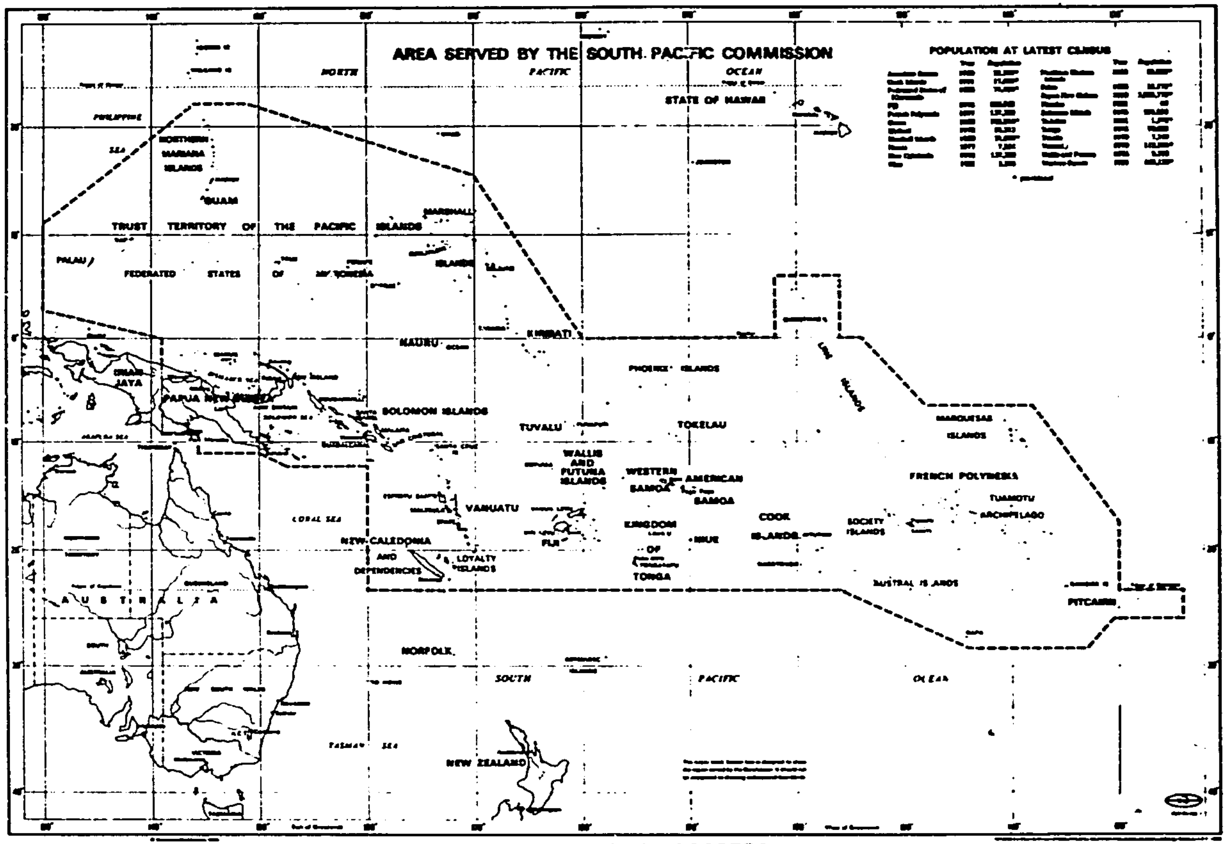
PHOTOGRAPH OF COURSE PARTICIPANTS AT
GOVERNMENT EXPERIMENTAL FARM, VAINI, KINGDOM OF TONGA

ACRONYMS OF NAMES OF ORGANIZATIONS THAT APPEAR IN PROCEEDINGS

CAB	Commonwealth Agricultural Bureaux
CASAS	Commonwealth Association of Scientific Agricultural Societies
CIBC	Commonwealth Institute of Biological Control
CICP	Consortium for International Crop Protection
CSIRO	Commonwealth Scientific and Industrial Research Organization
DSIR	Department of Scientific and Industrial Research
FAO	Food and Agriculture Organization of the United Nations
GTZ	German Agency for Technical Cooperation (GTZ)
IBPGR	International Board for Plant Genetic Resources
IFS	International Foundation for Science
IRETA	Institute for Research, Extension, and Training in Agriculture of The University of the South Pacific
ISO	International Standards Organization Technical Committee 81
MAFF	Ministry of Agriculture, Fisheries and Forests of the Kingdom of Tonga
ORSTOM	Office de la Recherche Scientifique et Technique Outre-Mer/Overseas Technical and Scientific Research Office
PPC/SEAPR	FAO Plant Protection Committee for the Southeast Asia and Pacific Region
SPC	South Pacific Commission
SPEC	South Pacific Bureau for Economic Cooperation
UN	United Nations
UNDP	United Nations Development Program
US or USA	United States of America
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USSR	Union of Soviet Socialist Republic
WHO	World Health Organization



MAP OF THE SOUTH PACIFIC

Date: Oct. 4
Time: 1415*

BACKGROUND AND OBJECTIVES OF THE COURSE

Niels von Keyserlingk and Dale G. Bottrell

Course Implementors

BACKGROUND

Most of the farmers of the South Pacific still practice a form of traditional agriculture, characterized by small, subsistence farms, polyculture (growing of two or more crops simultaneously in the same field in the same year), local, unimproved crop varieties, little or no artificial fertilizers or pesticides, and minimum tillage. However, this situation is changing. The countries are promoting increased production of agriculture and emphasizing the export of agricultural products. Fertilizers, pesticides, and mechanization are being introduced, and in many areas polyculture is giving way to the planting of monoculture.

Increased use of modern agriculture promises to benefit the people of the South Pacific. But many obstacles must be overcome before the crop yields can be increased and sustained on a continuing basis. One obstacle owes to a lack of adequate pest management systems to protect the growing plants and harvested products. A wide range of harmful insects, weeds, microorganisms, rodents, and other organisms--collectively "pests"--constrain crop production. Historically, as agricultural productivity

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*Date and time of presentation

has increased, so have the pest problems.

The pest problems in the South Pacific island countries will most likely worsen in the future, parallel with the expansion of monoculture and increased crop production. Further, all the island countries are vulnerable to the introduction of new (exotic) pests. The emphasis on greater export and exchange of agricultural products in the region has increased the threat of the introduction of exotic pests.

The crop protection products industry is expanding in the South Pacific, as evidenced by the recent increased use of pesticides in the region. The effectiveness of certain chemical agents, together with the increased yield and marketability of the products, have made pesticides very popular, although their disadvantages and their possible negative effects on the environment are not yet fully known. The farmers' lack of knowledge with respect to the proper use and mode of action of these products has already led to accidents and crop losses in some cases.

A particularly worrisome aspect of improper use of pesticides is their effect on the environment. In the islands of the South Pacific, which are small and isolated, pesticides present a much greater threat to the ecological equilibrium than they do in large continents.

The recent discovery in Tonga and Western Samoa of pesticide residues in drinking water, brackish water of the lagoons, fresh milk, and human fat points to the problems stemming from the incorrect use of pesticides. Further, there is evidence in some of the South Pacific islands that some insect pests and at least one plant pathogen have evolved genetically resistant strains and can no longer be controlled with pesticides that were previously effective. The evolution of genetically resistant strains of pests is of particular concern. Worldwide, in 1980, 432 species of insects, mites, and ticks, about 50 species of plant pathogens, five species of weeds, and two species of nematodes were known to have developed strains resistant to chemical pesticides (Georghiou, 1980). Included in this group are some of the world's most serious insect pests affecting agriculture and public health.

Experience with many crops in many areas of the world has shown that the best way to reduce effects of pesticides such as environmental pollution, human health, and pesticide resistance is to use the materials in combination with other pest control methods--such as insect and disease resistant plant varieties, cultural control, and biological control--in a strategy known as "integrated pest management" (IPM). The IPM strategy does not advocate the elimination of pesticides. These materials have played--and will continue to play--an important role in IPM. However, in integrated pest management, pesticides are used only as required to keep pests below levels which have been determined to be unacceptable, based on economic criteria. The approach draws first from the nonchemical methods; pesticides are used as a "stop-gap" measure. One of the features of IPM is that it tries to maximize on the use of various cultural practices already familiar to the traditional farmer. IPM systems in many areas of the world--both developing and developed--have been adopted successfully by farmers. The results have been encouraging: the use of pesticides has usually dropped significantly with no loss in crop yield or quality and in some cases the yields have increased.

Integrated pest management is not a new concept, and there are some examples to show that IPM has already been applied successfully against a few pests in the South Pacific. However, there is not a widespread understanding or appreciation of the approach in this region. One of the primary purposes of this training course is, therefore, to introduce the IPM concept and to show how it is applied to the farmers' fields. Experience around the world has shown that training--at all levels: for research technicians, extension officers, government officials, and, of course, farmers--is the most essential ingredient to successful IPM development and implementation. Without a proper understanding of the IPM concept and application, the unilateral use of pesticides can only be expected to increase and to create even more problems. The course organizers attach considerable significance to the importance of this course, and we hope that the trainees do too.

The idea to conduct a training course along these lines was born during our discussions in May 1980 when Dale G. Bottrell visited Tonga on an assignment for the South Pacific Regional Development Office of the United States Agency for International Development, Suva, Fiji. Some months later, in agreement with all course implementors--the Department of Agriculture in Tonga of the Ministry of Agriculture, Fisheries, and Forests (MAFF), Consortium for International Crop Protection (CICP), United States Agency for International Development (USAID), Plant Protection Project in Tonga of the German Agency for Technical Cooperation (GTZ), and the South Pacific Commission (SPC)--it was decided to hold a sub-regional training course on plant protection and IPM in Tonga for three weeks during May and June 1982. The devastation of parts of Tonga by the cyclone "Isaac" on March 3, 1982, forced us to postpone the course planned for May and June 1982 and reschedule it for October 1982.

This course was sponsored by GTZ, USAID, and CICP in cooperation with MAFF and SPC. The tasks of organizing the course were divided among the various organizations as follows:

- MAFF provided the facilities, hosted the course, and will print the proceedings
- GTZ and the Tonga-German Plant Protection Project were the principal course organizers, developed the course program, and provided funds required for the participation of lecturers from the South Pacific region
- CICP provided funds required for the participation of the trainees and the lecturers from the United States, invited the lecturers outside of the South Pacific,

and will assume major responsibilities for editing the proceedings

- SPC announced the course to the governments of all the countries in the SPC region and made all travel arrangements for the trainees.

The course was developed primarily for plant protection officers and extension officers concerned with advising farmers on plant protection matters. In the course announcement sent to the governments of the SPC region, it was stated that a degree or diploma in an agricultural subject would be desirable and that the course would be conducted only in English. We agreed from the outset that a maximum of 30 trainees snould participate in the course.

COURSE OBJECTIVES

As stated in the "Course Information Guide and Programme":

"The objectives of the course will be to assist trainees in identifying the diseases, insects, and other pest problems in their country, in assessing the losses caused by these diseases, insects, and other pests, and in deciding on the appropriate control measures.

Special attention will be given to measures which do not involve the use of pesticides. The correct use of pesticides when necessary will be emphasized."

The concept of integrated pest management will be stressed throughout the course. The course will include several practical laboratory and field exercises, demonstrations, and field trips. During the course, the trainees will be asked to develop guidelines for IPM programs in selected crops in the region, based on these key questions:

1. What are the real pests of a crop?
2. What limits them in nature, that is, what are the natural controls?
3. What are the other potential control methods?
4. When does control become profitable?
5. What are the economic, social, and environmental consequences of control?
6. What is the best combination of the control methods?

One very important aspect of the course will be for the participants to identify the major obstacles--biological, economic, social, and political--hindering the development and implementation of economically efficient and environmentally sound systems of integrated pest management. The course's program includes many discussions of experiences with IPM in other regions where the approach has advanced significantly. It also includes a discussion of the economics of pest control methods and the procedures that economists use to determine the cost effectiveness of these methods. The examples from these discussions will serve to show the essential steps that must be taken before IPM can be expected to advance further in the

South Pacific.

REFERENCE CITED

Georghiou, G. P. 1980. Implications of the development of resistance to pesticides: basic principles and consideration of countermeasures, pp. 116-129. Proc. Seminar and Workshop, Pest and Pesticide Manage. in the Caribbean, E. G. B. Gooding (Ed.). Vol. 2. U.S. Agency Int. Develop., Consortium Int. Crop Protection, Berkeley.

Date: Oct. 4
Time: 1445

INTRODUCTION TO AGRICULTURE IN THE SOUTH PACIFIC

'Epeli Hau'ofa

Before proceeding with the particular issue on which this address proposes to focus, I shall, by way of general introduction, state very briefly a couple of obvious facts about agriculture in the South Pacific islands region:

1. Throughout the region, agriculture is the most important industry, and with one or two exceptions, it forms the backbone of all island economies. The industry provides employment for the vast majority of our populations, and agricultural produce and products are the major sources of foreign exchange earning for most island states and territories.

2. Since the nineteenth century, agricultural production systems in the South Pacific have diversified. These systems can be grouped under the following broad categories:

   a. The plantation system. Until recently, plantations were completely under the control and ownership of expatriate individuals or companies. Expatriate ownership of plantations still continues although there is an increasing amount of localization of control. It is of interest that in many cases, the repatriated plantations have been kept intact instead of having been broken up into smallholder lots.

b. The nuclear estate-cum-smallholder system. This is a most recent introduction based primarily on models developed in Southeast Asia. A few examples of this system are the oil-palm projects in Papua New Guinea and Solomon Islands and the Seaqaqa sugarcane project in Fiji.

c. The smallholder commercial production system. Examples are cocoa and coffee planters in Papua New Guinea and the Fiji Indian sugarcane farmers.

d. The semisubsistence/semicommercial independent smallholder system. This system covers by far the largest number of people in the islands region. It should be noted that the vast majority of the rural population of the South Pacific are independent semisubsistence small-scale producers; and although among these people there is at present greater emphasis on subsistence production, the trend seems to be toward increasing commercialization, especially so in areas that are in close proximity to or are easily accessible to urban concentrations and to export ports.

The limited number of commercial rice growers in the region, the beef cattle raisers in parts of Melanesia, and the vegetable growers who produce for the domestic urban markets form an important, albeit small, commercial export network. The other food producers in the region are semisubsistence/semicommercial small-scale farmers who still use a variety of indigenous production techniques. The other production systems--the plantation system, the nuclear estate-cum-small-holder system, and the smallholder commercial system--concentrate on the production of cash crops for export.

I propose in this address to focus our attention on the indigenous food production systems in the South Pacific. There has been in recent years a growing concern in the region for adequate local production of food for domestic consumption. This is a long-standing worldwide concern, but it is relatively new to the South Pacific. It has risen not because of drastic food shortages as such, for food shortages have yet to become as serious a problem in our region as in some other regions of the Third World. The concern has risen because of the following reasons:

1. The high population growth rate throughout the region, varying from 2 to over 3 percent per annum
2. The increasing urbanization of the South Pacific societies with the consequent rise in the number of nonagricultural populations
3. The increasing proportion of food imports in the total

import bill--at least 25 percent in the late 1970s and continuing to rise

4. The dubious nutritional value of much imported foodstuffs--i.e., refined, polished, canned, and otherwise overprocessed foods; and the dumping of the cheapest and least worthy meat cuts in the islands
5. The persistent preference of Pacific islanders for familiar and actually nutritionally excellent tubers, corms, and other traditional food items over their imported substitutes
6. The higher cost of traditional foods in urban markets compared with imports such as polished rice and refined flour.

Most foods produced and consumed locally have been produced under the indigenous agricultural systems of shifting cultivation with gardens characterized by a polycultural mix of many food and nonfood crops, and intermixed with a variety of fruit and cultural trees. I need not go into this in detail for you all know it much better than I do. However, I would like to point out some of the merits of the indigenous agricultural systems or agroecosystems in our tropical region:

1. The existing agroecosystems have evolved over hundreds of years and are ecologically adapted to the islands. They are relatively pollution free and have so far required few modern technological or other imported inputs. Ecologically, they are self-sustainable, and, things being equal (although they never are), they could persist indefinitely.

2. These systems are energetically efficient. It has been estimated that, excluding solar radiation, the energy input into shifting cultivation is 0.02 joule for the production of one joule worth of food. By comparison, it has been estimated that in the United States, on the average, 10 joules of energy input are required to produce one joule worth of food. If the estimate for the United States is correct, then the present industrial system of food production can hardly be permanently sustainable given the world's limited supply of energy. On the other hand, the ecologically adaptive agroecosystems of the South Pacific have a good potential for permanence provided that the necessary balance between land and human population is maintained.
3. The shifting cultivation technique and the polycultural mix of many crops in the indigenous systems provide a fair measure of protection against insect pests and diseases. I am told that this has been observed to be the case although it has not been conclusively proven scientifically.
4. The same polycultural mix of crops has for ages provided adequately for the nutritional requirements of the South Pacific populations. The variety of root crops, leafy vegetables, and fruits found in our gardens supplemented occasionally with meat proteins from animals and fish are responsible for the generally good health of our rural populations.

5. Historically, the indigenous systems of the South Pacific have proved to be flexible and adaptive to changing circumstances. In the Papua New Guinea highlands, groups of people who live on the sparsely populated and forested fringe areas practice slash-and-burn, long-fallow systems while those who live in the highlands proper on densely settled grasslands practice shorter fallow systems and instead of natural recovery, use various techniques of soil enrichment. Micronesians and Polynesians who long ago emigrated to their present soil-less atolls adapted wonderfully to their stringent environments by digging large pits down to the water-lens where they developed various techniques of soil-creation for the cultivation of their food crops. And more recently, islanders throughout have successfully incorporated such cash crops as coffee, cocoa, and coconuts into their subsistence systems with little external guide and often in direct opposition to advice given by government agricultural officials. Given the fluctuations of commodity prices and the current parlous world economic situation, we can now see that the South Pacific semisubsistence/semicommercial producers have very wisely planted their feet on two worlds and have, thereby, maintained their necessary and basic security against the vagaries of

international trade and exploitation.

Although one does not want to romanticize the indigenous agricultural systems of the islands, one thinks that it is worth reiterating their merits, for despite the increasing appreciation in recent years of these systems, there are still those in influential positions who hold unjustifiable negative views of them as being primitive, unscientific, static, and unadaptive to the realities of our contemporary situation.

One of the important issues that has exercised the minds of regional policy makers and many others who are concerned with the problems of development in the islands is how we can produce locally sufficient amounts of food regularly to meet the nutritional requirements of our fast growing populations--both rural and urban. For the limited purposes of this address, I shall disregard the very important issues of distribution, marketing, and so forth and focus only on production.

There seems to be two main views on the question of increased food production. There are those who hold the view that because the indigenous production systems are geared largely for the producers' own and for social consumption, they are not capable of producing large surpluses on a regular basis to meet the growing demand for food. Therefore, according to this view, the solution lies on large-scale, fully commercial production of high-yielding crop varieties for the local market.

The other view is held by those who believe that the indigenous systems can be adapted to meet the growing demand and that this adaptation would in the long run be much better environmentally and socially than a full-scale introduction of any totally alien systems which in the South Pacific, because of the nature of our international connections, means the introduction of the energetically costly, and probably environmentally destructive, industrial agricultural system.

Large-scale, fully commercial production of local staples entails a movement toward monocropping of high yielding varieties and genetic simplification; it also entails high inputs of artificial fertilizers, herbicides, and other toxins that have elsewhere been reputedly responsible for the development of resistance in insect pests, weeds, and diseases that are supposed to have been eradicated. Such development could lead to a wholesale destruction of our nutritionally valuable traditional staples upon which most of our people depend. Monocropping could also affect adversely the existence of the great variety of food plants available today in our agricultural lands, variety that is necessary for providing adequate nutrition. Finally, large-scale commercial production of foods would be financially costly and would increase dependence on foreign suppliers for the necessary high technology inputs.

In view of what has just been said, the second alternative, that is, the adaptation of the indigenous food production systems merits serious consideration. As the geographer William Clarke of The University of the South Pacific says, "What is needed is a 'progressing with the past' toward the goal of sustained-yield agroecosystem, which could be a synthesis of bits from both traditional and modern fields of knowledge--the bits must be site-specific and not the inappropriate injection of fragments of industrialized technology." Clarke then enumerates the components of this synthesis, admitting their non-novelty except for their stress on permanence of production rather than on maximization.

From the field of modern science, according to Clarke, could come contributions through plant breeding and genetic engineering for the further development of plants with enhanced possibilities for characteristics such as nitrogen fixation and greater photosynthetic efficiency; through the use of trace-element fertilizers, ground rocks, and modest applications of, for instance, potassium, on deficient soils--this would lead to higher yields without large inputs of artificial fertilizers.

From the indigenous systems could come contributions through techniques of polycultural mix of many crops, and resistance to pressures toward monoculture that arise from cash cropping and other forms of intensification; and through the extension of local soil-management techniques such as mounding and composting in the Papua New Guinea highlands, terracing in New Caledonia, Cook Islands, and Fiji; and other traditional forms of soil erosion control. Where a change from shifting to permanent cultivation is desirable--and such change will come about in the near future in densely populated islands such as those of Tonga, Samoa, and Fiji--such techniques could be introduced.

And finally, there are under-utilized tropical crops in the region that could be distributed more widely for the expansion of food supplies and improved diets. The spread from Melanesia to the central and eastern Pacific of semiwild sago could provide a very large resource of carbohydrate. Similarly, many traditional leaf vegetables that are presently localized could be given wider distribution in the region. These have advantages over annuals such as cabbage and lettuce in their being permanent plants and with having higher nutritional values.

Even now with hardly any input from modern science, with increasing amount of time devoted by rural people to export cash cropping, and with the decline in the rural work force through urban drift and external migration, the indigenous agricultural systems throughout the South Pacific, with the exception of those on some densely settled atolls, have so far adapted and responded well and surprisingly to the demand for food to feed more mouths than at any other period in the history of Oceania.

This should not make us complacent, for a certain degree of inadequacy is appearing, and there is already growing intensification of the production of traditional staples in rural areas close to urban or other areas of high population concentrations. It is happening on this densely settled island of Tongatapu at this very moment, and it could be dangerous. The upper cover provided by coconuts and other fruit and cultural trees is being sacrificed for the sake of ease in plowing and other forms of mechanized land preparation for tilling. This growing intensification is leading toward increasing use of pesticides and artificial fertilizers on what is reputedly one of the most fertile soils anywhere.

It is, therefore, necessary to reexamine our attitudes toward indigenous agroecosystems and adapt them through some kind of synthesis with modern science, for therein lies perhaps the structure of permanence that ecologists have been talking about. I hope that what I have said will be touched upon in the course of this training workshop and with the level of knowledge and expertise which I, as a layman, can never hope to reach.

Date: Oct. 5
Time: 0840

AN OVERVIEW OF PLANT PROTECTION IN THE SOUTH PACIFIC

Ivor D. Firman

INTRODUCTION

Because of all the scientific disciplines, institutions, and administrative structures involved in plant protection, and the number and diversity of the countries in the region, a complete overview would be an exceedingly difficult and lengthy task.

This overview is far from complete and is justified only by explaining that it is presented as one of the brief introductory addresses to the training course. It is a very selective account of some past, present, and future activities and needs.

PLANT PROTECTION

Plant protection is concerned with all aspects of identifying, investigating, and, if necessary, controlling the pests affecting agricultural crops, forest trees, and other plants of economic or amenity importance. In this context, the word pest is used in its original, wide sense to include any organism or pathogen injurious to plants; controlling pests involves all stages of control from quarantine, through the growing and to the harvested or stored produce.

South Pacific

The South Pacific "region" is here taken to be the 23 countries served by the South Pacific Commission. They are American Samoa, Commonwealth of Northern Marianas, Cook Islands, Federated States of Micronesia, Fiji, French Polynesia, Guam, Kingdom of Tonga, Kiribati, Marshall Islands, Nauru, New Caledonia, Niue, Norfolk Island, Papua New Guinea, Pitcairn Island, Republic of Belau, Solomon Islands, Tokelau, Tuvalu, Vanuatu, Wallis and Futuna Islands, and Western Samoa (see map on page xxxii).

Together, these countries comprise thousands of islands covering an area of 29 million square kilometers less than 2 percent of which (551,000 square kilometers) is land. The islands range from small atolls and coral islands, through small and large volcanic islands, to the much larger "continental" islands such as that of which Papua New Guinea is a part. Because of this diversity, many different types of climate, vegetation, and human community are represented. Both subsistence and plantation agriculture can be found, and while there are places where no form of agriculture has been tried, there are others where attempts have been made to grow practically every type of economic plant.

PLANT PROTECTION REQUIREMENTS

National

Countries need to know which pests they have, how important they are, and how to control them economically if it proves necessary to do so. They also need to know which pests they do not have and how to avoid their introduction.

Larger countries with well-developed agricultural services will wish to develop the following capabilities:

1. A quarantine capability. This is needed both for import and export of plants and produce. Apart from the national interest, there is the need to comply with international requirements.
2. An extension capability. There is a need to advise growers on all aspects of plant protection.
3. A diagnostic capability. Organisms need to be correctly identified and their economic importance assessed.
4. A research capability. This may be linked with the diagnostic capability; specialists in such disciplines as plant pathology, entomology, nematology, weed science, vertebrate ecology, etc., are required. These specialists are also necessary to provide the background advice to quarantine and extension. Research may not always be the best word; the main activity might be adapting well-tried control measures to the local situation although there is also need for innovation to meet the special needs of the region. Extension staff need to get the specialists involved in real pest control problems so that practical solutions can be found.

As agriculture develops, new needs related to plant protection arise. These might be, for example, postentry quarantine facilities to allow the safe introduction of new crop cultivars, pesticide legislation and regulations to ensure the safe use of pesticides, or facilities for biological control programs.

Now that the UNDP/FAO-SPEC Survey of Agricultural Pests and Diseases has finished, some countries have a fairly good idea of the pest organisms they have present and, as a result, it was hoped to rationalize quarantine practices in order to facilitate regional trade. The effect on trade remains to be seen and, in any case, intraregional trade plays a very small part in the overall trading patterns of the region; but, in terms of plant protection generally the Survey only represents a beginning. Pest surveys need to be a continuing endeavor, and lists of diseases and insects are of little local use unless there are people who can interpret them and who can recognize the organisms concerned. It is also necessary to know how much damage the organisms are doing and how they can be controlled economically.

Wherever possible, a plant protection capability along the lines described above should be developed at the national level, and such development should be one of the main long-term objectives of any international or bilateral assistance programs.

Regional

Many countries will not be able to support anything but a very small plant protection capability; perhaps a small quarantine service and some agricultural extension officers with some plant protection training. These countries will benefit from regional specialist services to obtain information, advice, and emergency assistance when the need arises.

The main regional needs are for information and advisory services, for arranging training courses and workshops at various levels, for promoting contacts and collaboration between plant protection services, and for coordinating some aspects of international assistance. SPC's experience is that countries do make considerable use of information and advisory services. There are many technical questions which cannot be immediately answered at the local level and where rapid help from a regional body is useful. Those countries which have not yet trained or cannot support plant protection specialists need advice and practical help on a very wide range of problems.

There is much scope for training courses and workshops in the region on subjects such as disease and insect surveys, crop loss assessment, pesticide use, plant quarantine procedures, etc.

Some research activities are best carried out at the regional level, the Rhinoceros Beetle Project being a good example of this; a regional approach to more biological control work has also been suggested. Some plant introductions requiring special treatments or intermediate quarantine may be made more easily on a regional basis.

THE PAST

Prehistory

The plant protection workshops of two recent (1981) international conferences [Commonwealth Association of Scientific Agricultural Societies, (CASAS), seminar on Self Sufficiency in Food Production in the Pacific: Opportunities and Constraints, and International Foundation for Science, (IFS), Regional Meeting on Edible Aroids] stressed the need to take into account traditional practices which control or ameliorate pests and diseases.

A start has been made to document these practices as they relate to root crops following a recommendation at the IFS meeting.

History

There is no need here to go too far back into the history of plant protection except to recognize that there is a history which could be traced back in each country; tracing it means starting with bibliographic studies such as that made of agriculture in Fiji and picking out items of plant protection interest from the documents listed.

A bibliography of plant pathology and mycology in the area of the South Pacific Commission from 1820-1976 listed some 700 references. Two-thirds of them were published from 1950 onwards, and since that date, there has been a rapid, if irregular, increase in the number of published works. Some of the work which in the South Pacific (by Ivor D. Firman) to be given later in this course.

We can safely leave the entomologists to exceed easily the number of references which plant pathologists can cite and to present a Review of Major Insect Pests of Crops in the South Pacific (by Peter Maddison).

Some of the first regional activities in plant protection started with the formation of the South Pacific Commission in 1947. In planning the first program of work of the Commission, its Research Council placed at the head of a list of projects for economic development two plans for improvement of agricultural prospects. The first was for the introduction and distribution of economic plants, and the second contemplated research on the cultivation, marketing, and diversification of cash crops.

In order to introduce plants, a station equipped with quarantine facilities was established at Naduruloulou in Fiji. Although numerous plants were introduced and distributed, the benefits were thought to have been less than expected. This view was expressed only six years after the establishment of the station and might in retrospect be considered to have been premature, especially in view of the long-term nature of the work and subsequent revival of interest in a regional plant quarantine facility. Support for the station was reduced, and it no longer functions for plant introduction, although interest in plant introductions has continued with the SPC now acting mainly as a clearing house, directing territorial requests towards sources of material when necessary.

The Research Council when it first met also emphasized the interest to the SPC of projects for the biological control of insect pests, weeds, and rodents, but it was necessary first to review these problems. A conference was called in 1951 at which specialists in plant and animal quarantine from the member governments were to work out a practical method of assembling available information on pests, diseases, and weeds likely to be spread into or within the region, to suggest the best method of investigating quickly the existing gaps in preventive measures and quarantine, and to suggest a policy for action.

The result of the conference was that a Plant and Animal Quarantine Officer was appointed to the Commission in 1952 to coordinate quarantine operations, to collect and disseminate information, and to pay particular attention to the control of the coconut rhinoceros beetle. He put together the reports of animal and plant diseases in the region in a series of technical papers.

A regional plant quarantine conference was held in 1964 and made many recommendations aimed at improving plant quarantine throughout the region. The need for a plant protection officer or the services of consultants on plant protection and plant quarantine matters under the auspices of the SPC was recognized as was the role of the Commission as a regional channel for cooperation with international agencies, especially the FAO Plant Protection Committee for the Southeast Asia and Pacific region. Another outcome of this meeting was the preparation of an illustrated handbook (Exotic Plant Pests and Diseases) concerning dangerous pests and diseases to be excluded from the region as well as those present in some parts of the region, but of which further spread should be prevented.

When the first plant protection officer finished his assignment in 1955, his replacement was occupied chiefly in the search for predators and parasites of the rhinoceros beetle. This and other work on the beetle led to the establishment of a UN/SPC Rhinoceros Beetle Project based in Western Samoa which began formally in 1964. Responsibility for management of this project was transferred to FAO in 1972 although the Commission continued to provide some financial support. It seems that effective control of the beetle can be achieved largely through the use of a virus introduced and now established within the beetle populations. The project finished in 1975 with the member governments taking over the remaining facets of the work. Many scientists have worked in the region on the rhinoceros beetle, and their work resulted in a successful control measure and gave rise to numerous scientific papers and other publications.

The Commission has also concerned itself with rats, largely because of the damage they were thought to cause in agricultural production, but also of course in respect of the part they play in the spread of animal and human diseases. An expert on rat control has worked on secondment with the SPC resulting in the publication of various, practically-oriented papers on rat control and, more recently, in a new edition of a Handbook on Rat Control in the South Pacific.

In agriculture, the SPC work program results partly from recommendations made by regular conferences of directors of agriculture, livestock production, and fisheries from the member governments, some of these recommendations being endorsed by the Planning and Evaluation Committee which in turn advises the South Pacific Conference (with which the final decisions rest) on the work program of the Commission in relation to regional needs. In 1972, high priority was given to the appointment of a plant pathologist to the post of Plant Protection Officer, this post having been unfilled for many years, and such an appointment was made in 1974.

Recent History

There was a resurgence of interest in regional plant protection activity in the 1970s, and once again it had a lot to do with plant quarantine. One aspect of importance was trade in agricultural produce, and quarantine requirements were thought to be unduly restrictive, thus hindering the development of such trade. It was further thought that a thorough knowledge of the distribution of pest organisms would lead to a liberalization of quarantine regulations. Whether either of these premises was correct is open to doubt, but the eventual result was a FAO Survey of Agricultural Pests and Diseases in the South Pacific which added very considerably to our regional knowledge of the fungi, insects, nematodes, and viruses present and prepared some valuable reference material.

For the decade 1970-1979, there were some 500 citations relating to the SPC region in the CAB journals of interest to plant protection specialists (Helminthological Abstracts B, Review of Applied Entomology, Review of Plant Pathology, Weed Abstracts). Most of the citations referring, singly, to specific countries concerned Papua New Guinea (36 percent), Fiji (17 percent), Solomon Islands (10 percent), Western Samoa (6 percent), or New Caledonia (5 percent); a considerable proportion (19 percent) dealt with the region in as far as they referred to two or usually more countries.

Using broad interpretations of subject matter, almost half of the references dealt with entomology while 30 percent concerned plant pathology, 7 percent weed science, and 6 percent nematology. Another 8 percent dealt with mixed topics including general matters such as pest and disease surveys, quarantine, and pesticides.

It is doubtful if the amount of work published in the scientific press in different subject areas closely reflects any particular policy of research in the countries. Often it reflects the interests of a few active groups or individuals. Examples are banana pathology in Western Samoa, nematology in Fiji, forest entomology in Papua New Guinea, taro pathology in Solomon Islands, and biological control of citrus pests in New Caledonia. However, a study of a subject matter index should give a broad picture of the currently important crops and the problems causing concern.

Approximately 10 percent of the entries referred to coconut, 7 percent to forest trees, 7 percent to cocoa, 6 percent to banana, and 5 percent to taro.

Since 1970, there have been approximately 100 conferences, meetings, seminars, or training courses concerned with agriculture either held under SPC auspices, or with SPC assistance, or at which SPC was represented. A study of the reports of these meetings, of the, no doubt, equally numerous consultants' reports and of Department of Agriculture and other institutional reports would add to our knowledge of what was perceived by various agricultural scientists as the problems in plant protection. But we will only deal here with the most recent and relevant meetings as a way of introducing the activities now going on and the needs which country participants have drawn attention to.

THE PRESENT

At SPC's Third Regional Technical Meeting on Plant Protection (Port Moresby, Papua New Guinea, 1980), the country statements gave details of staff and facilities available for plant protection work, the most important disease, insect, and weed problems were indicated, and some of the quarantine problems encountered were described. For details, it is necessary to consult the working papers, but the following were among matters which provoked special interest:

1. Diseases and pests entailing the need for internal plant quarantine within individual countries (e.g., vascular streak dieback of cocoa caused by Oncobasidium theobromae in Papua New Guinea and a disease of coconuts caused by Marasmiellus cocophilus in Solomon Islands)
2. The need to update information about the quarantine facilities in countries of the region; so that trade in treated produce can be initiated or take place more freely, it was considered necessary that the facilities available in the region for fumigation and other treatments be determined and the efficacy of the operations established
3. The need for countries to report new outbreaks of important pests and diseases as required by the International Plant Protection Convention; SPC to be used as a clearing house for the information to be quickly disseminated locally
4. The urgent need for training in plant quarantine and produce inspection and the possibility of suitable correspondence courses
5. Quarantine problems associated with the import of orchids, other ornamentals, and timber

6. Treatments to prevent introduction of diseases on and in seeds, especially vegetable seeds
7. Pesticide legislation and the use of, perhaps, too many different and too toxic chemicals in the region
8. Irresponsible misuse of pesticides, especially paraquat
9. Several countries had experienced recent outbreaks of the coconut flat moth, Agonoxena argaula. Sweet potato scab caused by Elsinoe batatas also seemed to have increased in severity in recent years. Possible reasons for these and other changes in pest and disease status were discussed.

The items about quarantine facilities and reporting pest outbreaks were the subject of recommendations. Other recommendations concerned the need to evaluate spray machinery and to prepare guidelines to cover the introduction of biocontrol agents into Pacific island countries.

So, quarantine matters dominated the meeting with problems of pesticide use and application and biological control also coming in for important mention.

The very fact that a SPC Regional Workshop on Biological Control was held (Noumea, New Caledonia, 1979) indicates the importance attached to the subject. There were some specific recommendations about work on rhinoceros beetle virus, giant African snail, and rats, and about regional coordination. The participants also listed 10 Lepidoptera, 3 Diptera, 5 Coleoptera, 1 phasmid, 1 Heteroptera, 5 Homoptera, 1 Hymenoptera, 2 Acari, 1 mollusk, and 10 weeds which they considered to be of regional importance as far as their possible biological control was concerned.

SPC's plant protection activities center around providing information and advisory services including publications; practical field work, advisory visits, and consultancies; and training courses, workshops, and regional meeting. Some of FAO's earlier activities in rhinoceros beetle work and pest surveys have already been mentioned, and FAO and SPC have now already joined forces in a regional project to strengthen plant quarantine and plant protection services. Some countries of the region (Fiji, Papua New Guinea, Tonga, Solomon Islands, and Western Samoa) are members of the FAO coordinated Plant Protection Committee for the Southeast Asia and Pacific Region (PPC/SEAPR).

ORSTOM (Office de la Recherche Scientifique et Technique Outre-Mer) is a French organization with stations throughout the tropics. The Noumea center is the second largest and employs entomologists and plant pathologists. They mainly work in New Caledonia but do collaborate with and work in other countries of the region. The entomologists have carried out many projects but are especially concerned with detailed taxonomic work on certain groups of insects and mites while disease investigations have included work on coffee, potatoes, taro, and tomatoes.

The University of the South Pacific's School of Agriculture in Western Samoa offers courses in agricultural entomology, plant pathology, quarantine, and crop loss assessment. A modern plant protection laboratory has just come into operation; with these facilities, the University hopes to undertake research into some of the important insect pests and diseases of economic crops in the region. Regional liaison will take place through the University's Institute for Research, Extension, and Training in Agriculture (IRETA).

There are other universities in the region, two in Papua New Guinea and one in Guam. The latter, a land-grant institution, already plays a regional role in many scientific fields, including plant protection, especially in the Western Pacific.

Totokoitu Research Station, Rarotonga, Cook Islands, is managed by the Plant Diseases Division of DSIR, New Zealand, and draws upon a pool of expertise mainly with the various DSIR divisions and especially the Mt. Albert Research Centre in Auckland. It is mainly concerned with Cook Islands, but because New Zealand is involved in research and development projects throughout the Pacific, the association with an island-based research station has wider practical value. A great deal of work has concerned plant protection, and with projects on perennial crops well advanced, greater emphasis is now being given to other aspects of Cook Islands agriculture. Areas receiving particular attention are new or alternative fruit crops, an extended range of vegetables for local consumption, taro and cassava for export, and postharvest handling of fruit and vegetables with particular reference to sea freight. A significant development in the operation of the station has been the relocation of the research station of the Cook Islands Ministry of Agriculture at Totokoitu. The move has facilitated the integration of staff who are gaining valuable experience in the management and operation of the station and collaborating with New Zealand scientists.

This type of collaboration between aid agencies and national departments is also evident, for example, in Tonga where New Zealand and the German Agency for Technical Cooperation have contributed to facilities and staff at the experimental farm and in Western Samoa where Australian, FAO, and GTZ units are all located at the Crop Development Centre.

THE FUTURE

It will be best here for participants to discuss what ought to happen rather than try to predict what will happen.

The type of collaboration between aid agencies and national departments described above should ensure continuity and relevance in plant protection activity, but agricultural extension staff should continually press the specialists for answers to the practical problems encountered by farmers.

In quarantine, the next few years must bring better physical facilities and a broader base of well-trained staff. This will engender the confidence which is presently lacking among the quarantine officers themselves, the representatives of commerce who deal with them and between countries of the region.

It must be emphasized, however, that even now there is no evidence to suggest that quarantine is being misused, and there is no doubt that the few specialist advisers available do their best to ensure that all decisions are based on sound biological grounds.

Specific problems which need attention in the field are often known to national departments of agriculture, many of them are of regional significance, and some have been listed at the workshops and meetings already mentioned. On the other hand, there is very little real data on economic crop loss caused by pest organisms in commercial agriculture and insufficient knowledge about losses suffered by subsistence farmers. Without such information, it is not possible to allocate the limited plant protection resources rationally.

The region has already provided some good examples of the successful use of biological control agents. There is scope for much more work along these lines while at the same time ensuring that pesticides, when necessary, are used safely and efficiently. Specific "packages" of advice on plant protection are needed to suit the various local circumstances under which crops are grown; a recent example is an integrated control scheme for cocoa pests and diseases in Papua New Guinea.

Plant protection services need to be flexible because the specific pest problems facing agriculture will vary from time to time. This is because pest outbreaks can be seasonal or cyclical, new crops are tried, new pests enter the country, and the varieties grown and the cultivation practices used are liable to change.

Many countries of the region are now producing quite sophisticated development plans. The workshop at the CASAS meeting referred to earlier noted that: "Plant protection activity is an integral part of any agricultural development. Plant protection departments should be consulted at the beginning of any such developments. They could advise on the availability of healthy planting material and possibly predict some of the insect pest and disease problems likely to be encountered. If there were no ready solutions to these, a start could be made on enquiries and work to seek solutions." Finally, it emphasized that agricultural development needs a team approach, and plant protection specialists must be part of the team. Not a bad motto for us to bear in mind during this course.

Date: Oct. 5
Time: 0945

REVIEW OF MAJOR INSECT PESTS OF CROPS IN THE SOUTH PACIFIC

Peter Maddison

As an introduction, the approach to finding out "what are the real pests?" was discussed. The importance of getting to know what a healthy crop looks like was stressed; this can generally be gained by visits to the local market and to "good growers." To find typical examples of the damage caused by pests, it is often necessary to visit neglected plots rather than commercial farms, where the crops are regularly treated with insecticide.

There are many insect "pests" of crops in the Pacific region. A few examples of the more important ones will be discussed and illustrated below.

COCONUT

Coconut rhinoceros beetle, _Oryctes rhinoceros_, is found in American Samoa, Republic of Belau, Fiji, Papua New Guinea, Tokelau Islands, Tonga, Wallis Islands, and Western Samoa. The life cycle and effect of the virus _Baculovirus oryctes_ on the population of the beetle will be described. (Related beetles in the genera _Oryctes_ and _Scapanes_ occur in parts of Melanesia.)

Brontispa beetle (=coconut leaf hispine), Brontispa longissima, is found in American Samoa, French Polynesia, New Caledonia, Papua New Guinea, Solomon Islands, Vanuatu, and Western Samoa. Other species of Brontispa and related genera are found in Melanesia and Micronesia. The parasite, Tetrastichus brontispae, is important in the control of Brontispa beetles.

Coconut stick insect, Graeffea crouanii, is widespread in the Pacific islands. Related species occur in the Western Pacific region. In outbreaks, the coconut palms can be completely defoliated by stick insects.

Termites: The coconut termite, Neotermes rainbowi, can severely damage the stems of coconut so that they may break in hurricane winds. This termite is found attacking coconuts in the northern Cook Islands and Tuvalu. It has been found attacking other plants in Rotuma, Tonga, and Western Samoa.

Another termite, Microcerotermes biroi, makes carton nests on the trunks of palms. Its distribution extends from Solomon Islands to Western Samoa. This termite apparently does not damage the coconut, and its role may be that of a scavenger.

COCOA

Longhorn beetles: Several longhorn beetles, e.g., Glenea spp., damage the stems of cocoa.

Pantorhytes weevils, Pantorhytes spp., also damage the stems of cocoa. Both Pantorhytes spp. and Glenea spp. attack cocoa, particularly where che crop is planted on recently cleared land. They are found in Papua New Guinea.

Cocoa mirids (several species including Helopeltis and Pseudodoniella spp.) pierce the cocoa pods and suck the juices. Brown spots develop around the injury.

Rose beetles: Two species are concerned. They are Adoretus sinicus (found in French Polynesia, Guam, Hawaii, and the Marianas) and Adoretus versutus (found in Fiji, French Polynesia (?), Tonga, Wallis, and Western Samoa). These beetles damage the leaves of many shrubs and trees at night. Their larvae live in the soil and may feed on plant roots.

Cocoa webworm (Pansepta teleturga) larvae bore in small twigs. They are found in New Guinea.

Giant termite, Neotermes sp., is found in Papua New Guinea and can severely damage cocoa stems.

COFFEE

Probably, the most important pest of coffee is the coffee berry borer (Hypothenemus hampei). This beetle bores in the seeds of the unripe (green) coffee fruit.

CITRUS

Several scale insects and mealybugs are important pests of citrus. Of these, the California red scale, Aonidiella aurantii, is one of the best known examples. (Scale insects, mealybugs, aphids, and whitefly are important of many crops, including ornamentals.)

FRUITS

The fruit flies (Dacus spp.) are the most important group of fruit pests. The larvae tunnel in ripening fruits. The Queensland fruit fly, Dacus tryoni, is spreading in the Pacific region from Australia to French Polynesia and New Caledonia. The oriental fruit fly (Dacus dorsalis) formerly occured in Guam and the Marianas but has now been eradicated there; it remains in Hawaii.

The melon fly, Dacus cucurbitae, a pest of vegetables--particularly cucurbits--is found in Guam, Hawaii, the Marianas, and Papua New Guinea. Two fruit flies, Dacus facialis and Dacus kirkii, are important pests of capsicum, tomatoes, and other fruits in Tonga.

The fruit-piercing moth occurs throughout the region. The moth pierces fruits with its proboscis and sucks the juice. Its host plants include dadap, Erythrina spp., and it has been suggested that control could involve cutting down the dadap trees.

ROOT CROPS: Taro

The taro beetles, Papuana spp., cause considerable damage by boring into the corms of taro, banana, etc. One species, P. huebneri, has been accidentally introduced into Kiribati and is a serious pest of babai (Cyrtosperma) in Tarawa. Other species of Papuana are found in Melanesia.

The cluster caterpillar or taro armyworm, Spodoptera litura, eats the leaves of Colocasia taro as well as several other crops. Occasionally, outbreaks of this caterpillar can result in defoliation of large areas of taro, though it is normally controlled by a complex of parasites. It is widespread in the Pacific region.

The taro planthopper, Tarophagus proserpina, which pierces and sucks the juice from the petioles, is a widespread pest. It is important as the vector of virus diseases.

Other pests of taro include the taro hornworm, Hippotion celerio, and the cotton or melon aphid, Aphis gossypii, a virus vector. Both are widespread in the Pacific.

ROOT CROPS: Sweet Potato

Two species of weevil, Cylas formicarius and Euscepes postfasciatus, are widespread in distribution and cause severe damage by boring in the tubers.

BANANAS

Weevil borer, Cosmopolites sordidus, bores in the corms of bananas. It is of widespread occurrence in the Pacific region.

The banana aphid, Pentalonia nigronervosa, is also of widespread occurrence. It is important as the vector of bunchy top virus. The banana scab moth, Lamprosema octasema, is found from Northern Australia to Samoa and Tonga, though it has different feeding habits in the western part of its range, where its host plants are Nipa palm and Pandanus. The larvae scar the surface of the fruit. There are several parasites of the scab moth; these were studied by R. W. Paine.

VEGETABLES

The green looper caterpillar, Chrysodeixis eriosoma (=Plusia chalcites), is a major pest of many vegetables, particularly tomatoes, eggplants, and lettuces. It is very widely distributed.

The greasy cutworm caterpiller, Agrotis ipsilon, lives in the soil in the daytime; it emerges at night and chews through the stems of seedlings of many plants. The fruits of tomatoes may be damaged by caterpillars of the pinworm, Heliothis assulta, or tomato fruitworm, Heliothis armiger.

The pumpkin beetles, Aulacophora spp., are important pests of cucurbit crops. The beetles eat leaf and flower tissue.

Also on cucurbits, the 28-spot ladybird, Henosepilachna vigintioctopunctata, damages the leaves. (Both larvae and adults eat the leaves in a circular pattern of damage.) A related species, Henosepilachna sparsa, the 26-spot ladybird, eats the leaves of solanaceous crops (tomato, eggplant, Irish potato, etc.). Other related species occur in Papua New Guinea and Micronesia.

Brassicas (cabbages, cauliflowers, etc.) are damaged by several types of caterpillars. The widely distributed diamondback moth, Plutella xylostella, and the lesser cabbage moth, Crocidolomia binotalis, are probably the most important pests in the Pacific region. Leafminers are pests of many vegetable crops. The larvae mine in the tissues between the upper and lower epidermis of the leaf. Liriomyza spp. are important on beans, cucurbits, Solanaceae, etc. Liriomyza brassicae, cabbage leaf miner, is a pest of brassicas. The vegetable leafminer, L. sativae, is spreading in the Pacific region. It is found in Cook Islands, French Polynesia, Guam, Hawaii, the Marianas, and New Caledonia. Apart from this group of leafminers, which belong to the order Diptera (flies), other leaf miners are found in the orders of Coleoptera (beetles) and Lepidoptera (moths).

On okra, bele (Abelmoschus manihot), and related crops (family Malvaceae), and weeds, the bollworms (Earias spp.) are important pests. The larvae damage the developing fruits.

LEGUMES

Beans are damaged by several caterpillar pests. The bean pod borer, Maruca testulalis, is probably the most serious pest. The caterpillar bores in the developing pods. The bean leaf roller, Lamprosema diemenalis, is another widespread pest that damages the leaves of beans

GRASS CROPS

Corn earworm (tomato fruitworm), Heliothis armiger, bores into the developing cobs of maize and causes much damage. It is very widely distributed. Related species occur in Hawaii and Micronesia. The corn delphacid, Peregrinus maidis, is very widespread in distribution. It is important as a vector of diseases. The Asian corn borer, Ostrinia furnacalis, is a serious pest in the Western Pacific region.

Many borers (in the families Noctuidae and Pyralidae) damage the stems of rice. Rice is attacked by several planthoppers, the most important of which is the brown planthopper, Nilaparvata lugens.

NON-INSECT PESTS

Brief mention is made of invertebrate pests other than insects such as:

Mites

Spider mites (Tetranychidae) can severely damage leaves of several crops, particularly in dry, dusty areas. Other mites that may be important pests include gall mites (Eriophyidae) such as the hibiscus gall mite (*Eriophyes hibisci*). The broad mite (*Polyphagotarsonemus latus*) damages the young growth of capsicums, beans, etc., causing distortion of the leaves.

Slugs and Snails

Mostly, these are minor pests of vegetables. However, the giant African snail, *Achatina fulica*, is a major pest of vegetables and young plants of pawpaw, coffee, etc.

There are many more pests than mentioned in this brief review. These will be documented in the entomology report of the UNDP/FAO Survey of Agricultural Pests in the Pacific region.

Date: Oct. 5
Time: 1140

REVIEW OF MAJOR DISEASES OF CROPS IN THE SOUTH PACIFIC

Ivor D. Firman

INTRODUCTION

This review will be based on a previous one [Firman, I. D., 1978, Plant pathology in the region served by the South Pacific Commission, Review of Plant Pathology, 57(3):85-90] but includes some additional, more recent material. Fully indexed references to work published in the scientific press can be found in two recent bibliographies (Firman, I. D., 1978, Bibliography of plant pathology and mycology in the area of the South Pacific Commission, 1820-1976, South Pacific Commission Technical Paper, No. 176; Firman, I. D., 1982, Bibliography of plant protection in the area of the South Pacific Commission, 1970-1979, published by The University of the South Pacific).

A study of plant diseases in the region cannot be based solely on work reported in the scientific press; much can also be learned from farmers, agricultural scientists, and extension workers, and by reviewing the very numerous reports of departments of agriculture, institutions, consultants, conferences, and other such sources.

In a region as diverse as the one we are dealing with, a disease of major importance in one country may be insignificant in, or even absent from, another country. Much depends on the geographic distribution of the diseases, the type of agriculture and the crops grown, and the local environment. The following are sources of information on the geographic distribution of plant parasites: algae, angiosperms, bacteria, fungi, nematodes, and viruses:

*Dingley, J. M., R. A. Fullerton, and E. W. C. McKenzie. 1982. Records of fungi, bacteria, algae, and angiosperms pathogenic on plants. UNDP/FAO-SPEC Survey of Agricultural Pests and Diseases Technical Report, Vol. 2.

**Firman, I. D. 1975. Annotated bibliography of sources of information on plant disease distribution in the area of the South Pacific Commission, South Pacific Commission Technical Paper, No. 172.

*Mossop, D. W., and P. R. Fry (Eds.). 1982. Virus diseases of plants in the South Pacific. UNDP/FAO-SPEC Survey of Agricultural Pests and Diseases Technical Report, Vol. 7.

*Orton Williams, K. J. 1980. Plant parasitic nematodes of the Pacific. UNDP/FAO-SPEC Survey of Agricultural Pests and Diseases Technical Report, Vol. 8.

From these and other sources, a considerable amount of information is available about the distribution of parasitic organisms

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* The surveys on which these lists are based covered Cook Islands, Fiji, Kiribati, Niue, Tonga, Tuvalu, and Western Samoa although Tuvalu was not included in the nematode surveys.

** Contains references to American Samoa, Cook Islands, Fiji, French Polynesia, Gilbert and Ellice Islands (now Kiribati and Tuvalu), Guam, New Caledonia, New Hebrides (now Vanuatu), Norfolk Island, Papua New Guinea, Solomon Islands, Tonga, Trust Territory of the Pacific Islands (now Commonwealth of Northern Marianas, Federated States of Micronesia, Marshall Islands, and Republic of Belau), Wallis and Futuna Islands, and Western Samoa.

in the region. In contrast, there is very little information about the losses they cause, and that which there is has not been collected together and summarized. Our ideas on the importance of the different diseases in the region are, therefore, likely to be rather subjective.

BANANA

In order to grow export quality bananas, a complete package of plant protection measures is needed for disease and insect control. The main diseases are caused by fungi [leaf spots, especially black leaf streak (BLS) caused by Mycosphaerella fijiensis], bunchy top virus (?), and the burrowing nematode, Radopholus similis. These problems and the methods of control have been well documented.

Until recently, benomyl was giving adequate control of BLS, but strains of the fungus resistant to carbendazim (the breakdown product of benomyl) occurred in Western Samoa and benomyl ceased to be effective. Tridemorph is now used there. In the other export banana producing countries, a continuous regime of benomyl spraying is now being replaced with programs in which benomyl is mixed with, or alternated with, other fungicides.

Another new development is the use, at least experimentally, of Kpins (picloram) to destroy plants affected by bunchy top.

Where bananas are grown for local consumption, very few, if any, plant protection measures are taken. The diseases still take their toll, even though some of the plantain types are less susceptible to BLS, but quality and shelf life are not so important and yield loss is not always obvious.

BREADFRUIT

There are periodic scares about disastrous breadfruit diseases especially on atolls, but the problem is probably usually attributable to drought and/or salt damage and ground water salinity. Apart from this, no major diseases have been reported.

CASSAVA

The region continues to remain free from any major cassava disease, and every effort must be made to maintain this favorable situation. A graft transmissible mosaic has been found in Solomon Islands but is not the African cassava mosaic disease that has caused havoc in parts of Africa.

CITRUS

In as far as it cannot be satisfactorily controlled and its presence precludes the export of fresh fruit, canker (caused by *Xanthomonas citri*) must be considered a major disease in those countries where it occurs.

There are several leaf, fruit, and stem diseases, and where citrus is grown seriously on any reasonable scale, blanket fungicide sprays are usually applied to control them. But, there is usually no clear information about the losses caused by the various organisms or about the effectiveness of control measures. It is recognized that some virus diseases, especially tristeza, are fairly widespread. Interest is now being shown in virus indexing, selection of the healthiest budwood available, and the possibility of utilizing mild virus strains to lessen the effects of tristeza.

COCOA

Black pod and canker are important in most places where cocoa is grown in the region. There have been recent investigations in Solomon Islands on the sources of *Phytophthora palmivora* inoculum in cocoa plantations. The relative importance of such sources is known to differ from country to country in other parts of the world and so may also do so between Pacific island countries. The investigations provide information on epidemiology and, thus, can lead to improved control strategies against the fungus. Vascular streak dieback, caused by the fungus *Oncobasidium theobromae*, is important in the limited area of Papua New Guinea where it occurs and is a potentially serious threat to other areas and to other countries. There has been progress in searching for resistance and in providing disease-free planting materials.

The expansion of cocoa growing in the region has led to a demand for seed and sometimes vegetative planting material. So far, countries have resisted bulk imports and have observed satisfactory quarantine procedures. The latter need not prevent sufficient material being available to set up proper studies on the potential of new cultivars.

COCONUT

It has now been confirmed that one of the diseases described as of "unknown etiology" and long present in Guam is, in fact, Cadang-Cadang. It is urgent to know which other countries in the Western Pacific harbor this disease and, perhaps, surprising that it has not, apparently, spread into the rest of the Pacific.

A fungus, authoritatively identified as *Marasmiellus cocophilus*, has been found on coconut seedlings in Solomon Islands, and local quarantine restrictions were imposed to prevent its further spread. It is now necessary to compare this fungus with East African isolates, to know how widespread it is in the Pacific and to ascertain how important it is as a pathogen.

With the developing regional interest in coconut replanting, we can now expect more coconut problems associated with nurseries and young palms. Already, *Marasmiellus inoderma* has been recognized as a problem in nurseries of some coconut cultivars. It and some other fungi are seed-borne, and this fact does not seem to have been sufficiently appreciated in the past. It is necessary to develop clear national policies, based on the recommendations of the Plant Protection Committee for the Southeast Asia and Pacific region, about the import of new germ plasm. There is a belief in some quarters that germ plasm from outside the region is essential for coconut production to be improved. Although this could be the case, the benefits still remain to be proven under local circumstances, and the risks are still clearly considerable. There is no need to prevent much needed research into comparing cultivars or plant breeding, but as with cocoa, the work should be kept under proper scientific supervision, and pressure to make bulk imports of germ plasm should be resisted.

COFFEE

There have been new plantings of both arabica and robusta coffee in the region, but no particular plant disease problems have been reported. Vigilance continues in Papua New Guinea following the eradication of rust there in 1965. Rust does, of course, occur in some other countries, but coffee berry disease (*Colletotrichum coffeanum*) is still absent from the whole region.

GROUNDNUT

The *Cercospora* leaf spots and the stem rot caused by *Corticium rolfsii* were formerly the main problems in most countries of the region. They have now been superseded in importance by rust (*Puccinia arachidis*); this was first found in Papua New Guinea in 1972 and has probably also been in Solomon Islands for several years. Only recently (1980) has its spread to Fiji and Tonga been reported, and it is probably now even more widespread. Work is in progress to locate resistance and to achieve chemical control under local circumstances.

MAIZE

Apart from the publications dealing with the occurrence and spread of blister smut (Ustilago maydis) in Papua New Guinea, there has still been very little written about the diseases of maize in the region. The usual range of leaf-infecting fungi (Cochliobolus, Puccinia, Sclerospora, Setosphaeria, etc.) are well represented but are not necessarily present in all countries. The relative importance of these and other diseases, both in the field and in relation to quarantine precautions, remains to be assessed. The import of maize and other cereals for making up stock feed locally has raised some special quarantine problems.

OIL PALM

Viruses have been detected in oil palm, but no important disease problems have been reported. Oil palm diseases in South-east Asia and the South Pacific have been reviewed recently (1976).

RICE

Insects continue to cause the main problems in rice although several diseases including blast, brown spot, and sheath rot do occur. The white tip nematode, Aphelenchoides besseyi, has also now been found in Fiji, but so far none of the virus or bacterial diseases has been reported in the region.

SUGARCANE

It is mostly in Fiji, where the crop is the mainstay of the economy, that work on sugarcane diseases has been done. The Fiji Sugar Corporation, rather than the Department of Agriculture, is responsible for the crop, and according to their 1975 Annual Report, "the results of the research are reflected in the reduction of the incidence of diseases to virtual elimination point." Fiji disease, caused by a virus, and downy mildew were the two main problems and were brought under control by a combination of sugarcane breeding, introduction of new varieties, and commercial disease control.

The plant parasitic nematodes associated with sugarcane in Fiji have been studied recently.

SWEET POTATO

The little leaf or witches' broom disease of sweet potato was first thought to be caused by a virus, but mycoplasma-like organisms (MLO) have now been found in diseased plants. The disease occurs in Papua New Guinea, Solomon Islands, and possibly Tonga. It can be severe in areas with low rainfall and a distinct dry season, conditions which favor high populations of the leafhopper vector Orosius. The disease can also be spread when infected cuttings are used for propagation. In both Papua New Guinea and Solomon Islands, spread of the disease to new areas can be prevented by local quarantines. The disease has a restricted distribution in the SPC region; so, any transfer of planting material from countries where it is present should be as true seed or as plants which have been shoot-tip cultured and certified free of MLO.

Rogueing and careful selection of plant material are the most important control methods. So far, the prospects of control by using resistant cultivars do not seem promising.

Scab, caused by the fungus Elsinoe batatas, is an important disease in the region, and research into chemical control and the search for resistance need to continue.

TARO (and other aroids)

Diseases of these crops were reviewed recently (Jackson and Firman, 1981) at the International Foundation for Science Regional Meetings on Edible Aroids when special consideration was given to agreeing on guidelines for the movement of germ plasm.

Dasheen mosaic virus (DMV) is the cause of a nonlethal disease of edible aroids; infections sometimes retard plant growth and probably reduce yield. The disease is most common on taro, often seen on Xanthosoma and rare on Alocosia macrorrhiza. In Kiribati, it has been found on Cyrtosperma chamissonis. Although probably present throughout the region, there may be some islands where taro is as yet uninfected.

Diseases caused by two viruses (bacilliform particles of different size) occur in Papua New Guinea and Solomon Islands. Symptoms caused by infection of the two virus particles either alone or together varies between different cultivars. The common field symptoms are either those of the lethal condition where both particles are present ("alomae"), or symptoms caused by infection with the large bacilliform virus ("bobone"). The bobone symptom is only known to occur in plants which are resistant to alomae.

The large particle apparently only occurs in Papua New Guinea and Solomon Islands whereas the small particle occurs in most countries of the region and has been found in all the edible aroids grown except Cytosperma chamissonis. It has, however, been found in the ornamental, C. johnstonii, in Solomon Islands.

The virus vectors, the planthopper Tarophagus proserpina and the mealybugs Planococcus citri and Planococcus longispinus, are present wherever taro is grown in the region. Also, the taro grown, for example, in Fiji, Vanuatu, and Western Samoa are susceptible to the lethal disease. So, if the viruses were introduced, they could be spread and cause disease.

Taro leaf blight caused by Phytophthora colocasiae is the second major disease of the region with a restricted distribution; it occurs in Papua New Guinea and Solomon Islands. Yield losses of 25-50 percent are common in Solomon Islands due to plants having reduced numbers of functional leaves. The fungus also causes a postharvest decay of corms. Other Phytophthora spp. and, especially, several Pythium spp. cause root and corm rots in the region, but the species distribution seems to vary from country to country. Many species of nematodes are found on aroids in the region but, in general, the damage caused by them is slight.

Direct importation of vegetative material should be avoided in favor of transfer through intermediate quarantine outside the region, or as tissue cultured plantlets derived from shoot-tips. In both cases, indexing for dasheen mosaic virus is desirable. Seed offers an alternative method of moving aroid germ plasm as it is unlikely to contain virus particles and can be readily obtained. In the absence of techniques to detect taro, large baciliform virus in symptomless plants, vegetative material from Papua New Guinea and Solomon Islands should not be transferred to other countries.

Taro corms are notoriously difficult to store and usually rapidly decay after harvest. It has been found that they store well in polythene bags; root and cormel growth continues under the conditions of high humidity, and wound healing takes place so that fungal rotting is reduced altnough bacterial soft rot can become a problem.

YAM

Yam dieback caused by the fungus Colletotrichum gloeosporioides is a major problem (on Dioscorea alata) now that this crop is being grown intensively. Although it could be controlled by spraying fungicides at two-weekly intervals, the use of resistant cultivars offers a more effective solution. Certainly, satisfactory cultivars have been identified in Solomon Islands, and it can be assumed that resistant cultivars could be found in other countries.

Growers should be encouraged to select tubers from plants showing resistance and use only these for propagation. It is best to grow whole stands of resistant types rather than mixed varieties in order to minimize disease buildup. Other species of yam, *D. esculenta*, *D. nummularia*, and *D. pentaphylla*, are immune or resistant. Time of planting has an important bearing on disease control and is usually taken into account by local custom. In most countries of the region, planting is timed so that plants reach maximum height on supporting poles before the main rainy season. Tubers will then have formed before dieback occurs.

The fungus *Rhizoctonia*, attacking tubers, roots, and the stem below ground, has also been identified as a cause of dieback in Solomon Islands, and the disease probably occurs in other countries of the region as well.

VEGETABLES

The diseases which occur on various vegetables have been described (in such publications as the SPC Handbook on market gardening and Plant Diseases of Fiji by K. M. Graham) and are usually well known from other parts of the world. This does not necessarily mean, however, that diagnosis is easy; tomato, for example, may suffer from several different leaf spots (caused by such fungi as *Alternaria solani*, *Fulvia fulva*, *Myrothecium roridum*, *Phytophthora infestans*, *Pseudocercospora fuligena*, *Septoria lycopersici*, and *Stemphylium lycopersici*) not readily distinguishable by the uninitiated. Also, whereas *Stemphylium* may be common in Tonga and

Pseudocercospora in Cook Islands, they may not be present in other countries of the region.

There are often satisfactory methods of chemical control but, wherever possible, research is directed towards finding disease-resistant cultivars suitable to local conditions.

Date: Oct. 5
Time: 1415

TOUR OF CROPS AT THE EXPERIMENTAL FARM AT VAINI, AND PRACTICAL EXERCISE IN THE IDENTIFICATION OF REPRESENTATIVE CROP INSECT PESTS AND DISEASES

Coordinated by

Peter Maddison and Tevita Holo

In the afternoon, participants walked around the Experimental Farm with entomologist Peter Maddison, plant pathologist Tevita Holo, and some of the other resource personnel. They examined insect pests and diseases on a variety of crops including macadamia, citrus, kava, sweet potato, pigeon pea, taro, tomato, watermelon, and beans. Symptoms were examined and specimens collected for further examination in the laboratory. Methods of surveying and collecting were discussed.

In the Plant Pathology and Entomology Laboratories, specimens were examined further and such techniques as rearing insects, culturing fungi, preserving specimens, and preparing them for sending away for identification were explained. Reference collections of Tonga diseases and insects were also examined.

Date: Oct. 5
Time: 1950

EVENING WORKSHOP EMPHASIZING DISCUSSION OF RESEARCH AND EXTENSION PLANNING FOR PESTS ON SELECTED CROPS

Coordinated by Tevita Holo

First, the course participants were given an opportunity to discuss their impressions of the day's activities. The course trainees said that they were exposed to far too many insect pests and diseases for the details about any of them to be retained. It was, however, explained that the intention was to provide an overall view of the range of problems to be encountered and not to expect the trainees to learn details of each and every insect pest and disease. Similarly, the trainees felt they were bombarded with too many scientific names. The problems of insect pest and disease nomenclature were discussed in detail, and it was agreed that both common and scientific names should be used wherever possible. It was accepted that there were circumstances where the use of scientific names could not be avoided.

There was much concern expressed as to how new crop protection information could be best imparted to farmers. Although certainly an important topic, it had to be emphasized that the present training course was essentially concerned with training plant protection extension officers and not farmers.

Date: Oct. 6
Time: 0905

MAJOR WEED PROBLEMS OF THE SOUTH PACIFIC

Roy K. Nishimoto

In an effort to bring order to the world's literature on weeds, Dr. L. G. Holm and several others (refer Holm et al., 1977) reviewed the distribution and biology of 76 of the most important weeds of the world. They also ranked these weeds in relative importance. In this book, The World's Worst Weeds: Distribution and Biology, they indicate that of about 250,000 plant species, fewer than 250 have become important weeds of the world. However, it should be recognized that many others may become important in specific locations and/or cropping systems.

In a new book, Weed Handbook of Western Polynesia (in press), Dr. A. W. Whistler selected 82 weed species that were common or most troublesome in Samoa, Niue, and Tonga. It is interesting to note that Holm et al. and Whistler had 24 weed species in common.

Because of the diversity of weed species, practically every niche in an agricultural cropping system provides an environment where a weed species would flourish. Thus, each cropping system, or even small changes in the cropping practices within a cropping system, results in a different weed spectrum. Certain species like *Eleusine indica*, *Amaranthus* spp., *Portulaca oleracea*, and

Cyperus rotundus would commonly be serious weed pests in cultivated vegetable crops, but not in well-established banana that provided substantial shade. Species tolerating shade like Commelina spp. or vines like Mikania scandens are likely problems in established banana.

Since there are so many major weed species to discuss in this short period, it will be useful to classify weeds into several simple categories. This simple classification scheme is useful for predicting control measures.

One way to classify weeds is according to their life cycle: (1) Annuals--these germinate from seed, produce vegetative growth, flower, set seed, and die within one year. (Note: Weeds sometimes classified as annuals may live for longer than one year under tropical or subtropical conditions; however, this classification is useful since their primary mechanism of reproduction is from seed.) Annual species persist most readily under conditions of frequent cultivation such as in vegetable crops; (2) Biennials--true biennials germinate from seed, produce only vegetative growth during their first year, then flower, set seed, and die during their second year. These species are relatively unimportant in the tropics; (3) Perennials--these may germinate from seed, but more frequently from vegetative tissues, such as a fleshy root, stolons, rhizomes, tubers, bulbs, bulbets, etc., and can live for more than two years. Two groups are generally recognized: (a) simple perennials which do not have the ability to spread laterally; they often "overwinter" by a large fleshy root system; (b) creeping perennials which can naturally spread laterally by stolons, rhizomes, etc. Perennials arising from vegetative propagules produce much more robust growth as they emerge through the soil because of the relatively larger amount of stored food associated with the propagule, in contrast to those that germinate from true seed.

In addition to their life cycle, weeds are categorized by leaf morphology. Narrowleaf weeds are grasses (Gramineae) and sedges (Cyperaceae). Broadleaf weeds are primarily in the subclass Dicotyledonae, but some from the Monocotyledonae such as the Commelinaceae are arbitrarily placed in this category. These categories are helpful because susceptibility to herbicides can often be inferred according to these categories.

Recognition of the location of growing points of weeds are extremely important in considering control measures. While true seeds represent the reproductive growing points, vegetative growing points vary depending on annuals, perennials, grasses, or broadleaves. The growing point of the shoot apex of an annual grass is located near the soil surface; a perennial would have the same shoot apex growing point as well as growing points at each node of the lateral stems. An annual broadleaf has a growing point at the stem apex as well as at each leaf axil; the perennial broadleaf would have the same growing points plus growing points at each node of the lateral stems. Shallow cultivation practices or contact herbicides can easily get to growing points of annuals but not to perennials, thus limiting the scope of each control practice.

For this discussion, the major weed problems can be considered in two different systems: (1) disturbed cultivation system such as vegetable crops; (2) uncultivated cropping system such as established banana, coconut, pasture, and other perennial systems. In each system, there is substantial modification of species diversity depending on the individual cropping practice and microclimate. There is also considerable overlap in presence of weed species in the two different systems. However, the annuals have a tendency to predominate in a disturbed cultivation system such as an annual cropping system or when establishing a perennial crop. Perennials like Cyperus rotundus and Commelina spp. may also be problems in these "disturbed" cropping systems. Some perennials like Commelina spp. can also be bad problems in an uncultivated cropping system. Other perennials like Kyllinga polyphylla, Mimosa invisa, Psidium guajava, Lantana camara, and Chromolaena odorata are primarily serious pests of pastures and rangeland.

Practically all important weeds are introduced; thus, one of the most effective measures of control is preventing their entry by appropriate inspections at ports of entry. This is a function of many departments of agriculture. After introduction, the best time to control a new weed is when it first gets established, and can be effectively removed if the weed infestation is found early enough. This is the basis for noxious weed laws in the USA and many other countries.

Herbicides may be extremely important tools for eradication of limited weed infestation. The most common herbicides probably available in the Pacific are postemergence herbicides. Contact herbicides like paraquat are generally only effective on annual species but will control almost all annual weeds. Systemic herbicides such as 2,4-D, 2,4,5-T, dalapon, MSMA, and glyphosate are effective on both annuals and perennials. These work best when they move from foliar tissues to underground reproductive organs. Thus, excessive rates of some of these materials may disrupt the normal transport system and actually be less effective than the correct lower rate. Herbicides like 2,4-D and 2,4,5-T are most effective on broadleaf weeds such as those in the Dicotyledonae and some Monocotyledonae (Commelina spp.). Dalapon is primarily active on grasses, while MSMA provides control of many sedges and the "broader-leaved" grasses. Glyphosate controls most weed species, but is weak on a few such as Psidium guajava. Besides applying herbicides as sprays, some of these materials are effective by a high-concentrate drop or brush application to a frilled or notched bark. Glyphosate, 2,4-D, and 2,4,5-T applied in this manner appear to control many woody species.

Once established, weeds must be controlled by any number of methods, such as biological control, chemical control, physical methods, and cultural practices.

Biological control utilizes a natural enemy such as an insect or a disease-causing organism to control a weed. One of the reasons a newly introduced plant species becomes a weed is because of the lack of natural enemies. Several weed species have been fairly well controlled by this method. These include *Opuntia* spp., *Lantana camara*, *Ageratina riparia*, *Ageratina adenophora*, and *Tribulus terrestris* in Hawaii as well as *Clidemia hirta* in Fiji.

Physical methods include tillage (hoeing), mowing, slashing, mulching, and fire. Many of these practices are practical and effective if carried out in a timely fashion.

Cultural practices effectively utilize crop competition by using appropriate varieties and crop spacing. These are particularly useful for shade susceptible species like *Cyperus rotundus*. In considering control of any weed complex, it is very difficult to depend on any single practice, whether it be chemicals, slashing, or crop competition. More than one practice is usually necessary for effective control.

The following table lists some important weeds of the South Pacific. Following this is a list of selected references on weeds.

TABLE 1: Some Important Weeds of the South Pacific

(many after Whistler, in press)

SUBCLASS MONOCOTYLEDONAE

Family Commelinaceae

Commelina benghalensis L.	commelina
Commelina diffusa Burm. f.	spreading dayflower

Family Cyperaceae

Cyperus rotundus L.	purple nutsedge
Fimbristylis dichotoma (L.) Vahl	
Kyllinga breviofolia Rottb.	green kyllinga
Kyllinga polyphylla Thou. ex Link	Navua sedge

Family Dioscoraceae

Dioscorea bulbifera L.	bitter yam

Family Gramineae

Brachiaria mutica (Forsk.) Stapf	paragrass, California grass
Brachiaria subquadripara (Trin.) Hitch.	
Cenchrus echinatus L.	sandbur
Chloris inflata Link	swollen fingergrass
Chloris radiata (L.) Sw.	radiate fingergrass, plushgrass
Cynodon dactylon (L.) Pers.	common bermudagrass
Digitaria horizontalis Willd.	
Digitaria setigera Roth ex R. & S.	large crabgrass, hairy crabgrass
Echinochloa colona (L.) Link	junglericegrass
Eleusine indica (L.) Gaertn	goosegrass
Ischaemum rugosum Salisb.	
Oplismenus compositus (L.) Beauv.	
Panicum maximum Jacq.	guineagrass

Table 1 (cont'd)

Family Gramineae (cont'd)	
Paspalum conjugatum Bergius	sour paspalum
Paspalum dilatatum Poir.	dallisgrass
Paspalum paniculatum L.	
Pennisetum purpureum Schumach.	napiergrass, elephant-grass
Sorghum halepense (L.) Pers.	johnsongrass
Tricachne insularis (L.) Nees	sourgrass
SUBCLASS DICOTYLEDONAE	
Family Acanthaceae	
Blechum brownei Juss.	blechum
Ruellia prostrata Poir.	ruellia
Family Amaranthaceae	
Amaranthus gracilis Desf.	amaranthus
Family Capparidaceae	
Cleome viscosa L.	cleome
Family Compositae	
Ageratum conyzoides L.	ageratum
Asclepias curassivica L.	bloodflower milkweed
Bidens pilosa L.	beggar's tick, spanish needle
Chromolaena odorata (L.) King & Robinson	
Crassocephalum crepidioides (Benth.) A. Moore	
Elephantopus mollis H. B. K.	elephant's foot
Synedrella nodiflora (L.) Gaertn.	synedrella, nodeweed
Emilia sonchifolia (L.) DC.	Flora's paintbrush
Mikania scandens L.	mile-a-minute weed

Table 1 (cont'd)

Family Compositae (cont'd)	
Pseudo-elephantopus spicatus (Juss.) Rohr	false elephant's foot
Veronia cinerea (L.) Less.	little ironweed
Xanthium pungens Wallr.	Noogoora burr
Family Convulvulaceae	
Merremia peltata (L.) Merr.	
Family Cruciferae	
Lepidium virginicum L.	wild peppergrass
Family Cucurbitaceae	
Momordica charantia L.	balsam apple
Family Euphorbiaceae	
Euphorbia cyathophora Murray	Mexican fireplant, wild euphorbia
Euphorbia hirta L.	garden spurge
Euphorbia prostrata Ait.	prostrate spurge
Phyllanthus amarus Schum. & Th.	niruri
Family Labiatae	
Hyptis pectinata (L.) Poit.	comb hyptis
Family Leguminosae	
Acacia farnesiana (L.) Willd.	Ellington's curse, huisache
Cassia occidentalis L.	coffee senna
Cassia tora L.	peanut weed
Crotalaria pallida	rattlepod
Desmodium canum (Gmel.) Schinz & Thellung	kaimi clover
Desmodium tortuosum (Sw.) DC	Florida beggarweed
Indigofera suffruticosa Mill.	indigo
Leucaena leucocephala (Lam.) deWit	wild tamarind, lead trees

Table 1 (cont'd)

Family Leguminosae (cont'd)	
Mimosa invisa Mart.	giant sensitive plant
Mimosa pudica L.	sensitive plant
Phaseolus lathyroides L.	wild pea bean
Pueraria lobata (Willd.)Ohwi	kudzu
Family Lythraceae	
Cuphea carthaginensis (Jacq.) McBride	tarweed
Malvastrum coromandelianum (L.) Garcke	false mallow
Sida rhombifolia L.	arrowleaf sida, broom weed
Sida acuta Burm. f.	southern sida
Family Melastomaceae	
Clidemia hirta (L.) D. Don	Koster's curse
Family Myrtaceae	
Psidium guajava L.	guava
Family Onagraceae	
Ludwigia octovalvis (Jacq.) Raven	willow primrose
Family Oxalidaceae	
Oxalis corniculata L.	yellow woodsorrel
Family Passifloraceae	
Passiflora foetida L. var.	wild passionflower
Family Plantaginaceae	
Plantago lanceolata L.	narrow-leafed plantain
Family Portulaceae	
Portulaca oleracea L.	purslane

Table 1 (cont'd)

Family Rubiaceae	
Spermacoce assurgens Ruiz and Pav.	buttonweed
Family Solanaceae	
Physalis angulata L.	wild cape gooseberry
Solanum nigrum L.	black nightshade
Solanum torvum SW.	prickly solanum
Family Tiliaceae	
Triumfetta rhomboidea Jacq.	
Family Umbelliferae	
Centella asiatica (L.) Urban	pennywort
Family Verbenaceae	
Clerodendron philippinum Schauer	Honolulu rose
Lantana camara L.	lantana
Stachytarpheta urticaefolia (Salisb.) Sims	blue rat's tail, nettle-leaf vervain

SELECTED REFERENCES

Anderson, W. P. 1977. Weed science: principles. West Publishing Company, St. Paul.

Ashton, F. M. and A. S. Crafts. 1981. Mode of action of herbicides. John Wiley and Sons, New York.

Audus, L. J. 1976. Herbicides: physiology, biochemistry, ecology. Academic Press, London.

Fryer, J. D. and S. Matsunaka (Eds.). 1977. Integrated control of weeds. University of Tokyo Press, Tokyo.

Holm, L. G., D. L. Plucknett, J. V. Pancho, and P. Herberger. 1977. The world's worst weeds: distribution and biology. The University Press of Hawaii, Honolulu.

Kasasian, L. 1971. Weed control in the tropics. Leonard Hill, London.

Klingman, G. C. and F. M. Ashton. 1982. Weed science: principles and practices. John Wiley and Sons, New York.

Lambert, M. (Ed.). Weed control in the South Pacific. Handbook No. 10. South Pacific Commission, Noumea.

Pancho, J. V., M. R. Vega, and D. L. Plucknett. 1969. Some common weeds of the Philippines. The Weed Science Society of the Philippines. Los Baños.

The Weed Science Society of America. 1979. Herbicide handbook of the Weed Science Society of America, 4th edition. Urbana.

Whistler, A. W. (In press). Weed Handbook of Western Polynesia. GTZ, West Germany.

Date: Oct. 6
Time: 1120

RAT DAMAGE, ECOLOGY, AND CONTROL IN THE SOUTH PACIFIC

J. Morgan Williams

INTRODUCTION

Three species of rat, Rattus exulans, R. rattus, and R. norvegicus, are widespread in the South Pacific island countries. All cause agricultural damage, but the first two species are more widely distributed and cause the most damage, particularly to coconuts and cocoa. R. norvegicus tends to be confined to port areas or towns; this species is of limited agricultural significance on most islands. One other rodent, the house mouse (Mus musculus), is also found on some islands, but so far it appears to cause little agricultural damage.

The aim of this paper is to provide a general introduction to the management of rats, as agricultural pests, by discussing within three sections the following aspects:

1. Features of rat biology and ecology to aid species identification and appreciation of rodent capabilities
2. Procedures for assessing the nature and extent of a rat problem and, thus, if control is really required
3. Chemical control strategies and nonchemical methods for reducing damage.

This paper is based on a series of tables that summarize the significant features within the topics outlined above. The objective of the discussion is to assist plant protection personnel assess and constructively advise on rat problems within a sound ecological framework. It is suggested that this paper be used, in practical situations, in association with the South Pacific Commission Rat Control Handbook (see Rowe et al., 1975, under Suggested Resource Publications on Rat Biology and Control).

SPECIES IDENTIFICATION

It is vitally important in any crop protection program to know what species of pest organism is causing the problem. Table 1 summarizes the main features that characterize the pest rodents of this region. An important point is that these features refer to adults, but juveniles of all species should not prove too difficult to identify since young characteristically have softer, healthier looking fur while ears, tails, and feet are not normally scarred or scratched.

RAT BIOLOGY AND ECOLOGY

To manage rats as agricultural pests, or to integrate cropping systems into habitats they occupy, requires an understanding of their habitat requirements, reproductive potential, food habits, life history, behavior, senses, movement, etc. Without such knowledge, both time and money can be wasted on control programs. Rats have a great ability to adapt to changes in environmental conditions; thus, their behavior varies from one area to another

TABLE 1: Features Used to Identify the Pest Rodent Species of the Island Countries of the South Pacific

	Rattus norvegicus (Norway rat)	Rattus rattus (Ship or roof rat)	Rattus exulans (Polynesian rat)	Mus musculus (House mouse)
Weight (grams)	250-500	150-240	50-80	25-40
Total Length (centimeters)	32-46	32-45	20-30	15-20
Tail Proportion	Less than ½ total length	More than ½ total length	½ or more of total length	½ total length
Number of Teats	12	10	8	10
Ears	Small with fur on edges	Large, thin and naked	Nearly naked	Nearly naked
Color	Brown/grey back, lighter belly	Three color phases. Brown/white belly, or brown/grey belly, or black	Brownish grey/buff belly	Grey

which can require differences in control methods.

Table 2 lists a few of the more important features of rat biology which should be considered before control. The <u>most important</u> point is that rats are relatively intelligent animals, and control usually necessitates them eating poisoned baits. This is in marked contrast to the control of diseases and insects which requires a toxin to be applied to the organism which does not have to play any direct part in its own elimination.

Rat populations can increase rapidly if conditions are very favorable (i.e., abundant food, nest sites, few enemies, etc.). However, without any control all habitats (areas in which rats live) have a maximum carrying capacity, which in many cases is at quite a low level. That is, natural factors usually regulate rat population, as they do many of our other pests, and it is only when one disrupts the whole ecosystem by introducing an abundant food source, or removing their natural enemies, that they become a problem.

Rat numbers in agricultural habitats around the South Pacific have not been widely assessed, but three studies in Fiji indicate that the Polynesian rat can vary from 25 to about 145 per hectare in coconut and cocoa groves. There are no good density estimates for the other two species of rat.

Rats have considerable physical capabilities which should be kept in mind when attempting management. The combined abilities of the three species result in the group being capable of jumping

TABLE 2: Features of Rat Biology and Ecology

	Norway	Roof	Polynesian
Reproduction			
Season	All year if food available		
Gestation	21-23 days, can be pregnant again soon after birth		
Litter Sizes	7-8	3-5	2-5
Senses			
Hearing	Very good, can detect high frequency sounds		
Smell/Taste	Very highly developed, used to seek and identify foods (or poisons) plus know their environment		
Foods	All eat a very wide range of foods but need some with protein. Roof and Polynesian rats eat many insects. All rats, particularly Norway, approach new food items with caution. Only eat small amounts at first feed.		
Movement	All species will daily move 100 meters or more from nest site to food, but most rats occupy a relatively small area.		
Habitat Sites	A burrowing rat, poor climber, common in sewers and urban areas	A very good climber, seldom burrows, nests and feeds in trees	Climbs well but mostly occupies dry grassland areas, often under coconuts, small burrows formed
Species Association	All species can be found together but there is often vertical separation. Roof rats can displace Polynesian rats from palms where they are common.		

up to one meter, dropping 15 meters, without injury, swimming one kilometer, burrowing over one meter, climbing any rough surface, and gnawing holes in a wide range of materials. All these make them a formidable problem to manage.

ASSESSMENT OF RAT DAMAGE AND CONTROL FEASIBILITY

Killing rats with modern rodenticides is not very difficult, but the problem is to develop a safe system that will work effectively within the existing land use and administrative framework. Many rat control efforts have failed, simply because the problem was not properly assessed at the outset.

Table 3 outlines the types of questions that must be asked before any control is begun (should it prove necessary) while Table 4 outlines an approach for assessing damage to crops. Rats tend to cause an emotional, rather than economic, response from many people. When assessing damage, losses, and need for control, it is particularly important to consider two essential points.

First, i. must be realized that compensation for rat attack, and other pests, can occur. nat is, the damage the rat is causing may not reduce final yield, particularly if damage occurs well before harvest or if it affects the vegetative parts of the plant rather than the fruit. Rat damage to coconuts is a good example of the first point. Rats attack the green nuts between the third and seventh month of their formation, and it is now known that such damage, early in the nut development cycle, can

TABLE 3: When is Rat Control Worthwhile?

Assess your problem!!

Consider:	History Nature of present problem Control costs and expected benefits
History:	When did the problem begin? What was damaged or why were people concerned? What control has been tried? Was it successful, if not, why?
Nature of the Present Problem:	Loss of food or export crops (cocoa, coconuts, etc.) Damage to stored crops A public health problem Structural damage to building, rice bunds What species of rat is causing the problem? Is it a seasonal or continual problem? Who considers the rats a problem--farmers, agricultural officers, health nurse, or others?
Control Costs and Expected Benefits:	What is the cost/value of crops, stored food, or structural damage? Can the human health hazard be significantly reduced? What will rat control cost, who will pay? Estimate cost benefit ratios if possible.

TABLE 4: Assessing Rat Damage to Agricultural Crops and Effect on Production

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Measure Damage Symptoms

Count the number of damaged fruit, pods, nuts, etc., provided:

1. The sample period is representative of damage throughout the year

2. The area surveyed is representative of the whole area, whether it is one field or a whole district

3. The assessment procedure does not affect rat attack behavior

4. The damage symptoms are related to production loss via production comparisons on other evaluations.

Compare Production

Control rats in one or more areas, and compare crop production from this with one area where no control is carried out but damage levels have been similar in the past.

be at least partially compensated for (see Rowe et al., 1975 under Suggested Resource Publication on Rat Biology and Control). In contrast, there is no scope for compensation of rat damage to cocoa that occurs as the pods ripen. Thus, it is very important to assess the relationship between the damage symptoms and crop yield. (Appendix 1, an article by J. M. Williams entitled Rat Damage to Coconuts in Fiji. Part II Efficiency and Economics of Damage Reduction Methods.PANS 21(1):19-26, provides a discussion of the procedures used to determine this relationship and also of the economics of rat control in coconuts.)

A second point to consider is who pays for rat control. There seems to be a belief, possibly because commercial rat baits are expensive in the South Pacific, that a government agency should supply baits. This is a satisfactory approach provided costs are covered by the crop loss. But, supply of free baits tends to lead to highly uneconomic rat control practices.

Table 5 summarizes some South Pacific agricultural damage data and gives an indication of loss levels. However, note that percentage loss data can give a misleading impression of the actual economic value of pest damage.

An interesting aspect of rat attack of crops is how important they are as the rats' staple or main food. Grains such as rice and many vegetables provide a high proportion of daily requirements and, thus, the cultivation of these can help support large rat populations. In contrast, green coconuts, cocoa,

TABLE 5: Rat Damage to South Pacific Crops

Crop and Country	Damage Levels*	Reference
Coconuts		
Fiji	6.8%+ (3.6 nuts/palm/year)	Taylor (1930)
Fiji	28% (23 nuts/palm/year)	Paine (1934)
Fiji	0.5-16.6% (1.8-9.1 nuts/palm/year)	Williams (1974)
Kiribati	16-77% (2.8-23.2 nuts/palm/year)	Smith (1969)
Tahiti	28% (9.6 nuts/palm/year)	Lassalle-Sere (1955)
Tonga	5-13% (2-6.6 nuts/palm/year)	Pierce (1971)
Tokelau Island	0.78% (0-38 nuts/palm/year)	Whelan & Whelan (1971) Harrison (1972)
Cocoa		
Fiji	4-36% (50-9,500 pods/hectare/year)	Williams (1975)
Solomon Islands	1-49%	Friend (1971)
Maize		
Tonga	4-100%	Yamada (1973)

* Damage is defined as attack of fruit or fruiting body; the data do not necessarily represent a production loss. The figures in brackets represent nuts/palm/year for coconuts, pods/hectare/year for cocoa, and kilogram/hectare/month for pineapples. Percentage damage is of total fruits produced (i.e., damaged and usable).

TABLE 5 (cont'd)

Crop and Country	Damage Levels*	Reference
<u>Melons</u>		
Tonga	0.1-13.3%	Yamada (1973)
<u>Peanuts</u>		
Fiji	0-10%	Williams (1972)
Tonga	0-13%	Yamada (1973)
<u>Pineapples</u>		
Fiji	0-45 kilogram/hectare/month	Williams (1972)
<u>Rice</u>		
Fiji	Insignificant	Williams (1972)

* Damage is defined as attack of fruit or fruiting body; the data do not necessarily represent a production loss. The figures in brackets represent nuts/palm/year for coconuts, pods/hectare/year for cocoa, and kilogram/hectare/month for pineapples. Percentage damage is of total fruits produced (i.e., damaged and usable).

and sugarcane are not important basic rat foods and in all cases appear to be eaten primarily because of their high sugar content. These crops have been called "luxury" rat foods, and it is therefore an important aspect when considering the relationship between total rat numbers, or potential numbers in an area, and the level of crop damage.

METHODS OF DAMAGE REDUCTION AND CONTROL

Nonchemical Methods

This training course is emphasizing pest control methods that do not involve the use of chemicals. Table 6 summarizes features of four nonchemical methods or strategies used in rat management.

Banding palm trunks is, in theory, an attractive damage reduction method. However, the method is generally inefficient because senile (old, unproductive) fronds bridge bands on trunks of less than 12 meters (from crown to ground), and even a few fronds per hectare can allow many rats into palms. In addition, alloy banding materials are rapidly corroded by salt spray; rats can easily cross over the corroded bands.

"Breakback" trapping has limited application provided good baits are used and the other features outlined in Table 6 are noted. Cage or live traps are not a practical field rat control tool but are useful for catching rats when live specimens are required for purposes of species identification, for disease and

TABLE 6: Nonpoison Methods of Reducing Rat Damage to Crops

Habitat Modification

Features

Requires removal of cover nest sites, etc.

Only practical for intensive agriculture, e.g., irrigated rice, vegetables, peanuts, pineapples, and sweet potatoes

Requires considerable labor

May not reduce damage in some crops, e.g., coconuts where ship rat is present

Trapping with "Breakback" Type Trap

Features

Safer than poisons

Only suitable for treating small areas

Requires operator skills--careful placement, knowledge of rats

Requires a good bait--conditioning of an unset trap can improve catches

For good control, large numbers of traps are needed

Trunk Banding

Features

Only practical for preventing rat damage to coconuts

TABLE 6 (cont'd)

Trunk Banding Features (cont'd)

Once bands (aluminum or plastic) are placed, no further rat control is, in theory, needed.

Bands are frequently bridged by fronds, and rat damage therefore continues.

In salt spray areas, bands corrode rapidly.

Overall, the method is not very effective.

Ultra Sound Devices

Features

Consist of electronic unit that produces high frequency noise that rats can hear but most humans cannot.

Manufacturers claim they will drive rats from sheds, stores, etc.

Trials have shown that rats are not affected by these devices--they should not be purchased.

parasite surveys, etc. Another useful method, similar to trapping, uses glue or stick boards. Special glues are spread on sections of boards which are placed in rat runways. When attempting to run across these sticky boards, rats are caught in the glue. However, the method has most of the same limitations as breakback trapping. In most environments, rats are regulated by features of the habitat. Clearly, availability of cover and food are two of the most important features which affect their abundance, but predators also play a major role. The predators include cats, mongooses, dogs, owls, and snakes. However, they do not always keep rat numbers low enough to prevent crop damage, particularly in situations where a crop provides a great abundance of food.

Chemical Methods

Most field rat control requires the use of a rodenticide combined with a good quality bait. Tables 7-10 characterize the types of anticoagulant poisons currently available in the South Pacific region plus the steps involved in bait selection, preparation, and laying.

The use of rodenticides requires the same care and precautions as insecticides and herbicides, and they should be used only when absolutely necessary.

Anticoagulant poisons are most widely used for rat control, and the mode of action for all those listed on Table 7 is the same. They cause death by reducing the ability of the blood to

TABLE 7: Anticoagulant Poisons

Compound	Bait or Concentrate Trade Names	Concentration in Baits
First Generation		
Warfarin	Rentokil Warfarin 0.5, 1.0, 10.0, & 100%	Concentrates
	Rid rat	0.05%
	Biotrol	0.05%
	Rat Sak	0.025%
	Rodent Deth	0.025%
Diphacinone	Diphacin 120 (1.2%)	Concentrate
	Coopers Rat-Ex	0.005%
	Ramik	0.005%
Chlorophacinone	Drat	0.005%
	Rozol	0.005%
Coumatetral	Racumin 57 (0.75%)	Concentrate
	SBL Rodent Bait	0.05%
Second Generation		
Difenacoum	Neosorexa	0.005%
	Ratak	0.005%
Bromadiolone	Slagmor	0.005%
	Deadline	0.005%
	Bromotrol	0.005%
Brodifacoum	Talon	0.005%
	Volak	0.005%

TABLE 8: Rat Baits, Poisons, and Bait Acceptability Testing

Selecting a Bait

For good control all rats must eat some of the poison bait.

Whole or coarse ground wheat, maize, or rice are accepted by most rats.

Coconut meal, dessicated coconut, dried cassava, and similar materials can be combined with grain meals.

Up to 5% sugar (or molasses) and 3-8% vegetable oil can be added to improve bait acceptance.

If whole unhusked grain is used it must be soaked in an anti-coagulant solution because rats husk grains and surface coated poisons would not be eaten.

Checking Bait Acceptability

Use covered bait boxes spaced at least 10 meters apart.

Place 25-50 grams of one bait type in each box.

Place bait A in Box 1, bait B in Box 2, bait C in Box 3, etc., with at least 10 samples of each bait.

Change bait position each day, i.e., bait A to Box 2, bait B to Box 3, etc.

Run the bait choice test for at least four days and check bait consumption daily.

Checks can be made on rat activity in bait boxes by coating the entrance with talc (should not be perfumed).

Which Poison to Use

Depends on nature of problem but usually the cheaper compounds (Warfarin, Coumatetral, etc.) will provide good control if no evidence of resistance.

Try and purchase concentrates and mix own baits. It is usually much cheaper.

If there is evidence of Warfarin resistance or baits cannot be left in place for at least a week, use Bromadiolone or Brodifacoum in a prepared bait.

TABLE 9: Bait Mixing

Bait Preparation

Use good quality fresh materials and clean mixing containers.

For small quantities (5-6 kilograms) a wheelbarrow is good for mixing.

Larger batches (10-15 kilograms) can be done in a concrete mixer.

Combine finest bait materials and poison concentrate first, mix well, avoid inhaling poison powder.

Add coarser ingredients, sugar and oils; mix VERY THOROUGHLY.

Store in insect-proof plastic bags in a dry position. When in store check for mold.

Wax baits can be prepared by adding 30-35% (by weight) melted paraffin wax to the mixture. Stir in quickly and press into suitable bait trays or small paper cups. Final bait size should be about 50 grams.

Poison Dilution Factors

It is very important that anticoagulants are mixed at the correct concentration. Excess poison does not increase the kill, it usually decreases it!

Always follow the manufacturer's poison concentration recommendation.

Some useful dilution factors are:

0.05% in bait = 1 part of 0.5% concentrate to 9 parts of bait

0.025% in bait = 1 part of 0.5% concentrate to 19 parts of bait

0.01% in bait = 1 part of 0.5% concentrate to 49 parts of bait

0.005% in bait = 1 part of 0.5% concentrate to 99 parts of bait

TABLE 10: Bait Laying

Bait Positions

Loose meal baits need to be placed in a bait box, bamb:` tube, or similar weather protection.

Wax blocks can be:

1. Placed on the ground provided crabs, pigs, dogs, poultry, etc., do not eat them
2. Placed in the first fork of cocoa trees
3. Nailed to the trunk of coconut palms or placed in the crown.

Application Rate

Depends on the level of infestation but with Warfarin baits should not normally be greater than 3 kilograms/hectare/ application.

25-30 bait sites per hectare are usually adequate for most crops BUT less sites may be satisfactory in coconut plantations if all baits are placed in crowns of palms most frequently attacked.

Check baits every 2-3 days and keep in position for at least 14 days.

Brodifacoum and Bromadiolone baits can be applied at much lower rates (i.e., 1 kilogram/hectare) with as little as 10 grams at each bait site. A second application should not be made for at least 7 days--and only if there is still rat damage.

Remove any uneaten ground baits after 2 weeks.

Possible Reasons for Failure

If bait was well accepted, failure may be due to:

1. Baiting not done for long enough
2. Insufficient bait laid--no follow-up

TABLE 10 (cont'd)

Possible Reasons for Failure (cont'd)

3. Not enough bait stations
4. Control Program over too small an area--rats move in
5. Rats have been controlled in the area many times in the past, and resistance has developed.

If bait was poorly accepted, it may be because:

1. Bait of poor quality or not properly mixed
2. Bait stations were avoided by rats
3. Other foods palatable to rats were very abundant
4. Bait became moldy before sufficiently eaten
5. Rats can detect the anticoagulant in the bait.

clot. The poisoned animal eventually bleeds to death, usually by internal hemorrhage.

There is an important difference between the "first generation" and "second generation" anticoagulants. First generation compounds usually need to be eaten by rats for about 3-10 days. That is, continual small doses are needed to induce fatal bleeding. In contrast, second generation compounds kill by either a single feed or several small ones. Much less second generation poison is needed to get a good kill, and any bait a rat eats after the first feed does not hasten death but simply wastes bait and leads to the rat dying with large amounts of the poison in its body. Rats poisoned by the second generation compounds may in turn poison cats, pigs, or other animals that feed on them. Overall the application rates of second generation poisons (i.e., Talon) should be much lower than the earlier compounds and baits should not be replaced for at least a week.

Other poisons, usually called acute or single dose types, are used for rat control in some parts of the world. These include compounds such as zinc phosphide, sodium monofluoroacetate (1080), arsenic, and phosphorus. Most are of little value for rat control in the South Pacific because they are dangerous to handle and would pose great risks to farmers, domestic animals. and wildlife.

Tables 8-10, which outline bait selection, mixing, and laying, require little explanation except to stress that selection of good bait materials plus the correct concentration of the anticoagulant are two of the most important aspects of baiting.

Table 11 stresses aspects of poison safety. The risk to domestic pigs should be noted as well as the higher risks posed by the second generation anticoagulants.

CONCLUSIONS

The rat is a very successful species and can, under the right conditions, multiply rapidly. The rodents quickly adapt to new crops and field conditions so their pest potential is great.

Agricultural rat control, for production protection, should always be based on a good understanding of the economics of damage. It must also be an exercise in applied ecology since successful control is the regulation of populations to a low level. Control should never be evaluated on a basis of the numbers of rats destroyed but, rather, on a basis of the numbers that remain to be a future problem.

Finally, the methods used should consider the risk/benefit ratios as well as the cost/benefit ones. That is, the poisons used should have little or no effect on other nontarget animals (domestic or wildlife) in the environment, while providing the desired cost effective crop protection.

TABLE 11: Poison Safety

Poison Bait Mixing - Precautions

When mixing bait do not breathe in or swallow the powder concentrate.

Wear rubber gloves and if possible a dust mask.

Wash your hands and all exposed skin after mixing baits.

Wash all mixing equipment.

Store poison concentrate and baits in a secure shed. Label all bags, etc.

First Aid and Antidote

In case of accidental ingestion by humans get the person to vomit at once.

Call a doctor to enable a blood transfusion and/or administration of Vitamin K_1, an effective antidote.

Domestic Animals at Risk

Pigs are the most susceptible domestic animal and can be killed by less than 0.5 kilogram of Warfarin bait at 0.05%.

Poultry can also be killed but they need larger quantities.

Brodifacoum and Bromadiolone are very much more toxic than Warfarin and additional care should be taken with these poisons.

REFERENCES CITED

Friend, D. 1971. Rat damage to cocoa in the Solomons. South Pacific Bulletin 2:19-22.

Harrison, A. G. 1973. Rat damage to coconuts on Nukunonu atoll Tokelau Island and the desirability and feasibility of rat control--South Pacific Commission unpublished report. Second Regional Conference of Directors of Agriculture and Livestock Production, 8 p.

Lassalle-Sere, L. 1955. Rat control scheme for Tahiti planters, South Pacific Commission, Quart. Bulletin 1:5-6.

Paine, R. W. 1934. Observations on rat damage to coconuts in Fiji. Agric. J. 7(1):26-34.

Pierce, L. 1971. A preliminary report on rat damage to cocoa, on Tongatapu--special publication of the Tongan Department of Agriculture. 33 p.

Smith, F. J. 1969. Rodent research in the Gilbert and Ellice Is. Special publication. Gilbert and Ellice Islands Condominium. Department of Agriculture. 71 p.

Taylor, T. H. C. 1930. Early nutfall from coconut palms in Fiji with special reference to insects attacking flowers. Department of Agriculture, Fiji Bulletin 17.

Whelan, P. and C. Whelan. 1971. Rodent control research, Vava'u. Unpublished report of the Tongan Department of Agriculture. 164 p.

Williams, J. M. 1972. Rat damage, ecology and control research 1969-1972. A field report--special publication Fiji Department of Agriculture, 97 p.

Williams, J. M. 1973. Rat damage assessment and control in cocoa. Fiji Agricultural Journal 35(1):15-27.

Williams, J. M. 1974. Rat damage to coconuts in Fiji. Part 1. Assessment of damage--PANS 20(4):379-391.

Yamada, R. 1973. Rodent control final report 1972-1973. Tongan Department of Agriculture, Unpublished Report, 42 p.

SUGGESTED RESOURCE PUBLICATIONS ON RAT BIOLOGY AND CONTROL

Rowe, F. P., J. M. Williams, and E. J. Wilson. 1975
Rat Control in the South Pacific
South Pacific Handbook No. 1
South Pacific Commission, Noumea, New Caledonia

Williams, J. M. 1979
Rat Damage to Agricultural Crops
South Pacific Commission Advisory Leaflet No. 11

Howard, W. E. and R. E. Marsh. 1981
Division of Agricultural Sciences
University of California Leaflet 2896
Cooperative Extension, U.S. Department of Agriculture
University of California, Berkeley, California 94720 (USA)

Ministry of Agriculture, Fisheries and Food Anon 1976
Control of Rats and Mice
A reference manual for pest control personnel
Pest Infestation Control Laboratory
Hook Rise South
Tolworth, Surbiton
Surrey KT6 7NF England

Davis, R. A. 1970
Control of Rats and Mice
Bulletin No. 131
Ministry of Agriculture, Fisheries and Food
Pest Infestation Control Laboratory
England

Date: Oct. 6
Time: 1400

PRACTICAL EXERCISE IDENTIFYING WEEDS AND TRAINING ON RAT CONTROL MEASURES

Coordinated by

Roy K. Nishimoto and J. Morgan Williams

The practical exercise was intended to complement the formal papers on weeds and rodents presented at the morning's session.

The weed practical, coordinated by Dr. Nishimoto, included an exercise in weed identification in the field and a demonstration of a horse-drawn cultivator developed by the Tonga-German Plant Protection Project. Dr. Nishimoto showed the course participants some of the common species of annual and perennial weeds that occur in Tonga and other South Pacific countries. He pointed out the plant characteristics used to identify the species and to separate them from closely related species. Also, he discussed the ecological conditions that favor certain of the species.

The Tonga-German Plant Protection Project is exploring the use of horse-drawn cultivators in Tongan row crops. One of the cultivators was demonstrated in a field of growing maize. Benefits and limitations of the cultivation technique were discussed.

The rat control practical, coordinated by Dr. Williams, consisted of four parts. First, the course participants visited a coconut planting where the Tonga-German Plant Protection Project has a study to determine the relationship in level of rat feeding damage to coconuts and yield loss. Second, the participants observed in the laboratory live specimens of the common species of pest rodents in the South Pacific. Third, Dr. Williams displayed the commonly used trapping and baiting techniques used in rat control. And finally, he demonstrated the procedures for developing anticoagulant-impregnated baits used in rat control programs.

Date: Oct. 7
Time: 0905

COUNTRY REPORTS ELABORATED IN WORKING GROUPS: REVIEW OF MAJOR PEST PROBLEMS AND STATUS OF CROP PROTECTION IN REPRESENTATIVE COUNTRIES

The course trainees were partitioned into the following groups, depending on the country that they represented (some country representatives were not present for the group sessions):

Group 1	Group 2	Group 3
Guam	Fiji	Cook Islands
Northern Marianas	New Caledonia	French Polynesia
Papua New Guinea	Solomon Islands	Wallis and Futuna
Niue	Vanuatu	Western Samoa
Tokelau Islands	American Samoa	Tonga

Each group (with assistance from various course lecturers) met for 1½ hours and attempted to identify the principal crops and the major pests (insects, diseases, and others) affecting those crops and to describe the pattern of pesticide use and the application of nonchemical methods of pest control in the countries represented. Then, a representative from each of the three groups summarized the group's findings to all of the course trainees and lecturers.

The plant disease and insect pest experts from the South Pacific region seriously questioned the accuracy of some of the country reports. They pointed out that some of the insects and diseases reported are not known to occur in some of those countries for which reported; they also pointed out some of the available literature on disease and insect pest distribution and especially the publications arising from the UNDP/FAO Survey of Agricultural Pests and Diseases in the South Pacific.

Hence, because of the likely errors in reporting, the group listings of insect pests and diseases are not included here. The decision was made to restrict future group deliberations during the course to selected crops and pests which would be chosen during an evening session.

Also, because of the incompleteness of the information on patterns of pesticide use and use of nonchemical methods, the information assembled by the groups is not included here.

The recognition of the gaps in the participants' knowledge was treated in a positive rather than a negative way and was an important part of this exercise.

Date: Oct. 7
Time: 1400

THE INFLUENCE OF PESTS ON CASH CROPS

Fred Dori

"Pest" is a term used in Plant Protection to include animals, insects, pathogens, or weeds that destroy or reduce plant parts or products that are beneficial to man. Pests are responsible for increase in cost of production, processing, and marketing.

Destruction of crops by pests has been known to man since cultivation of crops began. The earliest reference to pest incidence dates back to the Middle Ages and the Biblical era. Cramer (1967) refers to historical documents of pest damage that have been related through the generations.

It was not until the early 19th Century that the significance of pests as a menace to crop production was realized, and an attempt was initiated to assess losses. Since then, estimates have been made on a yearly basis of crop losses in certain developed and developing countries. A minimum of 35 percent of agricultural production is said to be lost through pest depredation. The true figure is not known, for losses influenced by pests from many developing or undeveloped countries have never been evaluated (OECD, 1977).

Pests are dynamic in their behavior, influenced largely by changes in agricultural practices, but on occasions by natural disasters, for example, cyclones. Cash cropping, generally, is a monoculture practice utilizing land areas ranging from small backyard vegetable gardens to large-scale grain or plantation crops. Normally, a single crop is cultivated extensively on a site.

A cash crop environment is artificial and ecologically unbalanced. It favors potential noxious pests to multiply and, while attempting to secure food, they destroy and reduce crop production. The condition (cash crop environment) is ideal for pest development because of uniformity and unlimited food supply. Therefore, traditional mixed crop farms are generally less affected by pests, except for occasional outbreaks which are environmentally induced.

Pest activities therefore play a major role in the success or failure of cash crop production. For example, on cocoa in Papua New Guinea, pests are undoubtedly the key problems. Considerable losses have occurred from Pantorhytes weevils, vascular streak dieback (Oncobasidium theobromae), and both black pod and canker caused by the fungus Phytophthora palmivora. In parts of the country, cocoa plantations have been virtually abandoned because of the Pantorhytes weevils. The larvae of the weevils bore into the trunk or jorquette of cocoa trees and weaken branches. The problem is further complicated by Phytophthora palmivora, which infects trees through the sites of Pantorhytes damage. In advanced cases, older trees, 12-15 years old, are frequently killed by the disease.

Sugarcane is native to Papua New Guinea. Its cultivation has been on subsistence level until recently when commerical planting began for the manufacture of sugar. At this early stage of establishment, results from trials have indicated that two sugarcane stem borers, Chilo terrenellus Pag. (Pyralidae) and Sesamia grisescens Walk (Noctuidae), both endemic on local species of Saccharum and other host gramineae, will reduce production by at least 12 percent of the finished products. This will amount to about 4,800 tons of processed sugar.

Coconut palms in their natural habitat, on coastal shores, are relatively free from pests because of a number of factors such as isolation of one tree from another, age differences, and the nature of undercover or tree canopies. Where seasonal pest problems arise, they are naturally controlled. However, when the palm tree acquired its new economic status, extensive commercial cultivation began and the incidence of pests increased proportionally. Young coconut palms established in the vicinity of rainforests and rainforest-cleared areas in parts of Papua New Guinea and the Solomon Islands are preferred as alternate food sources by the rhinoceros beetles, Scapanes australis grossepunctatus St. and Scapanes australis Boisd., which normally live on wild palms and related plants in natural rainforests. Palm trees 18 months to 6 years old are damaged, and replanting is often necessary where young trees are killed outright. In the Gazelle Peninsula of East New Britain, 75 percent of young Rennel

Tall are killed, compared with 63 percent of the hybrid Rennel Tall x Malayan dwarf, and 33 percent Gazelle Tall (R. Brook, pers. comm.). On established plantations, mature palms were once seriously attacked by the introduced Oryctes rhinoceros in many Pacific islands. However, since the virus Rhabdionvirus oryctes was introduced, damage has been reduced considerably.

If rice is ever grown commercially in Papua New Guinea, it is likely to encounter serious pest problems that have occurred in the Solomon Islands. The pests which are considered potentially serious are the brown planthopper, Nilaparvata lugens Stal., the rice bug, Leptocorisa spp., and the leafrollers, Cnaphalocrocis medinalis (Gn.) and Marasmia poeyalis (Boisd.). Leafrollers have been recorded to cause 70 percent leaf damage on rice under experimental conditions. Similarly, where continuous cropping has been practiced, over 50 percent losses of matured rice have resulted from the brown planthopper's damage.

Management decisions on cultural practice on farms, especially of arable crops, are influenced or related in many ways to pest activities. The decision to plant crops at a certain time of the year with the view of avoiding peak activities of certain pests is a familiar practice in developed countries. Selection of crop varieties, for example, open head sorghum, is made on the premise that closed head varieties are more susceptible to Heliothis and sorghum head caterpillar. There are also clonal varieties of cocoa that are recommended to the growers.

Agronomic recommendations on thorough land preparation and even sowing of grain crops are both related to minimizing weeds and insect pest incidence. Despite the availability of such information, the control strategy adopted on seasonal crops still follows a pattern common to many developing countries with frequent prophylactic sprays, and little consideration for alternate control measures.

Coconut palms, cocoa, and oil palms are perennial crops, planted individually, e.g., oil palm, or mixed, as coconut with cocoa. The strategy adopted to encounter pest activities is in line with integrating cultural and biological controls with specific pesticides so that a beneficial environment is maintained and suited to the establishment of beneficial insects.

SELECTED REFERENCES

Bedford, G. O. 1976. Use of virus against the coconut palm rhinoceros beetle in Fiji. PANS, Vol. 22, No. 1.

Cramer, H. H. 1967. Plant protection and world crop production. Bayer, Ptlanzenschutz. Leverkusen.

McGregor, A. 1980. Black pod disease of cocoa. Harvest, Vol. 6, No. 3.

OCED. 1977. Report of the steering group on pest control under the conditions of small farm food production in developing countries.

Prior, C. 1979. Cocoa canker and sudden death. Harvest, Vol. 5, No. 2.

Smith, E. S. C. 1981. The use of crazy ants in the control of *Pantorhytes* in cocoa. Entomology Bulletin No. 4.

Stapley, J. H. 1978. Insect pest problems in tropical crops and the influence of the environment. Alafua Agric. Bull. Vol. 6, No. 4.

Tothill, J. D., T. H. C. Taylor, and R. W. Paine. 1930. The coconut moth in Fiji. The Imperial Bureau of Entomology, London.

Taylor, T. H. C. 1937. The biological control of an insect in Fiji. The Imperial Inst. of Entomology, London.

Date: Oct. 7
Time: 1540

THE INFLUENCE OF PESTS ON TRADITIONAL CROPS

R. Muniappan

The countries and territories in the South Pacific are small islands and have a fragile ecosystem. Introduction of new pests and diseases have caused serious changes in the ecosystem, economy, and livelihood of the people. In most cases of accidental introductions, pests get introduced without their natural enemies and find the tropical environment of the Pacific islands more congenial for buildup of their populations.

Because of my familiarity with the Micronesian region, most examples cited in this article are from this area. The pests are listed below by crop.

BANANA

Banana skipper: Pelopidas thrax (Hesperiidae).

This pest was first noted in Guam in 1957. It was one of the pests introduced into Guam from the Philippines. The adult is a dark brown-colored skipper with a yellow patch in the middle of the forewings. Eggs are hemispherical in shape and are laid on the under surface of tender leaves. Eggs hatch in 2-3 days after laying, and the young larvae feed on the margins of the leaves rolling tnemselves in leaf rolls. Young larvae are white in color with a black head. After the first instar stage, the larvae cover themselves with a white powdery waxy material. Pupation takes place within the leaf roll.

An egg parasite, Ooencyrtus erionotae, was also accidentally introduced into Guam from the Philippines.

In August 1973, P. thrax was discovered in Hawaii. The egg parasite, O. erionotae, was introduced into Hawaii from Guam in November 1973. A larval parasite, Apanteles erionotae, was introduced into Hawaii from Thailand in January 1974, and in 1974, Guam received the parasite from Hawaii. In addition to the host specific egg parasite, O. erionotae, a species of locally occurring Trichogramma also attacks the eggs of P. thrax on Guam. A pupal parasite, Brachymeria sp., which was introduced from Papua New Guinea in 1973 for the control of Pericyma cruegeri, has also been observed to attack pupae of P. thrax.

P. thrax is also known to occur in Saipan. The larval parasite, A. erionotae, was introduced into Saipan in 1975. These parasites keep the population of the banana skipper fairly well under control. However, the population of the banana skipper has been observed to increase after severe typhoons, possibly because of the ecological imbalance caused by the wind.

It is no longer a pest of significance in Guam, Hawaii, and Saipan.

Banana aphid: Pentalonia nigronervosa

It is a vector of the virus disease bunchy top. This aphid itself does not cause much economic damage, but the pathogen that it transmits is devastating to banana plants.

Bunchy top disease was introduced into Saipan around World War II from Okinawa. It was noted for the first time in Guam in 1972. For eradication of this disease, an herbicide (picloram) treated wooden pin prepared in Japan (keipin) was used in Guam on an experimental basis. Even though the keipin was effective in killing diseased banana trees, the USEPA did not permit its use beyond the experimental use period of one year because of some adverse effects.

Banana stem weevil: Cosmopolites sordidus

This weevil occurs in all tropical areas. Adults lay eggs at the base of the older leaf sheath. The young larva penetrates into the rhizome. It may grow up to 2 centimeters in length and finally pupates in a superficial part of the tunnel.

It has recently been discovered in Hawaii. The main predator of this pest in a histerid beetle, Plaesius javanus. It was introduced into Fiji in 1913-14 and from there to Guam in 1947.

Hololepta minuta and H. quadridentata (Histeridae) were also introduced into Guam from Trinidad in 1953 and 1954.

Dactylosternum hydrophiloides (Hydrophilidae) was introduced into Koror (Palau) in 1948 from Malaysia.

The taro cluster caterpillar (Spodoptera litura), Chinese rose beetle (Adoretus sinicus), and the coconut scale (Aspidiotus destructor) are some of the minor pests of bananas in Guam.

The banana scab moth, Lamprosema (Nacoleia) octasema, is not a pest of bananas in Micronesia.

Of all the pests in Guam, bunchy top disease is the most important.

It has severely curtailed production of eating varieties of bananas in Guam.

CITRUS

The citrus swallowtail butterfly, Papilio xuthus, was first recorded in Guam in 1925. It was presumed to be a migrant from the Orient. Caterpillars of this butterfly feed on citrus and Triphasia trifoliata.

In the early 1960s, P. polytus was accidentally introduced into Guam, and by 1967, P. xuthus disappeared from Guam. This is a possible example of species replacement.

There is an egg parasite (Trichogramma sp.) of P. polytus in Guam. However, the pupal parasite, Pteromalus luzonensis, introduced from the Commonwealth Institute of Biological Control in 1974, appears to be more effective in suppressing the population of P. polytus.

The citrus leafminer, Phyllocnistis citrella, is known to occur in Micronesia, Papua New Guinea, and Asia. Adults are small silvery white moths. Eggs are laid at 2 to 3 per leaf. On hatching larvae penetrate into the leaf tissue and mine. Epidermis over the tunnel appears silvery. Pupation takes place inside the tunnel.

Citrus bud mite (Aceria sheldoni), flat mite (Brevipalpus spp.), California red scale (Aonidiella aurantii), and citrus rust mite (Phyllocoptruta oleivora) are of some economic importance at different times.

The introduction of the orange spiny whitefly, Aleurocanthus *spiniferus*, in 1951 into Guam was of some concern. However, in 1952, some parasites of this pest, including *Prospaltella smithi*, were imported from Mexico and released in Guam. Recently, this pest has spread to Kosrae. It was found in Hawaii in 1974, and the parasite *Prospaltella smithi* was sent to Hawaii from Guam.

Fruit-piercing moths: *Othreis fullonica* and *Thyas miniacea*

Fruit-piercing moths are a problem in the South Pacific. In Micronesia, Kosrae suffers most from this pest. Fruit affected by this pest are oranges, guava, mango, soursop, etc.

COCONUT

There are over 150 insect pests known to attack coconut palms. Of these, about two dozen pests occur in Guam. Some of these pests are:

Scale insects:	*Aspidiotus destructor* *Lepidosaphes mcgregori* *Lepidosaphes duponti* *Lepidosaphes* sp. *Chrysomphalus* sp. *Furcaspis oceanica*
Grasshoppers:	*Phisis pectinata* *Valanga excavata*
Stick insects:	*Acanthograeffea modesta* (Truk) *Acanthograeffea denticulata* (Mariana Islands) *Graeffea coccophaga* (Ponape, Truk, and Yap)
Coconut moths:	*Agonoxena argaula* *Agonoxena pyrogramma*

Coconut weevil:	Diocalandra frumenti
Sugarcane weevil:	Rhabdoscelus obscurus
Mealybugs:	Pseudococcus saipanensis Pseudococcus cocotis
June beetle:	Holotricia mindanaoana
Copra beetle:	Necrobia rufipes
Termite:	Nasutitermes brevirostris
Chrysomelid:	Phytorus lineolatus
Bagworm:	Psychid sp.
Coconut beetles:	Brontispa palauensis (Guam and Palau) Brontispa mariana (Saipan, Rota, and Tinian) Brontispa chalybeipennis (Ponape, Kosrae, and Marshall Islands)
Rhinoceros beetle:	Oryctes rhinoceros (Palau only)

In 1924 and 1925, there were reports of Aspidiotus destructor causing serious damage to coconuts on Guam. To control this pest, it was recommended that the affected leaves be cut and burned.

In recent years, the coccinellid beetle, Pseudoscymnus anomalus, has controlled this pest very effectively.

The introduction of Oryctes rhinoceros into Palau around 1942 has seriously affected coconut production. Many parasites and predators have been introduced to control this pest. However, the South Pacific Commission program on use of the virus disease has been very effective.

The report of Brontispa palauensis in Guam in 1973 has been of some concern. The introduction of the larval-pupal parasite, Tetrastichus brontispae, from Saipan, New Caledonia, and Vanuata in 1974 suppressed the population of B. palauensis on Guam. A local earwig, Chelisoches morio, also feeds on this pest. Recently, severe infestations of the coconut red scale, Furcaspis oceanica, have been noted in Guam. Also, the small bagworm has become a serious problem on Guam. This bagworm scrapes the parenchymatous tissue of the tender coconut fruits. Damaged young nuts either fall off or develop into small nuts with a brown husk.

CORN

A leafminer pest, Phytomyza spicata, attacks the young corn plants. Corn webworm, Marasmia trapezalis, attacks the corn until the plants are about a month old. A larval parasite, Apanteles guamensis, is common on this pest.

The Asian corn borer, Ostrinia furnacalis, was first recorded in Guam in 1911. Until 1970, it was wrongly identified as Ostrinia nubilalis, and various parasites were introduced from Japan and the United States mainland without much success. This pest is responsible for the decline in corn production on Guam and the Northern Marianas. Recently, a project under Section 406 Tropical Agricultural Research Program of the USDA has been initiated for control of this pest. Corn earworm, Heliothis zea, becomes a serious pest of corn in certain years in combination with Asiatic corn borer in Guam.

Taro cluster caterpillar, Spodoptera litura, is a minor pest of corn in the early stages of its growth. Corn planthopper, Peregrinus maidis, becomes serious in certain seasons and also transmits a virus disease. The mirid bug predator, *Cyrtorhinus lividipennis*, has been introduced for biocontrol of this pest in the Marianas.

Other minor pests of corn are: *Holotricha mindanaoana*, *Anomala sulcata*, *Adoretus sinicus*, *Nezara viridula*, *Valanga excavata*, and *Rhopalosiphum maidis*.

CRUCIFEROUS CROPS

Diamondback moth (*Plutella xylostella*), cabbage borer (*Hellula undalis*), cabbage webworm (*Crocidolomia binotalis*), corn earworm, and the taro cluster caterpillar are some of the important pests in Guam.

Some parasites have been introduced for the control of diamondback moth.

H. undalis and *C. binotalis* are primarily controlled by using pesticides.

CUCURBITS

A bulletin on "Pests of Cucurbitaceous Crops and Their Control" from the University of Guam describes the pest problems of cucurbits in Micronesia.

Some of the important pests are:

Cucumber beetle:	*Aulacophora* spp.
Cucumber worm:	*Margaronia indica*
Melon fly:	*Dacus cucurbitae*
Melon aphid:	*Aphis gossypii*
Leaf miner:	*Liriomyza sativae*

The presence of melon fly on Guam and Rota in the Marianas prevents exportation of most vegetables and fruits to Japan and other countries. Efforts are being made for eradication of melon fly on Rota and Guam.

LEGUMES

Young seedlings are attacked by beanfly, Melanagromyza phaseoli. It attacks petioles of mature plants. Maggots tunnel into the stem and petioles. Two parasites of the genus Opius introduced from Hawaii into Guam are effective. Bean aphid, Aphis craccivora, is a common pest on seedlings and tender shoots of grown-up plants. Bean pod borer, Maruca testulalis, is a serious problem in the Pacific. It damages buds, flowers, and pods.

Serpentine leafminer Liriomyza sativae, is a serious pest in Guam and most of Micronesia. Farmers in Guam were able to control this pest by using chemicals until 1980. In 1981, the leaf miner on beans became a very serious problem, and farmers were not able to control it by chemical means. Upon reexamination of the species of leaf miner involved, Drs. Nafus and Schreiner discovered a new species of leafminer in Guam, i.e., chrysanthemum leafminer, Liriomyza trifolii, which is resistant to most insecticides.

The introduction of L. trifolii caused a reduction in bean production on Guam during this period. Attempts are being made to introduce parasites of this leaf miner from Hawaii into Guam.

Chinese rose beetle, Adoretus sinicus, and some stink bugs are of some economic importance in bean production.

SOLANACEOUS CROPS

Philippine lady beetle, Epilachna philippinensis, is a pest of solanaceous crops and is well controlled by introducing two parasites, namely, *Pleurotropis epilachnae* and *Pediobius foveolatus*.

Leafminer (*Liriomyza sativae*), corn earworm (*Heliothis zea*), fleahopper (*Halticus tibialis*), broad mite (*Polyphagotarsonemus latus*), and spider mite (*Tetranychus* sp.) are some of the other pests.

TARO

The South Pacific Commission bulletin on "Diseases and Pests of Taro: by G. V. H. Jackson describes the pests of taro in detail.

In Micronesia, the taro leafhopper (*Tarophagus proserpina*) and the melon aphid (*Aphis gossypii*) are of economic importance. Taro hornworm and the taro cluster caterpillar are minor pests.

In Truk, there is a large bagworm that feeds on the leaves of *Cyrtosperma* taro and banana, and it is not known to occur elsewhere.

Date: Oct. 7
Time: 2020

EVENING WORKSHOP EMPHASIZING DISCUSSIONS ON RESEARCH AND EXTENSION PLANNING FOR PESTS ON SELECTED CROPS

Coordinated by Niels von Keyserlingk

The objective of this workshop was to select four crops representative of the South Pacific region that would form the basis for later workshop discussions on the development of integrated pest management. The trainees were asked to select four crops that they would consider to be most important for these discussions. Although not all trainees agreed that the following four crops should have been selected, most of the trainees chose to select coconut, taro, banana, and tomato.

The trainees were asked to begin thinking about identifying the major insects, diseases, and other pests that affect these crops in the region and the requirements for developing integrated pest management systems for them.

Date: Oct. 8
Time: 0900

ANALYSIS OF THE ECONOMIC STATUS OF DISEASES, INSECTS, AND OTHER PESTS IN QUESTION

Dale G. Bottrell

INTRODUCTION

Pests are organisms that diminish the value of resources in which we are interested. They do this by interfering with the production and utilization of crops, livestock, and other resources needed for food and fiber; by transmitting diseases; and by reducing the perceived quality of the environment in which we live.

The classification of an organism as a pest does not depend just upon the nature of the damage it does, but also on the judgment made by people about the relationship of the organism to their own welfare. Standards for health, comfort, and freedom from worry all have a genuine value to people, even if a monetary value cannot be assigned to them (NAS, 1975).

A farmer's concept of pest may sometimes differ considerably from a pest control specialist's concept of pest. For example, farmers in some developing countries often feed their livestock weeds during periods when forage is scarce. They may let the weeds grow in the crop fields, even though they know that the weeds will reduce their crop yields (Hildebrand, 1981). Hence, these farmers are likely to resist using a herbicide or another control method that the pest control specialists recommend for controlling these "pests." Fears, religious and cultural background, level of education, and experience also influence the farmers' perceptions of pests and whether or not these individuals will adopt various control practices.

Therefore, the pest status of each of the reputedly injurious organisms must be analyzed under actual farming conditions, and development of criteria for control of each of the pests requires an analysis of a range of factors--environmental conditions, availability of labor, economic welfare, educational level, and attitudes of the farmer, and a variety of social and political factors. This paper discusses the general approach for analyzing the status of the pests in question and establishing economic criteria for their control in integrated pest management (IPM) programs. Another paper at this training course (W. C. Mitchell, Definition, Objectives, and Features of Integrated Pest Management) introduces the concept of IPM.

ESTABLISHING THE NEED TO TAKE ACTION

Identifying the "Real" Pests: The Key Pest Concept

Correctly identifying the pests and differentiating them according to their damage potential are essential steps in integrated pest management. Understanding the relationship of pest infestation and crop phenology is especially important. The crop may be highly susceptible to damage during one stage of growth but only barely, or not at all, susceptible during the other stages. For example, very low densities of a weed may cause serious yield reductions to some crops when the crops are young. But very high population densities of the same weed species may have no appreciable effect as the crops approach maturity.

A given crop field may be infested with dozens of potentially harmful pest species at any one time. For each situation, however, there are rarely more than a few pest species in sufficient density to cause significant damage. These often recur at regular (and often fairly predictable) intervals.

Pests that generally recur regularly and cause economic losses if not controlled are the focal point for integrated pest management programs; they are known as "key" pests (Smith and van den Bosch, 1967). Key pests are not always the commonest species in a crop, but they are generally the most serious. Most key arthropod (insect, mite) pest species lack effective natural enemies.

The key pests contrast to "occasional" pests or "secondary" pests which attain injurious levels only irregularly when conditions of the natural environment (e.g., optimal weather, low incidence of natural biological control) are particularly favorable for their increase. Another category of pests, "potential" pests, includes potentially harmful species that reside at subeconomic levels unless aggravated by human manipulations of the cropping ecosystem (e.g., introduction of a new crop variety, use of an insecticide that disrupts biological control) which favor their increase. Occasional and secondary arthropod pests often have effective natural enemies which, if not disrupted by insecticides or other environmental modifications, will keep these organisms from inflicting economic losses.

A final category of pests, "migratory" pests, is exemplified by migratory species (e.g., migratory birds, armyworms, or locusts) that do not reside in a given cropping area but occasionally enter it, sometimes causing severe damage.

ECONOMIC CONSIDERATIONS

In integrated pest management, it is assumed that each pest--insect, disease, weed, rodent, or other--has a population level below which there is no economic injury. Although all of the pests are potentially harmful, and remedial actions may be required to maintain them at noninjurious levels, IPM does not advocate eradication of the pests. Integrated pest management rejects the notion that the mere presence of a pest species necessarily justifies action for control.

A requisite to any IPM program is therefore to discern the "real" pests in a crop from those that may be perceived as real pests but actually are not. The population level at which a reputedly harmful species has just attained real pest status is the "economic threshold." The economic threshold is defined as the density of the population below which the cost of applying control measures exceeds the losses caused by the pest (Stern, 1973).

To establish the economic threshold, the "economic injury level" first must be determined. The economic injury level is the point at which a pest population begins to cause economic loss. As illustrated in Figure 1, the economic injury level is slightly greater than the economic threshold level. This difference in population densities provides a margin of safety for the time that elapses between when the threatening infestation is detected and when the pest control treatment is applied (Stern et al., 1959). In other words, the economic threshold is the point at which the treatment must be applied to prevent a pest from reaching the economic injury level.

Figure 2 depicts a simplified economic threshold for a crop pest. The net crop income decreases at an increasing rate as pest density increases above a crop tolerance level (N_1). Control costs to achieve various pest densities are represented by the curved broken line.

The economic threshold (N*) is the pest density (or amount of plant damage) at which incremental costs of control just equal incremental crop returns. At N* some crop income is sacrificed (CI_1-CI_2). Above N* the farmer would fail to get additional crop revenue in proportion to the greater cost of control. If controls

Figure 1: Relationship of economic threshold and economic injury level

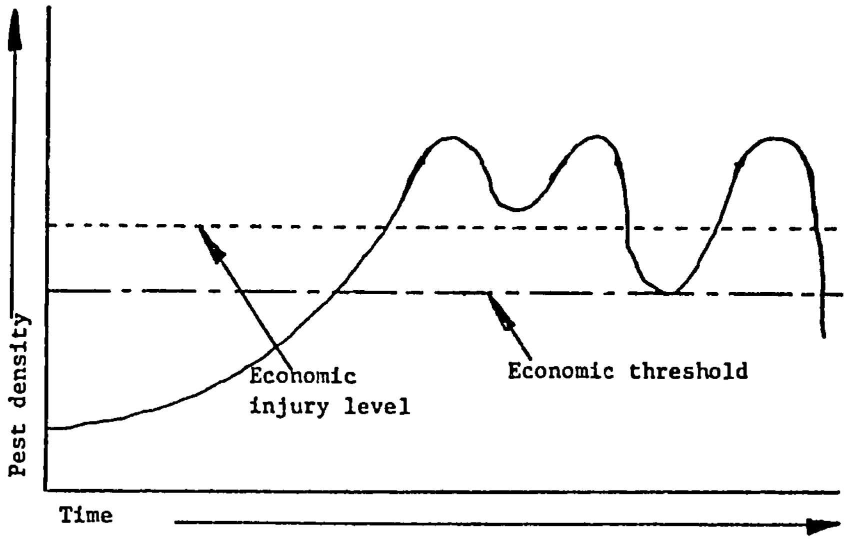
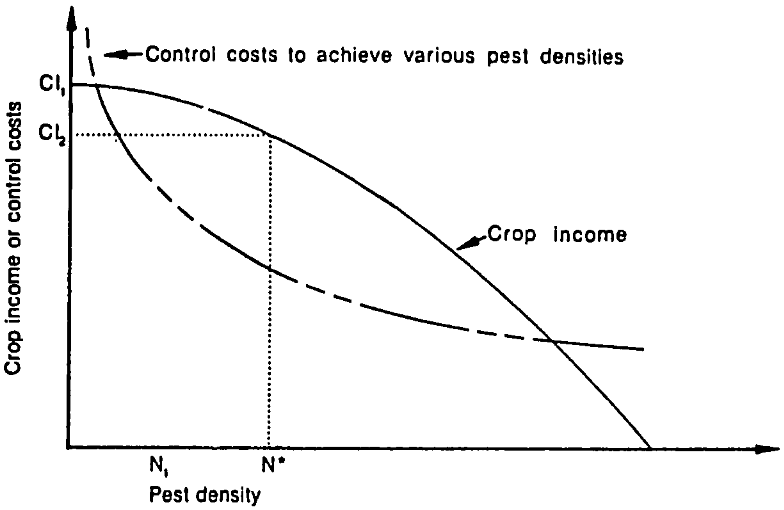


FIGURE 2: Hypothetical economic threshold
(Source: Carlson, 1971)



are initiated successfully at the tolerance or damage threshold (N_1), zero damage would occur but the costs of control would not be justified (Carlson, 1971).

Research Requirements

The concept of the economic threshold is actually much more complex than illustrated in Figure 2; economic thresholds must accurately reflect many complex and interacting variables. Ideally, they are based on accurate assessments of the potential damage, the human risks and uncertainties involved, and the ecological, sociological, and external economic costs of control.

Determination of economic thresholds is especially complex when more than strict profit-loss relationships are involved (Stark, 1971). For example, damage that causes nutritive losses or adversely affects the usability or palatability of a food produce is far more important than damage that merely affects appearance.

Establishing economic thresholds is even more difficult when a crop is attacked by a complex of pests. When a crop is attacked by a pest complex, growers may ask what should be done when the crop is infested by pest species A, B, C, and D, none of which has reached the economic threshold but each of which may be within one-half to three-fourths of it. Are the effects of multiple infestations additive, synergistic, or antagonistic? These basic questions have received far too little attention, and experimental techniques required for research on economic thresholds for pest complexes have lagged.

A substantial research effort is necessary to fill these voids in knowledge (Glass, 1975; Main, 1977; Stern, 1973; Apple, 1977). Procedures for establishing economic thresholds are covered in another paper at this training course (Examples of Case History Studies Involving the Analysis of the Economic Status and Determining the Need for Control by D. B. Bottrell).

APPLYING THE ECONOMIC THRESHOLD CONCEPT

To the farmer or extension agent, an economic threshold is merely a gauge to determine the need for a remedial control measure, such as a pesticide application. Monitoring the pest populations and the natural control factors can establish the need, or lack of need, for these measures. Population monitoring is conducted in a variety of ways. The most common method consists of field surveys by extension agents or the farmers themselves. When monitoring shows that a pest population is rising to damaging levels, despite the presence of natural controls or the use of a pest management component such as resistant crop varieties, steps may be necessary to prevent significant crop damage. The economic threshold tells the farmer or extension agent when to apply the remedial measures. Remedial measures that cause minimum disruption to the natural enemies should be selected. It is unwise to rely on any control method that disrupts the natural control system even temporarily unless there is great certainty that the target pest can be permanently eliminated or unless other alternatives fail.

The key pest concept and use of economic thresholds may not have as much application to control of plant pathogens or weeds as to insects. If one key weed species is removed from a crop, it may be replaced by another weed species that is just as damaging or even more damaging. For certain pathogens, preventive measures must be applied before the plants are exposed to the initial inoculum (spores, etc.). Therefore, the key pest and economic threshold concepts may not apply to the control of some weeds and plant pathogens. In other cases, these concepts do apply and their application will lead to a more economically efficient and environmentally sound system of pest control (Adkisson, 1976).

CONCLUDING REMARKS

Establishing economic thresholds involves much work and sometimes considerable expense (Glass, 1975). The economic thresholds must be periodically revised to account for changes in crop growth, crop varieties, natural enemy populations, management practices, marketing standards, and commodity prices, for example. However, even crude thresholds are better than none, especially for sporadic pests and those to which the crop plants have a reasonably high tolerance. Learning the characteristics of plant growth and crop development and keen observation of the pests for several generations are important first steps. Initially, IPM programs can be based on crude economic thresholds, then the thresholds can be refined as additional information becomes available and the farmers gain more experience using them.

Used properly, economic thresholds can lead to a reduction in unnecessary crop losses and also to more efficient use of pesticides and other control procedures, as illustrated by various other papers at this training course. In summary, the economic threshold is the "keystone" of integrated pest management.

REFERENCES CITED

Adkisson, P. L. 1976. Integrated pest management--a foreward to the conference, p. 1-3. In Proceedings, U.S.-U.S.S.R. Symposium: the integrated control of the arthropod, disease and weed pests of cotton, grain sorghum and deciduous fruit, September 28-October 1, 1975, Lubbock, Texas. Tex. Agr. Exp. Sta. MP-1276.

Apple, J. L. 1977. The theory of disease management, p. 79-101. In J. G. Horsfall and E. B. Cowling (Eds.), Plant disease: an advanced treatise. Vol. 1. How disease is managed.

Carlson, G. A. 1971. Economic aspects of crop loss control at farm level, p. 2.3/-2.3/6. In L. Chiarappa (Ed.), crop loss assessment methods. Food and Agr. Organ., Rome.

Glass, E. H. 1975. Integrated pest management: rationale, potential, needs and implementation. Entomol. Soc. Amer. Spec. Pub. 75-2.

Hildebrand, P. E. 1981. Generating technology for traditional farmers--the Guatemalan experience, pp. 31-38. Proc. IX Int. Congr. Plant Protection. Vol. 1. Plant Protection: Fundamental Aspects. Entomol. Soc. Amer., College Park.

Main, C. E. 1977. Crop destruction--the raison d'être of plant pathology, p. 55-78. In J. G. Horsfall and E. B. Cowling (Eds.), Plant disease: an advanced treatise. Vol. 1. How disease is managed. Academic, New York.

National Academy of Sciences. 1975. Pest control: an assessment of present and alternative technologies. Vol. 1. Contemporary pest control practices and prospects; the report of the executive committee. Washington, D.C.

Smith, R. F., and R. van den Bosch. 1967. Integrated control, p. 295-340. In W. W. Kilgore and R. L. Doutt (Eds.), Pest control--biological, physical, and selected chemical methods. Academic, New York.

Stark, R. W. 1971. Integrated control, pest management, or protective population management, p. 111-129. In Toward integrated control. U.S. Dep. Agr. Forest Service Res. Paper NE-194.

Stern, V. M. 1973. Economic thresholds. Annu. Rev. Entomol. 18:259-280.

Stern, V. M., R. F. Smith, R. van den Bosch, and K. S. Hagen. 1959. The integrated control concept. Hilgardia 29:81-101.

Date: Oct. 8
Time: 1055

THE CONCEPT OF ECONOMIC INJURY LEVEL AND ECONOMIC THRESHOLD LEVEL IN VIEW OF ECONOMICS IN CROP PRODUCTION

Rainer Rathey

ECONOMICS IN PLANT PROTECTION

In recent years, the economist increasingly has been asked to support the specialists in plant protection. Especially in crop protection, the economist's contribution relies largely on the knowledge of other scientists.

In relation to crop protection matters, frequently, questions arise such as:

1. Is this particular control measure profitable?
2. Is the repetition of this control measure profitable within one production cycle?
3. Which application schedule maximizes the contribution of crop protection to the profit of this cropping activity over a number of years? (within a certain crop sequence or crop rotation).
4. Which application intensity maximizes the contribution of crop protection to the profit of a certain cropping activity?

5. Which control measure is the most cost-effective one? (comparing several feasible control measures).

All these questions center around a comparison of costs and benefits involved within a certain control measure. Basically, there are two economic criteria applied to the answer of the above-mentioned questions:

Economic Criterion 1: The total costs of a given control measure within one production cycle (growing period of a crop) have to be smaller than or at least equal to the value of crop yield which results from this control measure; or, value of yield reduction $\geq$ total costs of control.

Economic Criterion 2: The last application within a given control measure has to result in additional benefits (value of yield) which are greater than or at least equal to the costs of this last application.

Both criteria do not consider the farmer's situation, but if a particular control method is substituted by another, e.g., biological-chemical-mechanical control of weeds, then the economic evaluation cannot be carried out without considering the farmer's situation.

SUMMARY

Four typical areas in crop protection where economics are involved are as follows:

1. Introduction of a new control method (mechanical, chemical, biological, or a new application technique such as spraying with airplane)

2. The economics of a given control measure (economic injury level, economic threshold level)
3. The optimal timing of control measures (profitability of additional control measures)
4. Evaluation of preventive measures before the occurrence of any insect pests and diseases (forecasting systems and probability calculation).

This concept of economics in plant protection is based on Reisch and Zeddies (1977).

TERMS AND THEIR DEFINITIONS

Within this lecture, we shall now focus on point two: the economics of a given control measure.

Economic injury level (EIL) = the lowest pest population level that will cause economic damage, that is, the amount of injury which will justify the total cost of a control measure (see Economic Criterion 1).

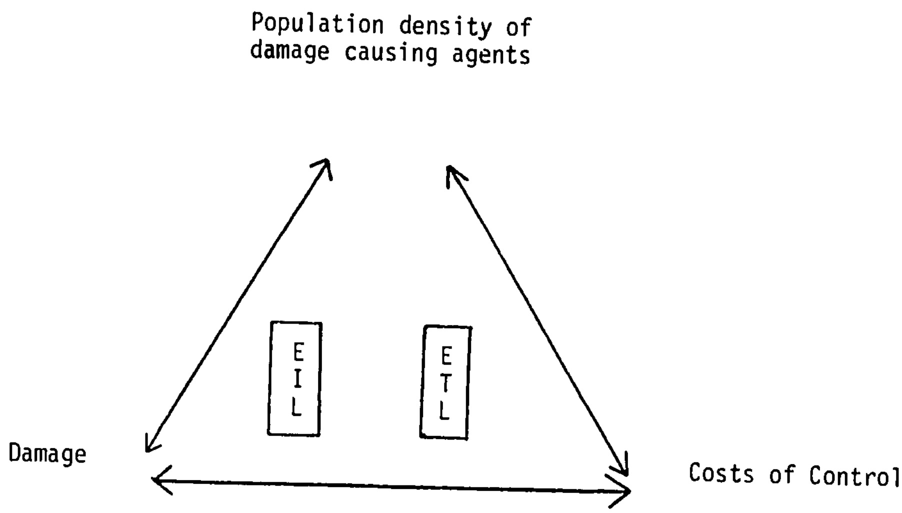
Economic threshold level (ETL) = the pest population level at which the control measure should be initiated and determined to prevent an increasing population from reaching the economic injury level.

In most cases, the EIL is greater than the ETL, as required to allow for a suitable time span before the control measure shows any effects. The difference between EIL and ETL depends largely on:

1. The nature of the pest
2. The ecology

3. The climate
4. The susceptibility of the crop concerned
5. The effectiveness of the control measure at a given application rate.

The concept of EIL and ETL is based on Stern et al. (1959). Three main independent variables determine the EIL:

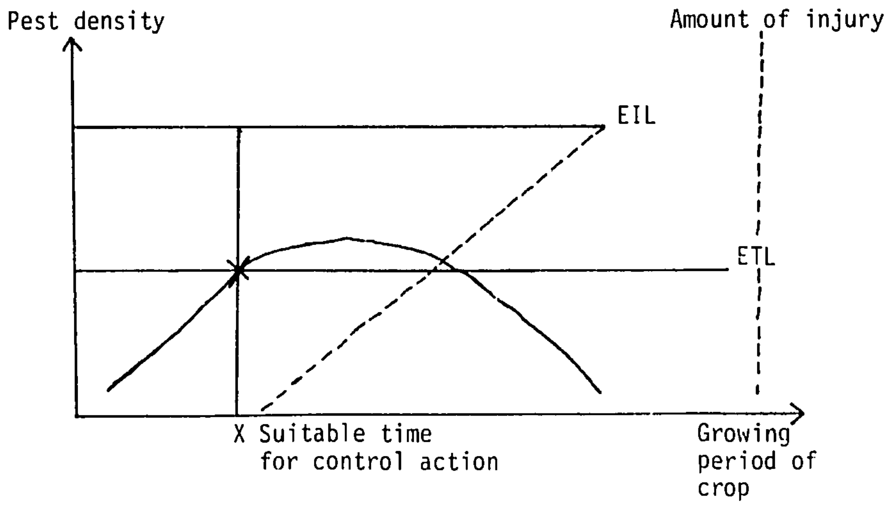


These three variables are not only independent but also correlated with each other. This is the reason why computerized models and regression analysis are involved to calculate the respective injury levels and threshold levels. This is obviously not yet the case in the South Pacific because of the high costs and research inputs needed for this sophisticated approach. But, a so-called "intuitive approach" may be as valuable, bearing this concept in mind. This approach implies that:

ETL = the population level, where one can sufficiently predict that the final amount of damage (yield reduction) caused by an uncontrolled pest population will justify its control (see Economic Criterion 1).

This means that control actions may be initiated when zero damage occurs but at a level of population where one can sufficiently predict the resulting damage. This is the case for aphids at an early stage in watermelons or for the taro hornworm as long as there are only egg clusters.

THE RELATIONSHIP BETWEEN EIL AND ETL



EXAMPLE: Armyworm in taro, Western Samoa (personal communication with Hans Braune and Osaka Aukuso).

From the economic point of view, it is also very important to know by how much the pest population level reached at point X has to be reduced, or, in other words, which is the level to which the pest population has to be reduced at a given point of time. This aspect has largely been ignored on the assumption that the highest "kill" is the best (see following section on population dynamics and ETL). For example, it is sufficient to reduce the level of hornworm population in taro to 10 percent, that is, one hornworm in every 10 plants.

Finally, the ETL may be reduced; thus, the control measure may start earlier with a larger number of applications onto a level where the farmer "feels himself safe." The farmer wants to avoid any risks and is prepared to pay an "insurance fee" by unnecessary applications of control measures (extension work!).

This is the case with watermelon growers in Tonga: 10 applications of fungicide (Manzate, Benlate, Milcurb) are necessary against gummy stem blight and powdery mildew, but only 5 applications of an insecticide (Malathion) are necessary. Fungicides and the insecticide are mixed together. This has tempted the farmers to use the insecticide in all 10 applications. This results in approximately 16.0 Tongan dollars (T$) per acre that the farmer is prepared to pay as an "insurance fee" for his watermelons.

PROBLEMS IN IDENTIFICATION OF EIL AND ETL

Some major topics will be discussed in relation to population (density), damage, and costs of control measures.

Population Dynamics and ETL

These aspects are discussed in Diercks and Heye (1970).

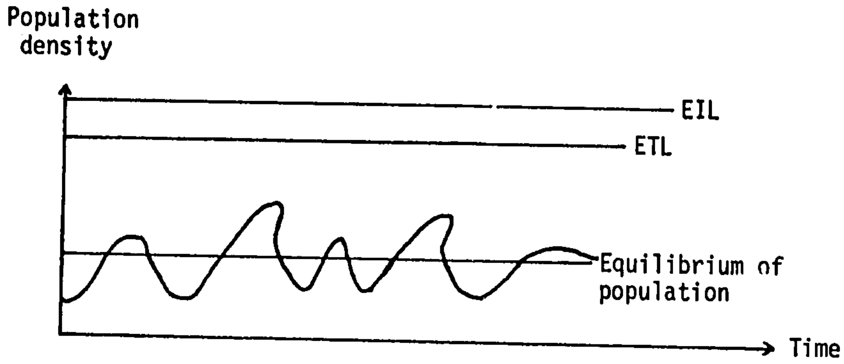
In an ideal situation, all biotic interactions in nature reach an equilibrium. Damage-causing agents are often well balanced with their natural enemies. This well-balanced ecology has been disturbed and will be disturbed further by a growing man/land ratio and growing nations. But, there still are natural constraints to insect pests and diseases causing a damage which is defined by man only.

Environmental factors that decide whether or not the natural equilibrium will be passed by the fluctuations of pest population are:

1. Climatological factors including natural disasters such as cyclones
2. Land utilization including the method of bush clearing and land preparation
3. Cropping intensity including the crop rotation system, cropping sequence, intercropping, etc.

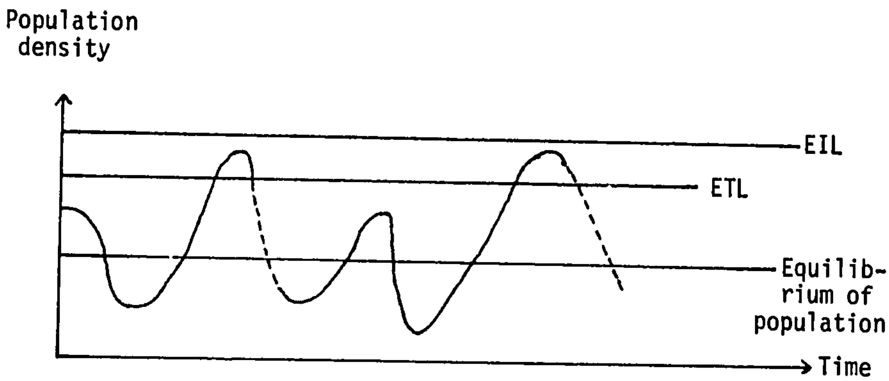
The following typical cases can be distinguished:

Case A



Any control measures initiated in this situation may cause a disturbance of the natural equilibrium which may result in increasing control measures and costs.

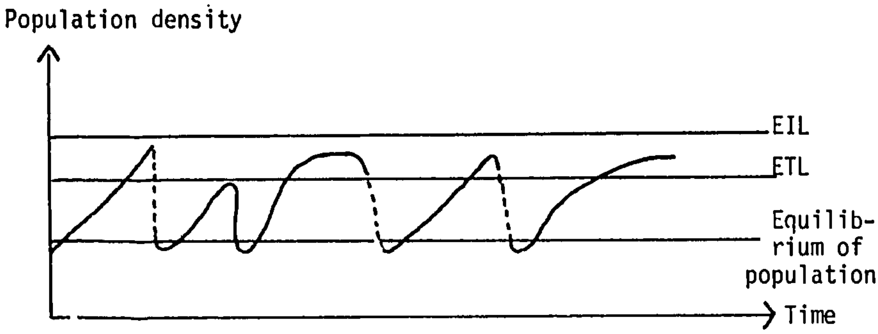
Case B



Here, a control measure is required only twice to reduce the pest below the ETL, and any additional measures may have the same negative (economic) effects as in Case A.

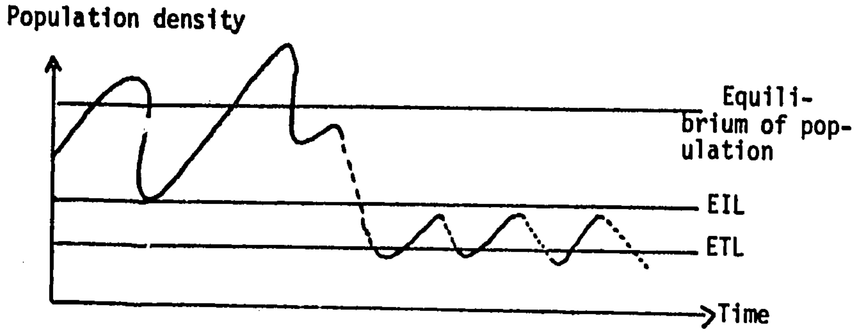
A disturbance of the natural equilibrium may be caused by a slash-and-burn land clearing, a technique which has a devastating impact on the natural enemies of insect pests. Before the natural enemies have had a chance to repopulate, some insect pests such as armyworms, hornworms, and grasshoppers may build up to outbreak levels and cause serious damage to the new crops planted in the cleared areas. The result from slash-and-burn or other ecological disruptions may be the appearance of a "new" pest which did not cause any economic damage at all before.

Case C



In this case, the equilibrium is very near ETL and EIL. The timing of control measures depends largely on the frequency of fluctuations of the population density; thus, in many cases it is a function of climate and ecology.

Case D



After an initial period, a constant control is necessary as EIL and ETL are extremely lower than the equilibrium which is often the case for high value export crops. The equilibrium level of population density does not allow any exports of this crop but may allow a lower yield for domestic consumption (bananas).

HOW TO DETERMINE EIL AND ETL

At first, it seems to be quite easy; investigate the three main independent variables:

1. Costs of control measure
2. Necessary reduction in yield (gross return) to cover the costs of the control measure
3. The corresponding density of pest population related to crop or soil units.

Field trials have to be designed to answer exactly these questions. Approaches are:

1. Crop yield and mortality rate of pest population
2. Capacity of damage per individual pest and different levels of mechanical de-leafing (taro)

3. If one single individual pest destroys a single fruit completely (fruit fly), it is quite easy to establish EIL.

Greater uncertainties are involved if:

1. The period between counting of insect pest and disease levels and the actual damage occurrence is long (armyworms)
2. The precondition to establish EIL/ETL is the determination, e.g., the density of spores in the air (sophisticated measurements are necessary with spore traps).

The above-mentioned three main variables are independent, correlated with each other, and are fluctuating within their system. Thus, EIL and ETL are never constant figures but ranging within certain limitations.

COSTS AND BENEFITS

Fluctuating markets result in changing prices for crops (short term, seasonal, long term); thus, ETL and EIL are influenced accordingly.

The same crop may have different disposal routes (export, subsistence, local market):

Export)	Watermelons, cabbages: for each disposal
Subsistence)	route, different prices → different quality
Local market)	requirements → different EIL

For example, the head cabbage spraying program per acre per crop with Ambush and Lepidex costs approximately 51.0 T$ and 10 man-days labor. This is based on quality standards for the cabbage which were set overseas by the importers.

One crop may have several potential products:

Cassava:

1. Starch factory price (0.05 T$/kilogram)
2. Direct consumption (0.16 T$/kilogram)
3. Fodder (0.09 T$/kilogram).

Or, for example, the production of seed potatoes requires a much lower EIL and ETL than the production of potatoes for consumption.

On the other hand, the costs of control measures vary over time:

1. Material costs
2. Application costs
3. Labor requirement.

Lower material costs and a higher labor productivity allow for a higher EIL and ETL.

ECOLOGY

The ecology is even more important concerning the variability of EIL and ETL. Here, just a summary of the main factors influencing EIL and ETL is given:

1. Soil and climate
2. Variety of crop
3. Fertilizer

4. Density of weeds

5. Secondary insect pests and diseases.

They all determine the gross yield, and together with a typical farmer's situation in respect to his objectives, needs, and availability of production factors it determines his way of growing a particular crop. Thus, his optimal range of gross margin for this crop is determined. A lower EIL and ETL may result in the fact that for this group of farmers it is not economical to grow this crop anymore.

Cropping methods and ecology may also change the tolerance level or even resistance in respect to certain insect pests and diseases. This results in lower EIL and ETL and thus in higher costs. On the other hand, the regeneration capability of a crop may increase in a certain environment; thus, it allows for a higher EIL and ETL resulting in lower costs.

If the costs for plant protection control measures are as high as 43 percent of the variable cost for a particular crop (e.g., bananas, grown for export, in Tonga: 265 T$ for nematode control, black leaf streak, aphid, and scab moth control, compared to a total of 623 T$ variable cost), every improvement resulting in lower costs will have a great beneficial impact on the grower as well as the national economy (Englberger et al., 1982). Because most of the materials used in these control measures are imported, a reduction of material costs of 10 T$/acre each year results in the saving of 10,000 T$ (for 1,000 acres) of foreign exchange earnings. This equals approximately

40 tons of copra exports at a world market price of 250 T$/ton.

LIMITATIONS OF THE EIL/ETL CONCEPT

The establishment of EIL and ETL requires a constant use of computer models and regression analysis based on sophisticated long-term research and a monitoring-forecasting system established over a well-defined homogeneous area. This approach is in most cases not feasible and economically not viable for most South Pacific countries, even on a regional level. Thus, the "intuitive approach" (Dale G. Bottrell) is the more appropriate method for the South Pacific countries.

The intuitive approach allows for the establishment of preliminary EIL ranges including large safety margins to minimize the economical risk. The once established ranges have to be constantly revised because of the nature of the variables determining the EIL and ETL. These levels are never really fixed, and they are by no means absolute figures. As the intuitive approach requires very much experience, the extension agent should contact as many experts as possible. The scientists should work together with other disciplines such as the economist and, in particular, the farm management specialist.

The establishment of EIL and ETL requires a permanent biotechnical learning and understanding of the "rules" of a natural environment (ecology) by the extension agent.

REFERENCES CITED

Diercks, R. and Ch. Heye. 1970. Notwenoligkut unol Problematik der Ermittlung von Schadensschwellen Werten. Zeitschrift Pflanzinkrankheiton und Pflanzenschutz, 11/12/70: 610-627.

Englberger, K., R. Rathey, and M. Daysh. 1982. Banana Production in Tonga, Department of Agriculture, Technical Bulletin No. 4, Tonga, p. 55-63.

Reisch, E. and J. Zeddies. 1977. Eimfuhrung in die landwirtschaftliche Betriebslehre, Banol 2: Spezieller Teil, Stuttgart, p. 161-72.

Stern, V. M., R. F. Smith, R. van den Bosch, and K. S. Hagen. 1959. The integrated control concept. Hilgardia 29:81-101.

Date: Oct. 8
Time: 1325

EXAMPLES OF CASE HISTORY STUDIES INVOLVING THE ANALYSIS OF THE ECONOMIC STATUS AND DETERMINING THE NEED FOR CONTROL

Dale G. Bottrell

INTRODUCTION

Other papers at this training course discussed economic aspects of crop protection and introduced the concept of the economic threshold (refer to the papers, Analysis of the Economic Status of Diseases, Insects, and Other Pests in Question by Dale G. Bottrell, and The Concept of Economic Injury Level and Economic Threshold Level in View of Economics in Crop Production by Rainer Rathey). As noted in the first paper, the economic threshold is the "keystone" of integrated pest management (IPM), an approach to pest control discussed at this training course by W. C. Mitchell: Definition, Objectives, and Features of Integrated Pest Management. The economic threshold is defined as the population level at which a reputedly harmful organism has just attained "real" pest status. In other words, it is the density of the population below which the cost of applying control measures exceeds the losses caused by the pest (Stern, 1973; Glass, 1975).

This paper discusses various procedures that have been used to determine the economic status of pest organisms, as required to establish the economic thresholds and to pinpoint when and where use of a remedial control is truly justified. There has been little published on these aspects of pest control in the South Pacific. Therefore, this paper discusses various approaches that have been taken with pests and crops in other regions. The general approaches reviewed here are applicable in this region, although they must be modified to account for the local pests and cropping conditions.

DETERMINING THE RELATIONSHIP OF PEST DAMAGE AND CROP LOSS--GENERAL PROCEDURES

There are no standard procedures for determining the relationship of pest damage (or pest infestation) level and crop loss, as required to establish the economic threshold. Some of the commonly used techniques are discussed.

Small Plot Techniques

A common procedure in insect and weed studies involves the use of small experimental field plots, situated side by side, each subjected to a different level of pest density. Different levels of pest attack are achieved by artificially infesting the plots (e.g., infesting plants in the field with insects reared in the laboratory) or by controlling the densities of the natural infestations. Probably the best known method is the use of small, replicated experimental plots that become naturally infested with insect pests or weeds; each plot receives a different level of pesticide treatment, usually producing from 0 to 100 percent control. Although this method has wide application, it has certain drawbacks.

One drawback relates to the effect of the pesticides on the plants. Some systemic insecticides may produce increased yields, independently of their effect on the insect infestations. Other pesticides may be phytotoxic and may cause yield losses.

Another drawback relates to the drift of the pesticides between plots, especially when insecticidal sprays are used. The insecticidal drift may not be sufficiently potent to kill the pests in the untreated plots, but it may kill insect natural enemies residing in them and thus unleash the pests that the natural enemies regulated; this would give treated plots a yield advantage over the untreated plots. Barriers (plastic screening, etc.) suspended between the plots may sometimes be effective in reducing the problem of drift.

To get realistic results, the experiments should be conducted in farmers' fields, situated in areas protected from any pesticide treatments that the farmers may apply to the non-experimental areas. All variables (e.g., soil fertility, crop variety and age, irrigation level, and tillage) but the techniques being used to vary the level of pest infestation should be held constant in the experimental plots (Stern, 1973). The samples must be sufficiently large and must be taken uniformly over the plots. Small samples may suffice if the pests are uniformly distributed over the field and plant growing conditions are uniform. Lack of uniformity in distribution creates special problems when establishing economic thresholds for nematodes

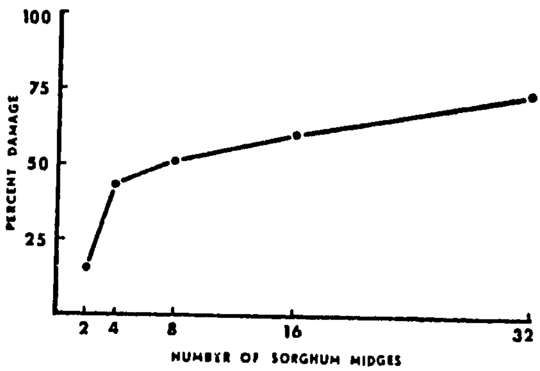
(Barker and Nusbaum, 1971).

Cage Technique

The cage technique has been used many times in studies to establish economic thresholds for insects. The technique involves confining whole plants or plant parts (cereal grain heads, plant leaves, etc.) in wire or cloth screen cages and introducing the desired range of pest numbers into the cages. Cate (1969) found the use of cloth sleeve cages to be quite useful in studies conducted to establish the economic threshold for the sorghum midge (*Contarinia sorghicola*) on field grain sorghum. He caged from 2 to 32 adult female sorghum midges per head of the blooming grain sorghum plants. (Female midges lay eggs in spikelets of flowering sorghum heads, and larvae hatching from the eggs devour the developing florets.) Data showed that two midges per head probably caused sufficient damage to warrant control, and 32 per head resulted in damage to nearly 75 percent of tne florets (Figure 1).

The cage technique has some obvious limitations. For example,

FIGURE 1: Relationship of sorghum midge density (number per grain sorghum plant throughout blooming stage) and damage to the grain florets, based on field cage studies (Cate, 1969)



the cages may drastically change the microclimate around the plants, interfering with their normal growth, and they may interfere with the pests' normal behavior--feeding patterns, etc. Also, the cages may exclude natural enemies that would operate on the pests under natural conditions. Experience has shown that for pests that have effective natural enemies, economic thresholds cannot be properly established or used without proper consideration being given to the presence of these beneficial organisms.

Simulated Damage

Numerous investigators have attempted to simulate pest injury by removing or injuring leaves or other plant parts. Simulation techniques have been devised to mimic injury by insects, diseases, and rodents, for example, and have wide application.

Poche' et al. (1981) reported on a field study which simulated rat damage to IR-8 rice in Bangladesh. The damage was simulated by cutting the rice stems with a sharp instrument. Rice fields were subjected to four simulated damage levels: 0 (control), 10, 25, and 50 percent of the stems cut. A modified splitplot sampling design was used with ten plots (each one-square meter) receiving each damage level in three growth stages: tillering, booting, and maturity. Results were as follows: cutting stems of the tillering rice did not significantly reduce the harvest yields, but cutting even 10 percent of the stems of booting or mature rice significantly reduced the yields. Poché et al. (1981) therefore concluded that rat control should not begin before the booting stage.

This example illustrates the importance of the effect of plant maturity when establishing economic threshold levels. The economic thresholds are rarely static over time; they usually must be adjusted to account for seasonal changes in crop growth.

Techniques of simulation may not realistically mimic the damage caused by some pests. For example, some insects inject toxins into the plants, a process which is not easily mimicked. The damage simulation techniques should be used only after the behavior and ecology of the pests and their interactions with the plants are reasonably well understood and experience shows that the simulations are realistic.

Quantitative Models

Mathematical models of plant growth, crop yield, and pest population dynamics offer much potential in sharpening the approach to the establishment of economic thresholds. Computer models that provide a theoretical explanation for the self-limiting effect of injurious or competitive organisms on crop yields have been developed for a number of crop/pest situations. However, nearly all of the work on crop/pest modeling has been done in the developed countries. The developing countries rarely have the resources required to develop sophisticated computer models.

The "Intuitive" Method

Often, economic thresholds can be tentatively based largely on scientific intuition. Familiarity with the growth characteristics of the crop plants and the population dynamics of the pests are important first steps. In fact, economic thresholds being used today in some of the most highly effective integrated pest management programs in the USA were initially derived mostly from trial and error, intuition, and "guesswork"--not hard data. Even crude thresholds are better than none, especially for sporadic pests and those to which the crop plants have a reasonably high tolerance. The crude thresholds can always be refined as additional data become available and the farmers gain experience using the thresholds.

INTERPRETING THE RESULTS

To compute economic thresholds from the experimental data requires regression of yield reduction on pest population level. If y represents a loss (expressed as a percentage of crop yield, for example) and x the pest population level (e.g., number of pests per meter of plant row, per 100 plants, or per hectare) or the plant damage level (e.g., percentage of leaf area damage, percentage of stems damaged), then in its simplest form, the relationship would be linear; in other words the level of loss would be directly related to the level of the pest population or pest injury. For example, when x is 1 and y 10 (10 times greater than x), then when x is 1.1, y is 11 (still 10 times greater than x) and so on. However, levels of pest damage and crop damage may not be--and, in fact, often are not--perfectly correlated and the relationship of plant damage and yield reduction may not be linear.

It is useful to seek advice of statisticians, crop physiologists, and others who may assist in designing the experiments to establish economic thresholds and in interpreting the results. It is particularly important that crop economists are contacted. They should be taught the principles of economic thresholds and should be consulted about the economic realities of threshold values which are to be adopted by the farmers.

However, the crop protection specialists should not let the statisticians or the other disciplines do their "biological thinking" for them. The crop specialists must ultimately decide what economic threshold levels should be used on the farmers' fields.

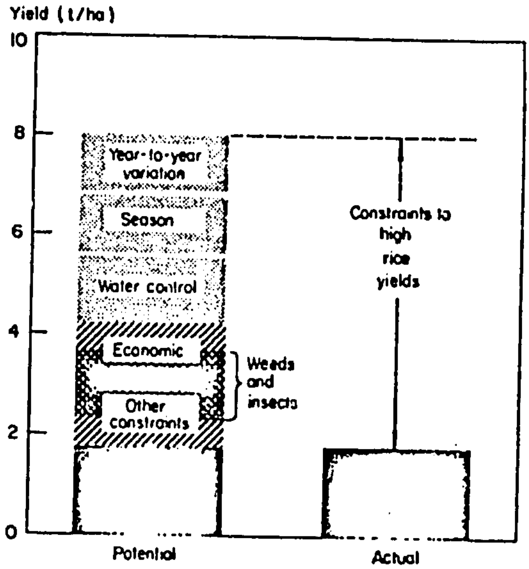
Several factors may complicate the interpretation of the data from which the economic thresholds are established. One of the problems is that of separating the damage of pest species A from B, C, or D, and so on, when all species attack the crop plants simultaneously. Also, the question arises: do unattacked plants residing next to attacked plants produce a compensatory yield? These and other factors should be taken into account when designing the experiments and interpreting the results. Statisticians, again, should be consulted, and computer models may be of value; but neither statisticians nor models are a substitute for common sense, keen observation, and carefully planned ecological investigations of the pests in the crop environments.

Separating crop losses caused by pests from crop losses caused by other constraints such as weather, soil fertility, and poor management--that is, explaining the gap between "potential" and "actual" crop yields, is another problem. As shown in Figure 2, pests, (weeds and insects) are just one of several major factors that keep the actual rice yields in the Philippines (about two tons per hectare) well below the potential yields (about eight tons per hectare).

USING THE ECONOMIC THRESHOLDS ON FARMERS' FIELDS

Research efforts to establish economic thresholds are wasted unless the end product is used successfully by the farmers. Researchers and extension workers must translate the research information into information that the farmers can understand and use without difficulty. The best way to expose farmers to the use of economic thresholds in integrated pest management is through "pilot" demonstrations conducted on the farmers' fields. Demonstrations showing how to use the economic thresholds and the IPM techniques should be a continuing activity; as new information and techniques become available, they should be used to upgrade the "prototype" IPM scheme being demonstrated. There should be a concerted effort to make these demonstrations highly visible and accessible to the farmers. Experience in many parts of the world shows that pilot demonstrations, conducted under conditions familiar to the farmers, are the single most effective way to get the farmers to adopt IPM on their farms.

FIGURE 2: Factors constraining rice yields in the Philippines (Herdt and Wickham, 1978)



To the farmer or extension agent, an economic threshold is merely a gauge to determine the need for remedial control measures, usually the application of a pesticide. Monitoring the pest populations and the natural control factors can establish the need, or lack of need, for these measures. Population monitoring is conducted in a variety of ways. The most common method consists of field surveys conducted by extension agents or the farmers themselves. When the surveys show that a pest population is rising to damaging levels, despite the presence of natural controls or the use of a pest management technique such as a pest-resistant crop variety, steps may be necessary to prevent significant crop damage.

ECONOMIC THRESHOLDS FOR PESTS OTHER THAN INSECTS

The term economic threshold was first articulated by entomologists (Stern et al., 1959). It gained considerable attention as an "insect management" concept before integrated pest management came to include all classes of pests.

Work on economic thresholds for nematodes, plant pathogens, and weeds has progressed less rapidly than for insect pests. Control of nematodes, plant pathogens, and weeds has been approached largely by preventive means, i.e., using pest-resistant varieties and crop rotation to control nematodes and plant pathogens and using preventive herbicide treatments, tillage, and crop rotation to control weeds. Thus, until recently little thought was given to the use of economic thresholds for control of most of these pests. Plant pathologists are now beginning to think seriously about the use of economic thresholds (Main, 1977). The development of economic thresholds for weed pests has received some attention. The value of information on the effect of weed density on crop yields is illustrated by the following example.

The giant foxtail (Setaria faberi) is considered one of the worst weeds of maize in the USA (NAS, 1975). As an aid to reduce losses by this pest and to facilitate proper control, the University of Illinois developed the following guidelines.

To figure yield losses:

1. Estimate potential yield of maize if field were free of weeds
2. Count giant foxtail plants per linear 30 centimeters of row at several locations in the field. Determine the average weed density
3. Using the data of Table 1, calculate expected yield losses from the weed pest. For example, if the potential yield is 62.6 quintals of maize per hectare and the density of giant foxtail averages 50 plants per linear 30 centimeters of row, then a yield loss of 25 percent (see Table 1) or 15.6 quintals would be expected.

The economic threshold for giant foxtail is very low, as apparent from Table 1. For pest species that have low economic thresholds, the pest monitoring program selected is particularly important. The monitoring techniques must be sensitive to slight

TABLE 1: Effect of giant foxtail on maize yields

Number of Weeds Per 30 Centimeters	Expected Reduction in Maize Yield (Percent)
1	8
3	9
6	12
12	16
50	25

SOURCE: Cooperative Extension Service, University of Illinois (unpubl. leaflet) changes in the pest population density so as to give the farmers or extension agents ample warning that the pests are approaching economic threshold levels. In the case of giant foxtail, the maize farmers may profit from the use of remedial measures (post-emergence herbicides or cultivation techniques) when they find an average of less than one weed plant per 30 linear centimeters of row.

REFERENCES CITED

Barker, K. R., and C. J. Nusbaum. 1971. Diagnostic and advisory services, p. 281-301. In B. M. Zuckerman, W. F. Mai, and R. A. Rhode (Eds.), Plant parasitic nematodes, Vol. 1, Academic, New York.

Cate, J. R., Jr. 1969. Texas A&M Univ., Tex. Agr. Exp. Sta. (unpublished report).

Glass, E. H. 1975. Integrated pest management: rationale, potential, needs and implementation. Entomol. Soc. Amer. Spec. Pub. 75-2.

Herdt, R. W., and T. H. Wickham. 1978. Exploring the gap between potential and actual rice yields: the Philippines case p. 3-29. In Economic consequences of the new rice technology. Int. Rice Res. Inst., Los Baños.

Main, C. E. 1977. Crop destruction--the raison d'être of plant pathology, p. 55-78. In J. G. Horsfall and E. B. Cowling (Eds.). Plant disease: an advanced treatise. Vol. 1. How disease is managed. Academic, New York.

National Academy of Sciences. 1975. Pest control: an assessment of present and alternative technologies. Vol. II. Corn/soybeans pest control. Washington, D.C.

Poché, R. M., M. E. Haque, M. Y. Mian, P. Sultana, and M. A. Karim. 1981. Rice yield reduction by simulated rat damage in Bangladesh. Tropical Pest Manage. 27:242-246.

Stern, V. M. 1973. Economic thresholds. Annu. Rev. Entomol. 18:259-280.

Stern, V. M., R. F. Smith, R. van den Bosch, and K. S. Hagen, 1959. The integrated control concept. Hilgardia 29:81-101.

Date: Oct. 8
Time: 1500

FIELD DEMONSTRATION OF RESEARCH TO ESTABLISH ECONOMIC THRESHOLDS FOR TARO INSECT PESTS AND RESEARCH ON CHEMICAL CONTROL OF SWEET POTATO DISEASE ORGANISMS

Coordinated by

K. Englberger and P. Vi

The Tonga-German Plant Protection Project has several field studies at the Experimental Farm at Vaini to determine the economic feasibility of pesticide use on crops and to pinpoint when and where use of pesticides is truly justified. At this field demonstration, the course trainees learned about the procedures being used in these studies and observed the field plots where they are being carried out.

Mr. Englberger explained the studies to establish economic threshold values for the taro armyworm: armyworm damage to leaves of the taro plants is being simulated by hand removing (cutting) different portions of the leaves in different plots. The artificial simulation technique was found necessary because natural infestations of armyworms often do not reach high levels on the Experimental Farm. The "pros" and "cons" of the technique were discussed. It was pointed out that the simulation probably does not realistically mimic the armyworm's feeding on the taro leaves. The armyworms tend to feed between the leaves' lateral veins and do not necessarily restrict their feedings to any one portion of a leaf. The simulated damage, on the other hand, is confined to the first half or so of the distal portion of the leaf, and it results in removal of the lateral veins. In any case, the demonstration spawned some good discussions and pointed up the need for more research on economic thresholds of the taro armyworm.

Ms. Vi discussed her work on chemical control (with fungicides) of several species of fungi attacking sweet potato. She is studying the effectiveness of several fungicides on several varieties of sweet potato exhibiting various degrees of fungal resistance and yield potential. The course participants asked many questions concerning evaluation of the results as required to establish economic threshold values.

Date: Oct. 11
Time: 0945

CULTURAL CONTROL IN MODERN PRACTICE

Dale G. Bottrell

INTRODUCTION

Cultural control is the deliberate manipulation of the environment to make it less favorable for pests by disrupting their reproductive cycles, eliminating their food, or creating an environment favorable for the pests' natural enemies. Many procedures, such as strategic scheduling of plantings, tillage, irrigation, harvesting, and fertilizer applications, crop rotation, destruction of wild plants harboring pests that disperse to crops, and use of pest-free seed and planting stock, can be employed to achieve cultural control. One of the oldest and most effective methods of pest suppression, cultural control is widely applicable in integrated pest management--IPM (refer to the training course's paper, Definition, Objectives, and Features of Integrated Pest Management, by W. C. Mitchell, for a discussion of the IPM concept).

Many cultural practices are simple, inexpensive, and easily adopted by individual farmers, with only slight modification of routine operations. Yet successful implementation of some requires participation over a large geographical area and their adoption may require the assistance of government services (Stern et al., 1976).

Successful use of cultural control requires a knowledge of the crop--its growth characteristics, agronomic practices, and harvesting procedures--and also of the biology and ecology of the pests and their natural enemies. With this knowledge, the IPM specialist then seeks to find agronomic practices that will réduce the pest population numbers and damage.

The change in agronomic practice obviously should not lead to other problems. A cultural practice that effectively reduces one pest problem but creates or intensifies another pest problem or proves to be agronomically unsound in the long term would be self-defeating. The cultural practices must be carefully tested under actual farming conditions and then carefully synchronized with and integrated into the farmers' crop production systems. Successful synchronization and integration requires an interdisciplinary team approach--pest control specialists, agronomists, and other relevant disciplines cooperating with the farmers and focusing on the cropping system as a whole.

The following are just a few examples of the diverse ways in which cultural control can be used.

CROP ROTATION

Much has been learned about preventing pests from becoming seriously destructive in cultivated fields by following the principles of good crop rotation; a crop of one plant family is followed by one from another family that is not a host crop of the pest to be controlled. One of the oldest methods of pest control, crop rotation is most effective against pests with a restricted plant host range and, for insects, those with limited capability to disperse.

Crop rotation is one of the most important measures for controlling plant-parasitic nematodes and is currently the only economical method for controlling some of these pests (Good, 1972). It is a long-established practice to reduce the severity of soil-borne fungi and bacteria (Zentmyer and Bald, 1977). The method is very effective in reducing weeds, but the effectiveness and economy of herbicides have relieved farmers in many areas from the strict necessity to practice crop rotation for this purpose.

Traditional farmers in many developing countries routinely rotate grain legumes (e.g., mung bean, cowpea) or vegetables with cereal grains such as rice and maize. Through trial and error and generations of experience, they know that the rotations increase their yields. Part of the yield increase probably results from the rotations' damaging effects on the pests, but the real effects have not been well documented in the developing countries.

In Peru before the arrival of the Spanish, the Inca Indians had a 7-year rotation for potatoes which was enforced by law. Through trial and error, the Incas must have learned that this rotation gave the best potato crops. It is now known that the destructive potato cyst nematodes (*Globodera pallida* and *Globodera rostochiensis*) occur in extremely high levels in most potato-growing areas of the Peruvian Andes where the 7-year rotation is not practiced. Where the 7-year rotation is practiced, the potato cyst nematodes occur at lower, nondamaging levels (Glass and Thurston, 1978).

Like other pest control techniques, crop rotation has some limitations. If herbicides are used for weed control, the possibility of toxic residues carrying over from one crop to the next has to be taken into consideration. Often, populations of pests other than the target pest increase on the alternate crop. Some crops used in rotation are often of such low value that they contribute little to farm income. Further, alternate crops may require additional farm machinery. Nonetheless, rotation is frequently a useful pest control technique and has an important place in many IPM schemes (Glass, 1975).

TIME OF PLANTING AND HARVESTING

Control of some crop pests can be achieved by manipulating the date of planting or harvesting the crop so that the susceptible stage of the crop coincides with a time when the pests are least abundant (or when the pests' natural controls are most abundant).

By changing or carefully selecting the time when a crop is planted, the farmer may avoid the egg-laying period of a particular insect pest; get young plants well established before the heavy pest infestations develop; or shorten the period that a crop is susceptible to pest attack.

In many cases, losses to pests can be greatly reduced by harvesting early, especially when near-damaging infestation levels are noted as the crop reaches maturity. Early-harvest practices have been useful against the sugarcane borer (*Diatraea saccharalis*), sweet potato weevil (*Cylas formicarius elegantulus*), potato tuberworm (*Phthorimaea operculella*), pea weevil (*Bruchus pisorum*), cabbage looper (*Trichoplusia ni*), imported cabbage worm (*Pieris rapae*), and many other insect pests (Flint and van den Bosch, 1981). These practices may be useful not only in protecting the current crop but also reducing the numbers of pests available to infest the next crop.

SANITATION AND DESTRUCTION OF ALTERNATE HOSTS AND VOLUNTEER PLANTS

This approach involves the removal or destruction of breeding refuges, shelter, or resting sites utilized by pests. The method has been successful against many diseases and insect pests on a variety of crops (Glass, 1975; Zentmyer and Bald, 1977). Destruction of maize harvest residues has reduced populations of the European corn borer (*Ostrinia nubilalis*) and various stalk borers (e.g., *Diatraea lineolata*). In China, the upper parts of the maize plants are cut from the plants just prior to maturity and used for animal food. After harvest, the remaining plant residues are chopped and plowed under, or used as fuel. The Chinese have developed numerous other sanitation methods that are used widely today against a variety of insect pests (NAS, 1977). Removing diseased plants (rogueing, pruning infested parts, and removing or chemically treating plant material containing disease organisms) have been successful in plant disease management (Zentmyer and Bald, 1977).

Crop-free periods are sometimes necessary to prevent the continuous multiplication and spread of viruses, especially in the case where herbaceous crop plants are grown all year. Successful control of virus diseases of lettuce and crucifers requires a crop-free period (Glass, 1975).

Field borders, ditch banks, and other areas surrounding the crops are often important sources of pests, and destruction and removal of debris from them may reduce the pest problems. However, these areas may also harbor beneficial species--pollinators, insect predators and parasites, and wildlife. Therefore, the desirability of this approach must be carefully evaluated for each pest situation (Glass, 1975).

Pest populations may often be effectively suppressed by destruction of their alternate plant hosts (i.e., their secondary hosts, weeds, or volunteer crop plants). This technique, in effect a weed control, has been more effective against plant diseases than other pests.

MIXED AND ROW INTERCROPPING

Multiple cropping, typical of the more traditional, less productive systems of agriculture, involves the use of many crop species planted in a scattered or staggered pattern, as discussed by

J. A. Litsinger, Environmental Diversity and Insect Pest Abundance with Reference to the Pacific, at this training course. Litsinger and Moody (1976) cited examples which show that some pest problems are less destructive in the intermixed crops than in crops grown in monoculture. For example, intercropping of maize and groundnut (peanut) reduces the corn borer Ostrinia furnacalis in maize in the Philippines (R. S. Raros, unpublished data, cited in Litsinger and Moody, 1976; IRRI, 1974). In the Congo Basin, maize and cucurbits are intercropped because the cucurbits shade out the weeds and help to conserve moisture (Miracle, 1967).

The growing of maize, beans, and squashes together--a system developed by Pre-Colombian American Indians--facilitates effective weed control (Mangelsdorf, 1974). The beans climb and twine on the stalks of maize, exposing their leaves to the sun without drastically shading the leaves of the maize plants, and the squash vines spread out over the ground between the hills of maize, choking out weeds.

Increasing crop diversity can sometimes be used to increase insect predator and parasite populations in a given crop. In the cited example of a maize-peanut intercropping system in the Philippines, predatory spiders (Lycosa spp.) were more effective against the corn borer in maize being intercropped than in maize grown by itself (R. S. Raros, unpublished data, cited in Litsinger and Moody, 1976; IRR, 1974). Because of their greater diversity, mixtures of crops may create more ecological niches for harboring fauna such as predators and parasites. If intercropping favors these beneficial forms, integrated pest management will gain (Litsinger and Moody, 1976). However, wrong intermixes can increase pest problems on one or more of the intermixed crops. Therefore, the advantages of the practice must be carefully weighed against potential harmful side effects (Smith and van den Bosch, 1967).

TILLAGE

Tillage is a time-honored method for controlling many weed species. However, in many crops in many areas the practice is rapidly being replaced with herbicides because they may be easier, less energy intensive, and more profitable over the short run. Herbicides also eliminate soil erosion, soil compaction, water loss from the soil, and pruning damage to the crop plants' roots, problems often associated with tillage (Day, 1978).

Yet, tillage remains one of the most effective weed controls and also can be used effectively against a variety of insect pests, plant pathogens, and nematodes. With soil tillage, the pests are killed by mechanical injury, starvation through debris destruction, desiccation, and exposure. Tilling the soil may expose various soil-inhabitating pest insects, making them easy targets for insectivorous birds, thus enhancing biological control.

WATER MANAGEMENT

Water management procedures (e.g., timing of irrigation, flooding, drainage) based on a sound understanding of pest biology may provide economical and effective control of some pests. Careful control of irrigation water is one of the most effective ways for controlling soil pathogens. Flooding of fields has been used to control some root-infecting fungi. In some cases, reduced irrigation or rainfall prevents root knot nematode (Meloidogyne spp.) eggs from hatching, thereby reducing larval invasion of the crop roots (Van Gundy, 1972). Management of irrigation water can also reduce certain weed problems (Glass, 1975). Flooding, which has been practiced by every rice-paddy farmer in Asia for the last several thousand years, evolved in rice, in part, as a means to control weeds and probably also pest fungi, insects, and nematodes (Glass and Thurston, 1978).

FERTILIZER MANAGEMENT

The use of fertilizer may be an important factor in the development of pest populations. The fertilizer may have either a stimulating or a depressing effect. High levels of nitrogen in a fertilizer generally have a stimulating effect on the pests, and may increase their severity; avoidance of excess nitrogen fertilizer therefore may reduce such pests. For other pests (especially weeds), an extra amount of fertilizer may speed up the crop's growth, allowing the crop to "outrun" the pest populations or to be more tolerant to them.

TRAP CROPS

The practice of attracting pests to small plantings of crops which are then destroyed or sprayed with a toxicant has been quite successful against some plant nematodes, parasitic weeds, and insect pests (Flint and van den Bosch, 1981).

In Hawaii, squash and melon fields are often surrounded by a few rows of corn which attract large numbers of the melon fly (*Dacus cucurbitae*), a major insect pest of melons and squash. Treatment of the corn "trap" plants generally controls the flies, leaves no insecticide residues on the melon or squash crop, and is harmless to natural enemies of the crop plants (van den Bosch and Messenger, 1973).

Some nematodes may be controlled by trap crops. Highly susceptible crops are allowed to grow in infested fields until the second stage larvae enter the roots and begin to develop. Before the nematodes mature, the plants are destroyed. However, plant destruction must be properly timed and implemented or the nematode population may increase manyfold (Glass, 1975).

A major limitation of the trap-crop technique is the expense of producing and destroying a crop that brings no income.

USE OF PEST-FREE SEED AND PLANTING STOCK

Planting stock that harbors nematode pests is shipped all over the world, and many weed species have been spread extensively in crop seed. Many farmers continue to plant nematode and virus-infected transplants or seed pieces of crops such as sugarcane, sweet potato, strawberry, and tobacco. Yet, the use of pest-free seed and planting stock is one of the most effective and economical methods of pest control (Glass, 1975).

When contaminated seed and planting stock are introduced into an area, all of the farmers may be affected. Therefore, legal enforcement to prevent the introduction of contaminated material into a pest-free area may be appropriate.

WEED MANIPULATIONS

Because weeds can cause heavy losses to crops and their control may result in significant yield increases, their positive role is seldom considered. There are situations, however, in which they are advantageous in cropping systems (Zandstra and Motooka, 1978). For example, effective biological control of some insect pests depends on the presence of weeds which serve as reservoirs of parasites and predators that prey on the insect pests. Giant ragweed (Ambrosia trifida) is a host plant of the stalk borer Papaipema nebris. Both the stalk borer and the European corn borer (Ostrinia nubilalis), insect pests of maize, are attacked by the insect parasite Lydella grisescens. Hsiao and Holdaway (1966) found that the first generation of the European corn borer normally appeared too late in the season to host significant numbers of the parasite. However, the presence of giant ragweeds infested with Papaipema nebris allowed an early building up of parasites and also a significant increase in level of parasitization in second, third, and fourth generations of the European corn borer.

Zandstra and Motooka (1978) reviewed beneficial effects of weeds. They recommended that weed scientists and other crop protection scientists cooperate in studying the relationships between pests, "beneficial" weeds, and crops and devise cultural systems to maximize the benefits of potentially advantageous weed species.

CONCLUDING REMARKS

The list of other cultural methods, some of which are discussed in various papers presented at the training course, is almost endless. Even subtle manipulations in the cropping system--such as small changes in row crop density or distance between plant rows--may cause a rather drastic shift in the status of pest species in a crop. The manipulations may productively affect a damaging pest, but they may also permit establishment of new pest hierarchies. The goal with any of the cultural practices should be to manipulate the cropping systems in such a way to hold the target pests to tolerable levels while avoiding disruptions of these systems.

REFERENCES CITED

Day, B. E. 1978. The status and future of chemical weed control, p. 203-213. In E. H. Smith and D. Pimentel (Eds.), Pest control strategies. Academic, New York.

Flint, M. L., and R. van den Bosch. 1981. Introduction to integrated pest management. Plenum, New York. 240 p.

Glass, E. H. 1975. Integrated pest management: rationale, potential, needs and implementation. Entomol. Soc. Amer. Spec. Pub. 75-2.

Glass, E. G., and H. D. Thurston. 1978. Traditional and modern crop protection in perspective. BioScience, 28:109-115.

Good, J. M. 1972. Bionomics and integrated control of plant parasitic nematodes. J. Environ. Quality 1:382-386.

Hsiao, T. H., and F. G. Holdaway. 1966. Seasonal history and host synchronization of Lydella grisescens (Diptera: Tachinidae) in Minnesota. Annu. Entomol. Soc. Amer., 59:125-133.

IRRI. 1974. IRRI annual report for 1973. Los Baños, Philippines.

Litsinger, J. A., and K. Moody. 1976. Integrated pest management in multiple cropping systems. Multiple cropping, Amer. Soc. Agron. Spec. Pub., 27:293-316.

Mangelsdorf, P. C. 1974. Corn--its origin, evolution and improvement. Belknap Press of Harvard Univ., Cambridge.

Miracle, M. P. 1967. Agriculture in Congo Basin. Univ. Wisconsin Press, Madison.

National Academy of Sciences. 1977. Insect control in the People's Republic of China. CSCPRC Rep. No. 2. Nat. Acad. Sci.

Smith, R. F., and R. van den Bosch. 1967. Integrated control, p. 295-340. In W. W. Kilgore and R. L. Doutt (Eds.), Pest control--biological, physical, and selected chemical methods. Academic, New York.

Stern, V. M., P. L. Adkisson, O. Beingolea, and G. A. Viktorov. 1976. Cultural controls, p. 593-613. In C. B. Huffaker and P. S. Messenger (Eds.), Theory and practice of biological control. Academic, New York.

van den Bosch, R., and P. S. Messenger. 1973. Biological control. Intext, New York.

Van Gundy, S. D. 1972. Nonchemical control of nematodes and root-infecting fungi, p. 317-329. In Pest control strategies for the future. Nat. Acad. Sci., Washington, D.C.

Zandstra, B. H., and P. S. Motooka. 1978. Beneficial effects of weeds in pest management--a review. PANS, 24:333-338.

Zentmyer, G. A., and J. G. Bald. 1977. Management of the environment, p. 121-144. In J. G. Horsfall and E. B. Cowling (Eds.), Plant disease: an advanced treatise. Vol. I. How disease is managed. Academic, New York.

Date: Oct. 11
Time: 1330

USE OF DISEASE RESISTANT VARIETIES

Paul van Wijmeersch

INTRODUCTION

Economic pressure for more food in the heavily populated European countries stimulated the investigation of diseases and their control. Work by Prevost and De Bary dates from the latter half of the nineteenth century. The rediscovery in 1900 of Mendel's laws of heredity (1866) and their application to genetics soon offered new techniques for disease control. The difference in disease reaction of specific varieties and specialization of fungi, first recognized by Eriksson and Ward and later studied in detail by Salmon, Freeman, and others, directed attention to disease resistance as a control measure.

Early examples of the development of plant resistance by selective breeding include potato varieties resistant to *Phytophthora infestans* and, in the early 1920s, the selective breeding of new wheat varieties resistant to the Hessian fly (Bottrell, 1979).

During the last thirty years, the advances in this field have given disease resistance top priority in the improvement of field crops. An estimated 75 percent of U.S. cropland utilizes disease resistant varieties developed during the past 50 years. Returns from investments in the development of disease resistant varieties probably exceed $1 billion annually in the United States alone (NAS, 1975).

TERMINOLOGY

"Resistance" can be defined as having "less disease" while total resistance (immunity) is a clearly defined condition of "no disease;" resistance is always manifested on a scale relative to something else, in most cases the most "susceptible" variety (Simmonds, 1979).

"Tolerance" is also sometimes used to describe a type of resistance. Tolerant plants, by rapidly repairing or overcoming injury, have the ability to survive and perform satisfactorily at levels of infection that cause unacceptable losses to other plants of the same species. Tolerance does not depend on the ability to limit the growth and development of the pathogen.

GENETICS OF RESISTANCE

Genotype, Phenotype, Major Genes, Polygenes, and Expression of Resistance

The "genotype" (genetic constitution of total of genes) is responsible for inherited characteristics of a species and determines the tendency of the organism to react in a particular way to a certain environment. The result of the interaction between the genotype and the influences of the environment is the "phenotype." The phenotype is thus what is observed by the breeder. Two plants with exactly the same genotype can have a different phenotype because of different environmental influences.

When variation is due to one or a few major genes, these major genes have a sharp, consistently identifiable phenotypic effect (e.g., color). When it is due to many genes (polygenic variation), the individual genes involved have a small phenotypic effect.

True resistance is a genetic characteristic but is influenced to a greater or lesser extent by various environmental factors, some affecting the plant and some concerning the pathogen. Disease resistance is determined in part by morphological and physiological processes in the plant The morphology and physiology of the plant are governed by the genotype but are still influenced by environmental factors, such as weather conditions, soil fertility, and soil moisture content

Specific and General Resistance

In specific or vertical resistance mechanisms, the resistance is due to one or a few major genes, is mostly dominant, absolute (resulting in immunity or near immunity), and usually pathotype-specific *

From the plant breeding point of view, specific or vertical resistance is very attractive because of the immunity it seems to offer. Moreover, it is quite obvious that in most cases breeding for one or a few major genes is easier than for polygenes. This mechanism has, however, some major disadvantages:

Firstly, as the resistance is only due to one or a few major genes, the chances of a breakdown of the resistance by mutation

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* Pathotype-specific: a pathotype, e.g. Phytophthora infestans, has different strains which differ in performance on specific host genotypes. They are said to differ in virulence. A pathotype is a strain which has more or less defined virulence characteristics.

or recombination of genetic information in the pathotype is very high. Only very few examples can be given of specific resistance being long lasting. Usually it does not last longer than a few years, especially in the case of air-borne fungal pathogens. The reason is quite obvious. The pathogenic organisms have enormous potential for developing new virulent forms. Well documented examples of resistant varieties succumbing to a new strain of a pathogen are stem rust of wheat and late blight of potatoes. Moreover, if large acreages of highly resistant crop are planted, natural selection is applied to the pathogen so that any potential genetic change that could result in virulence has a highly selective advantage (Welsh, 1981).

Secondly, specific resistance does not protect the plant against an attack by other diseases which, although they were of little economic importance or even unknown in the past, become epidemic. Frequently, the replacement variety does not carry genes conditioning resistance to the pathogen races suppressed by former varieties, with the result that nothing is gained in the long run.

To conclude, we could say that from the plant breeding viewpoint, specific or vertical resistance has often been discouraging, but has not been by any means a total failure. It has often provided a period of some years of resistance, and secondly, against less mobile pathogens such as soil fungi and nematodes it has sometimes been very effective.

In general or horizontal resistance mechanisms, the resistance is due to many genes (polygenic) acting in an additive or complementary manner. There is no sign of Mendelian segregation, but the resistance is fairly highly inheritable. The plant has a stable protection mechanism, not highly subject to radical change when a single mutation in the pathogen occurs. The host has protection against a wide array of genetic variability in the pathogen. It rarely approaches immunity and is less stable over a range of environments than monogenic resistance, but the disease level is often low enough to be economically acceptable, and it maintains a fair control or minor diseases. Some levels of disease may be present during the year, but losses are greatly reduced. The pathogen is allowed to maintain a population in limited numbers so that intensive selection pressure for highly virulent types is reduced (Welsh, 1981).

However, because general resistance shows no sign of Mendelian segregation, breeding can be very laborious. It took about 40 years of breeding to develop an Irish potato clone with a useful degree of general resistance against late blight.

If the general resistance is too low, the variety fails, as many have failed. If it is high enough for practical purpose, for example, in combination with chemical control in some seasons, the variety will survive at a level determined by its overall economic value.

Breeding for Resistant Varieties

The basic aim for breeding for disease resistance can be summarized as follows: to produce varieties that resist diseases sufficiently for growers to be relieved of controlling them by other means. More realistically, we could say that the plant breeder's task is to reduce the disease level to zero (immunity) if feasible but, more usually, to a level at which losses are reduced to an economically acceptable level. From the agronomic point of view, resistant varieties are of value only if they combine resistance with good agronomic characteristics.

Sources of Resistance

It is quite clear that to start a breeding program for disease control there must be a source of resistance to a particular pathogen.

The first source and also the most appropriate is certainly the selection from the existing varieties. By planting the existing varieties under environmental conditions favoring disease development, a preliminary selection can be made.

A second source of resistance is the importation of resistant germ plasms from outside the country. The reason for importation can be the lack of resistance in the local varieties or to increase the sources of resistance in order to decrease the risks inherent of having only one source of resistance.

Although this source of resistance has proved to be valuable, there are some disadvantages:

Firstly, the resistance can be pathotype-specific. If so, there is a good chance that the "resistant" variety will be susceptible once introduced, because the pathotype is different in both countries.

Secondly, extreme care should be given to the possibility of importing new diseases into the country.

A third source of resistance is resistance in related species or genera.

A fourth source of resistance may sometimes be obtained from useful mutations induced by radiation or other means.

Methods of Selection and Breeding

A. When genes for resistance occur in the existing varieties with acceptable characteristics, selection within these varieties will almost always provide the easiest and most satisfactory method of developing resistant strains.

B. When adequate resistance is not found in commercial varieties but only in types that cannot be used commercially because of their unsuitable agricultural properties, either the backcross or pedigree methods are usually selected. The succeeding generations are then reselected.

With either method one of the parents is chosen for its good agronomic characteristics, and the other parent is selected on basis of demonstrated high level of resistance.

Backcross

If the resistant parent is wholly an unadapted type, the backcross method is the logical choice of breeding procedure. The principle is simple enough. Having made a cross between two parent varieties, the F1 hybrid and subsequent generations are crossed recurrently to one parent. The other (the resistant one) parent's genetic contribution to progeny will be halved each generation and will ultimately become very small.

If, however, the donor plant (resistant one) contributes a selectable character (here resistance), this may be maintained by selection in the face of backcrossing.

The outcome is a stock that approximates the "recurrent" parent in genetic contribution but carries one or a few genes from the donor plus, unavoidably, one or more other characteristics.

Pedigree of bulk method

If the breeder is satisfied that the resistant parent can also contribute to improved adaption, quality, or yield, he may choose the pedigree or bulk methods of handling segregrating generations.

The pedigree method has been very widely used in breeding for disease resistance, and the majority of disease-resistant varieties have been produced by this method (Allard, 1960).

C. Clones

As a lot of the tropical crops are propagated clonally, the methods of breeding in such a population will be discussed in greater detail.

A clone is a group of plants originating by vegetative propagation from a single plant and therefore of the same genotype (can be obtained by grafting).

Clonal crops are all perennials, though several (notably the tubers such as potato, cassava, and sweet potato) are treated agriculturally as annuals and replanted at each crop cycle.

1. Breeding methods

All clonal crops are, by nature, perennial outbreeders. They are intolerant of inbreeding and individuals are highly heterozygous. Breeding is normally easy and quick because once a good clone is obtained, it is genetically fixed. Breeding of clones reduces quite simply to crossing of heterozygous clonal parents and selecting in the F1 seedlings and in subsequent vegetative generations with the object of isolating one or a few best segregations (Simmonds, 1979).

The first selection should be as weak as possible and should only be for characteristics known to be highly inheritable. This selection should only be intensified when substantial quantities of individual clones are available to reduce the environmental effects. Ultimate decisions should be made upon trials replicated over sites and seasons.

2. Problems with clone breeding

In most clonal crops, a degree of reproductive derangement is present and sometimes so highly developed as to forbid normal sexual reproduction altogether.

The clonal crops can be divided into two groups:

a. Those producing a vegetative product

This group nearly always shows reduced flowering developed, presumably, by a correlated response to selection for vegetative yield.

The extremes are yams, aroids, and sweet potatoes in which many cultivars never flower.

Cassavas and potatoes show much reduced flowering in relation to their less-selected relatives. Superimposed on this tendency to suppress flowering, there is also a good deal of sterility in these crops. This is probably sometimes also an aspect of correlated response to past selection but polyploidy as in potatoes, sweet potatoes, and yams and interspecific hybridity are also involved.

b. Those producing a fruit

While there is no question of suppression of flowering, the reproductive pecularities and sterility problems remain.

For example: polyploidy in bananas and breadfruit, hybridity in bananas, parthenocarpy and self-incompatibility in pineapples, parthenocarpy in bananas and many clones in which seeds and pollen are sterile so that they simply cannot be bred at all. Parthenocarpy, or related phenomena, occur also in some grapes, citrus, and breadfruit.

To summarize: most clonal crops present flowering and fertility problems, often very acute ones. Often, potential parents cannot be used at all, or, if they can, may not be crossed in all desired combinations. Genetic interpretation is commonly impossible or, at least, inappropriate. The essential simplicity of clonal breeding systems noted above, is therefore overlain by formidable practical difficulties.

3. Clonal degeneration

Clonal degeneration can result from somatic mutations which, in some cases, occur in frequencies high enough to be quite troublesome. Virus diseases, however, are the principal factors responsible for clonal degeneration.

D. Induced infection

Programs of breeding for diseases resistance cannot proceed unless the causal organism is present to induce the symptoms that will allow the plants with adequate resistance to be distinguished from susceptible genotypes (Allard, 1960). Plants resulting from breeding programs should be tested in circumstances of high infection pressure.

There are two possibilities

First, experimental infection in glasshouse or laboratory. Resistance to viruses, for example, is usually tested in a glasshouse by mechanical transmission or by infestation with viruliferous insects.

Second, field testing using artificial infection or augmented natural infection.

Augmented infection may be achieved by inoculating the seed or planting material before planting, by interplanting "spreader" rows of plants of very susceptible varieties, by spray or other infection of the crop, or by soil inoculation with nematodes or fungi (Simmonds, 1979).

E. General problems in breeding for resistance

1. Many crosses which appear desirable for disease

resistance prove worthless because the progeny are sterile and there is no means of acquiring seed. This kind of problem has been mentioned above. In other instances certain undesirable factors appear to be linked to the resistance. Sometimes undesirable linkages do not become apparent until a very late stage.

2. The biggest problems, however, are the variability of pathogens and the possibility of attacks by unexpected pathogens. This problem is especially acute in the case of vertical or specific resistance. Therefore, the aim of the plant breeder should be:

For the minor diseases

To obtain a little resistance to several diseases because extreme susceptibility to what is normally thought of as minor disease can kill an otherwise excellent variety.

For the major diseases

For the major diseases, something more positive is needed. The objective should be to obtain polygenic (general) resistance. This resistance is less likely to be completely broken down by a new race of a pathogen. Breeding can be laborious but the product is likely to be stable. Less laborious and less stable is resistance of multilines or mixtures.

A multiline is formed by backcrossing two or more cultivars with resistance based on one or a few major genes in a single genetic background and mixing the products.

A mixture is obtained by mixing distinct varieties which have complementary genes for resistance. Multilines and mixtures do not offer the immunity which has been sought from specific resistance, but resistance would appear in the field as if general.

Vertical or specific resistance: Although vertical resistance, based on one or a few major genes, is likely to be less stable than general resistance, it can provide effective protection for a period of several years and, as mentioned above, in the case of less mobile pathogens such as soil fungi and nematodes, it can be very effective.

REFERENCES CITED

Allard, R. W. 1960. Principles of plant breeding. John Wiley & Sons, New York.

Bottrell, D. G. 1979. Integrated pest management. Council on Environmental Quality. U. S. Govt. Printing Off. Washington, D. C.

National Academy of Sciences. 1975. Pest control: an assessment of present and alternative technologies. Vol. 1. Contemporary pest control practices and prospects; the report of the executive committee. Washington, D. C.

Simmonds, N. W. 1979. Principles of crop improvement. Longman, London.

Welsh, J. R. 1981. Fundamentals of plant genetics and breeding. John Wiley & Sons, New York.

Date: Oct. 11
Time: 1500

WORKING GROUPS TO REVIEW TRADITIONAL CROP PROTECTION TECHNIQUES IN TARO AND COCONUT IN THE SOUTH PACIFIC

The course participants (trainees and lecturers) split into two groups, one to discuss taro and the other coconut. Each group attempted to identify traditional techniques of pest control--known methods that farmers have reputedly developed themselves and have been using for a long time to combat pests. For taro, many traditional methods could be identified, but for coconut few could be identified with certainty. The results are reported on pages 252 - 253 of these proceedings.

Date: Oct. 12
Time: 0920

FACTORS THAT MERIT ATTENTION IN BIOLOGICAL CONTROL PROGRAMS

D. F. Waterhouse

Biological control, in its traditional sense, is the use of parasites and predators to keep a pest's numbers below levels at which the damage caused is economically significant.

The most spectacular examples come from the introduction of beneficial organisms from the region of the world where an introduced pest originated. More recently, biological control has also involved the successful encouragement--perhaps through early or mass release--of native parasites, as well as the use of bacteria, fungi, viruses, and nematodes.

Except in very limited areas, biological control does not eliminate the pest. If it did, the controlling agents would die out, unless they could survive on some other host. They have limited opportunities for doing so because, wherever possible, the natural enemies selected for use are either completely, or nearly completely, specific to the pest concerned.

Although biological control may be so successful that no other control measures are required, quite often it is necessary, and almost always desirable, to integrate biological control with other measures, including at times the careful use of pesticides.

Pesticides remain man's most powerful, general-purpose, method of pest control, and it is sensible to use them when the advantages from doing so outweigh the disadvantages.

Where it is available, biological control has many advantages, including the facts that:

1. It is generally nearly or completely specific to the pest species and thus does not interfere seriously with non-target species
2. It produces no undesirable residues in foodstuffs or the environment, i.e., it is nonpolluting
3. Once established the organisms involved are self-replicating. There is thus no need for continuing input of energy (in the form of fossil fuels) into control of the pest in the form of chemicals, and machinery or, indeed, of manpower
4. It is generally completely compatible with all other means of control except for pesticides, although some pesticides are acceptable and others are compatible if used selectively.

The earliest examples of successful biological control involved the use of natural enemies against introduced pest organisms, which developed to very high densities and became pests in new countries, attaining far greater abundance there than in their country of origin.

Under these circumstances, it was not unreasonable to suggest that the differences in density might be due to the fact that the organism (whether it be insect, mite, weed, or other pest) was attacked by various natural enemies in its country of origin but not in the new country. Further, if one or more of these natural enemies could be introduced safely into the new country, the balance could be re-established.

The oft-repeated saying "Balance of Nature" is, of course, not the steady equilibrium produced when an analytical chemist's balance comes to rest. Instead, it is similar to the tightrope walker's balance, whereby deviation from an average upright position is continuously counteracted by a reaction in the opposite direction. There is no truly stationary state but, instead, regular fluctuations about a mean density. It is characteristic of pest species that the level of abundance attained is intermittently or permanently unacceptable to man. Release by broad spectrum pesticides of potential pest species from the control exacted by their natural enemies has highlighted the importance of biological control in recent years.

Unless upset by pesticides or gross environmental change, biological control, once established, characteristically remains effective. That is to say, coevolution appears to ensure that pests seldom develop resistance to biological control agents. In this respect, biological control seems to have an advantage over the use of resistant plant cultivars.

Some pests probably will not be amenable to biological control since available organisms do not have the properties required to regulate the pest populations at a low enough level to avoid economic damage. On the other hand, biological control is a particularly appropriate method where a certain amount of damage can be tolerated. Where absolute freedom from the pest is required, for example the absence of codling moth from an apple or pear or of fruit fly maggots from the fruits that fruit flies attack, then other methods must be employed instead, or in addition.

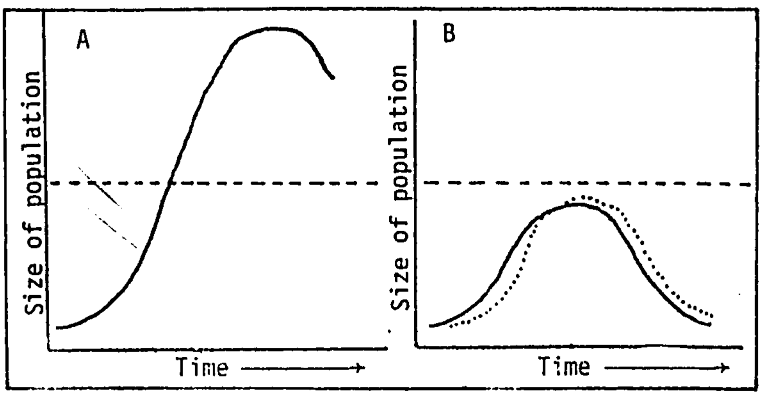
Figure 1 illustrates in a very simplified way a population curve for a pest "before" and "after" biological control. After biological control, upward movements in pest abundance are followed by increases in the populations of their enemies, which thereby tend to bring pest numbers down again.

A pest without or with few natural enemies in its new country is likely to be a better choice than one already having a number of them. Organisms known not to be pests in their native land, or which are relatively less abundant there, are particularly appropriate candidates. Less obvious candidates are native pest species, fostered by agricultural development, which lack particular sorts of natural enemies known to attack related species elsewhere.

In view of its basic features, biological control is particularly applicable to pest problems in which:

1. A certain amount of pest damage or nuisance is acceptable
2. The initial or recurrent costs of other control methods

Figure 1: A pest population before and after the introduction of a natural enemy



are too high in comparison to the value of the crop

3. Existing control measures or their deleterious side-effects are unsatisfactory or unacceptable.

What steps, then, are involved when considering whether or not to embark upon a biological control project? It should be emphasized at the outset that it is seldom possible to complete one step before proceeding with the next.

STEPS TO BIOLOGICAL CONTROL

1. The first step is to establish that the organism is, indeed, a pest and is doing sufficient damage to warrant the expenditure of resources to reduce its abundance. This is often not as easy as it sounds, and much valuable effort can be expended on relatively unimportant species, effort that could far more profitably be diverted to more important pests.

2. The next is to get it accurately identified. Identification enables information to be stored and retrieved, and this applies both to your own records and to those of others. It may enable a taxonomist to say immediately whether the pest is certainly, or in all probability, a native or an introduced species. It also leads on logically to:

3. A search of the literature for information on many key aspects, such as its biology, world distribution, pest status elsewhere, natural enemies, whether biological control has been attempted, and if so, with what success. Such a search would,

for example, soon indicate that biological control of a number of species of prickly pear was likely to be successful whereas, on the contrary, that the introduction of wasp parasites to control blow fly abundance was not.

4. If successful biological control has been achieved elsewhere, the success can be repeated, providing that the climate and other conditions are similar. It is then a matter of obtaining stocks of the agent(s) from the successful country or the country of origin of the pest and, after ensuring their freedom from fellow-travellers, in the form of hyperparasites or diseases, rearing, and releasing them.

5. Any biological control agent employed must have an acceptable level of host specificity. That is, it must restrict its attack to the pest, or at most to it and closely-related species and not affect any economically useful or otherwise beneficial species.

Degrees of host specificity vary between:

a. within a species, where only one biotype of the host is affected;

b. between species, where only one species of a genus is attacked;

c. a group of species; or

d. a wide range of species.

In general, only the last category of potential control agent must be excluded, although there are some circumstances under which even such species may be acceptable.

6. It is essential to stress the need to ensure that only the organisms selected are released and only after approval by appropriate government authorities. In their native land, the beneficial organisms are often attacked by their own natural enemies, including diseases. If freed from these before liberation in a new country, the beneficial organisms may be expected to be even more effective than in their native land.

7. Before proceeding with an attempt to repeat a success elsewhere, it is essential to consider two factors. The first is what natural enemies are already attacking the pest and whether or not they are having an effect. This will help to influence the selection of additional species. It may also render unnecessary the introduction of a species that is already present.

The second factor to consider is whether there are, indeed, different circumstances in the new country which would prevent the natural enemy becoming effective. An example of this might be the wish to utilize parasites of a citrus scale which is under successful biological control in California (USA), where only limited and very selective pesticides are necessary nowadays that the parasites are being used. Let us imagine that there are a series of citrus pests causing some economic loss in a Pacific island and that pesticides need to be applied. Perhaps most or all of the Pacific island citrus pests occur in California where they are under biological control. There would be little merit in introducing parasites for the target scale, if pesticides are still required to control the other pests. That is to say, it may be necessary to embark on the biological control of a series of pests in a particular crop because the use of a pesticide against any one may render ineffective the use of biological control agents against the remainder.

8. In general, it is desirable to obtain natural enemies from climatic regions that are as closely similar as possible to those in the new country. In this way, the strains obtained are likely to be best adapted to the new conditions.

9. It is also desirable to introduce a degree of genetic diversity in the stocks of the natural enemy. This generally means bringing in, if possible, at least a few hundred individuals. Opinions differ on whether stocks should be drawn from the center or the periphery of the range of the species in its native land, and climatic considerations may influence the choice.

10. Where an important pest is introduced, but there is no information on its biological control elsewhere, it may be desirable to consider a search for natural enemies in its native country. The United Kingdom's Commonwealth Institute of Biological Control, a component of the Commonwealth Agricultural Bureaux, is willing to contract for such a search if a country does not wish, or is unable, to undertake it.

11. Where a pest is known or believed to be native to the region, it is necessary to make a detailed study of its biology and

of the factors influencing its abundance. If it has become abundant, or more abundant, in recent years, what changes in agriculture or other features are likely to have brought this about? Have any of these changes had an adverse effect on natural enemies, and are there ways of manipulating the system to favor natural enemies? If new varieties have been introduced, for example many of the earlier new, high-yielding varieties of green revolution rice in Southeast Asia, is it possible to select pest-resistant strains? Massive outbreaks of brown planthopper (and the virus, tungro, that it transmits) were influenced by the shorter stemmed, denser growing plants. This pest is now partly controlled by resistant varieties of rice and by avoiding, wherever possible, the insecticidal destruction of the small, water-skating, predatory Microvelia bugs. In this particular instance, there is not thought to be much promise in attempting to bring in from elsewhere natural enemies of the brown planthopper, because none are known which are effective where pesticides are liberally applied.

12. Since the majority of those attending this course are likely to have limited resources to mass-rear insects regularly, I shall only mention briefly the possibility of mass releases of parasites or predators (whether native or introduced) so as to overwhelm the pest. This type of release is not expected to maintain its numbers, so must be repeated when pest numbers build up again.

Another variant is to release laboratory-reared natural enemies earlier than they would occur normally in the field, so they are able to build up and overtake the pest before it attains damaging populations. This approach also must be repeated each season.

13. If a biological control program is to be initiated, it is highly desirable to obtain quantitative data in advance on the distribution, abundance, and losses from the pest so that, at a later stage, the success of the program can be evaluated. This will assist other programs in the future but, more importantly, it will indicate whether further organisms need to be sought.

14. In considering any approach to pest control, the question of cost-effectiveness must be considered. Reliable figures for the overall cost of research, application of the results, and estimates of benefits that are credible to economists are diffi- cult to obtain. One such exercise relating to the CSIRO Division of Entomology is shown in Table 1. The benefit is clearly sub- stantial in each case.

It may be instructive to discuss, with the foregoing as a background, a pest which is currently being considered for bio- logical control in Tonga. This is coconut spike moth, _Tirathaba complexa_, which also occurs in Samoa and Fiji. The larvae of this moth attack both the male and female coconut flowers. Opposing views are held on whether or not this attack influences the number of nuts set.

TABLE 1: Costs and Benefits (Projected to 2000 A.D.) of Four Australian Biological Control Programs in 1975 Values ($Australian Millions), Discounted at 10 Percent

Pest	Cost of Research	Benefits
Skeleton weed (*Chondrilla juncea*)	2.39	261.2
Sirex wasp (*Sirex noctilio*)	6.27	12.8
Twospotted mite (*Tetranychus urticae*)	0.67	14.4
White wax scale (*Gascardia destructor*)	1.07	1.5
Totals	10.40	296.5

It is well established that only about a quarter of the 20 or so female flowers on a flowering spike survive to produce mature nuts, the remainder being shed up to 9 weeks or so for a variety of reasons. This is much the same as the way in which many of the early fruiting bodies of cotton and apples are shed. "Normal" nutfall is ascribed to such causes as the inability of the tree to sustain the development of more than about half a dozen nuts at a time, so that any nutlets in excess of this number are shed. Abnormal nutfall is ascribed to superimposed factors, including insect pests.

In Fiji, Taylor (1930) concluded that the main cause of abnormal nutfall was the spike moth, *T. complexa*, and that copra production would be increased by over 30 percent if it were eliminated. This was concluded on the basis that the larvae destroyed a significant number of the female flowers that would otherwise have developed into nuts. In Tonga, an overall loss of 35 percent of nuts has recently been attributed to this species.

However, there are a number of conflicting facts. One of these is that the use of systemic insecticides did not increase the number of nuts set in Tonga over a 13-month period, although it is not clear whether the insecticides controlled *Tirathaba*. Another is that, in Malaysia, when a closely related species, *T. rufivena*, was controlled, either by insecticide application or by removing the sheaths shortly before the spathes opened, there was no increase in nut production. Furthermore, female flowers were mostly bored in the second week after the spike opened, whereas the maximum fall of female flowers occurred in the fifth week and continued on until the ninth week. During the interval between the second and ninth weeks, the palm appeared to be able to drop damaged flowers first and later some undamaged ones until the required level of ultimate retention was attained. This work was done by Corbett (1931) and was based on experiments with nearly 10,000 female flowers. He calculated that Tirathaba would have to bore 58 percent of female flowers before causing any reduction in yield of nuts, whereas an average of only 9.4 percent was found to be damaged.

In Papua New Guinea, T. rufivena is not considered an important pest of coconuts. In Fiji, Paine (1935) who was responsible for selecting and introducing the four parasites for biological control of T. complexa which have become established, was unwilling to claim success on the basis of an increase of as little as about 1 percent in the number of 4-month old nuts.

Returning now to the steps I outlined earlier as being involved when considering whether or not to embark upon a biological control project, we have really still to answer the first, namely is the organism a pest worthy of investment of resources for biological control?

Step 2, accurate identification, and step 3, literature search, are rather more complete. Step 4, also, if there is any confidence that the results in Fiji are of economic significance.

Without proceeding to comment on subsequent steps, the question must be asked, is it feasible to establish in the near future whether or not Tirathaba is causing economic loss in Tonga, and how would one go about this task? I look forward to hearing your views on this matter.

REFERENCES CITED

Corbett, G. H. 1931. The control and economic importance of the greater coconut spike moth, Tirathaba rufivena Walker. Straits Settlement and Federated Malay States Dept. Agr. Scientific Series 8:1-14.

Paine, R. W. 1935. The control of the coconut spike moth (Tirathaba trichogramma Mayr.) in Fiji. Fiji Dept. Agr. Bull. 18:1-30.

Taylor, T. H. C. 1930. Early nutfall from coconut palms in Fiji. Fiji Dept. Agr. Bull. 17:1-42.

Date: Oct. 12
Time: 1050

REVIEW OF EXISTING PEST CONTROL METHODS USING BIOLOGICAL AGENTS

M. K. Kamath

INTRODUCTION

Biological control is the use by man of living organisms to reduce the harm caused by pests, or as the International Biological Control Programme puts it, "using biota to control biota." This entails the introduction of natural enemies of a pest species into areas where they did not already occur, and where, hopefully, they will colonize, increase, and control the pest.

The ancient Chinese are said to have used Pharaoh's ant (*Monomorium pharaonis*) to combat stored product insects by introducing nests into their barns, but it is not recorded whether this was successful.

Biological control began as an accepted scientific technique in the late 1880s (1888-1889) with the completely successful and permanent control of the cottony cushion scale, *Icerya purchasi* (Order Homoptera), a major pest of the young citrus industry in California (USA) by the introduction of the coccinellid predator, *Rodolia cardinalis*, an Australian ladybird, now known as the Vedalia beetle.

Mauritius has the distinction of the first recorded attempt at biological control with apparent success--the introduction in

1762 of the Indian mynah bird to combat the red locust *Nomadacris septemfasciata*. Most biological control attempts during 18th and 19th centuries were, however, crude, generally involving vertebrate predators, which being nonselective, had limited use.

Another biological control success receiving wide publicity was the control of the introduced *Opuntia* cactus in Australia in 1925 by a phycitid moth larva, *Cactoblastis cactorum*, from Argentina. By the late 1920s, this cactus was no longer a problem over some 25 million hectares of land in Queensland and New South Wales.

Further biological control successes would have been widely publicized had there not been the outbreak of World War II and the advent of the broad spectrum insecticide DDT.

Biological control has continued to develop despite often inadequate and inconsistent support and the opposition by proponents of chemical pesticides. It reached maturity during the last 15 years with the acceptance of the integrated control and pest management philosophies, and it is now perceived increasingly as a desirable alternative to chemical control.

In recent years, considerable interest has been evoked all over the world in the application of biological control methods of controlling crop pests and weeds. Three of the major reasons for this have been: (1) the rapid development of resistance to chemicals by a number of insect pests and mites; (2) the hazards that many of the recently developed, most potent, powerful organophosphorus and other toxic compounds pose to human health, domestic animals, and wildlife; and (3) the accumulation of chlorinated hydrocarbons or their degradation products in food chains, and the more general dangers of destroying the pollinators and useful, and often essential, natural enemies which are keeping other pests in check.

BIOLOGICAL CONTROL IN FIJI

In the South Pacific, in the areas where biological control work has been actively pursued, Fiji has had outstanding successes against some major pests of coconut and a terrestrial weed. One may cite a few spectacular examples:

1. The remarkable and complete control of the small leaf moth of coconut, Levuana iridescens B.-B. (Lepidoptera: Zygaenidae), the larvae of which caused considerable defoliation of the coconut palms and virtually threatened the existence of the copra industry. Extensive surveys carried out in Indonesia and Malaya in 1925 yielded a potential parasite, Ptychomyia remota (Diptera: Tachinidae) of an allied moth, Artona catoxantha Hamp. Six months after the first introduction of this Tachinid parasite it was found throughout Fiji where Levuana was a problem, and there were no reports of any new outbreaks of the pest from any parts of Fiji during the following years.
2. The control of the coconut scale, Temnaspidiotus

destructor Sign. (Hemiptera: Coccidae) by means of the ladybird beetle, Cryptognatha nodiceps Mshl. (Coleoptera: Coccinellidae), shipped from the West Indies in 1928

3. The control of the coconut leaf miner, Promecotheca coeruleipennis Blan. (Coleoptera: Hispidae) in 1933, following introduction of parasites from Java, Pediobius parvulus (Ferr.) and Dimmockia javanica Ferr. (Hymenoptera: Eulophidae)
4. The very successful control of the terrestrial weed, Koster's curse, Clidemia hirta (L.) D. Don in 1930-1931 by means of the thrips, Liothrips urichi Karny (Thysanoptera: Thripidae) from Trinidad, West Indies.

The reasons assigned for the success of these projects were:

1. The restricted nature of the island fauna, which offers little competition to introduced species, compared with that which they would encounter in continental areas
2. The favorable climate, which permits of growth and reproduction throughout the year
3. Adequate financial support to search for and introduce effective natural enemies against the target pests.

The examples as shown in Table 1 relate to the period 1911-1960, when biological control had a lot of attention paid to it in Fiji. After this period, especially between 1961 and 1968, there was a decline in the emphasis and effort placed on this approach, probably due to the advent of the powerful contact

TABLE 1: Natural Enemies Introduced in Fiji for Control of Insect Pests and Weeds between 1911 and 1981

Crop/Pest	Natural Enemy	Control Status
Banana		
Cosmopolites sordidus (the weevil borer)	*Plaesius javanus* (Coleoptera: Histeridae)	Partial
Lamprosema octasema (the scab moth)	*Chelonus striatigena* (Hymenoptera: Braconidae)	Partial
Coconut		
Temnaspidiotus destructor (the coconut scale)	*Cryptognatha nodiceps* (Coleoptera: Coccinellidae)	Complete
Promecotheca coeruleipennis (Hispid leafminer)	*Pediobius parvulus* (Hymenoptera: Eulophidae)	Complete
Levuana iridescens (the small leaf moth)	*Ptychomyia remota* (Diptera: Tachinidae)	Complete
Tirathaba complexa (the spike moth)	*Apanteles tirathabae* (Hymenoptera: Braconidae)	Substantial
	Venturia palmaris (Hymenoptera: Ichneumonidae)	

TABLE 1 (cont'd)

Crop/Pest	Natural Enemy	Control Status
Tirathaba complexa (cont'd)	*Argyrophylax basifulva* (Diptera: Tachinidae)	
	Palexorista painei (Diptera: Tachinidae)	
Oryctes rhinoceros (the rhinoceros beetle)	*Baculovirus oryctes* (virus)	Substantial
Rice		
Susumia exigua (the leaf roller)	*Trathala flavo-orbitalis* (Hymenoptera: Ichneumonidae)	Partial
Spodoptera litura and *Pseudaletia separata* (swarming caterpillars and armyworm)	*Apanteles marginiventris* (Hymenoptera: Braconidae)	Partial
Sugarcane		
Rhabdoscelus obscurus (weevil borer)	*Lixophaga sphenophori* (Diptera: Tachinidae)	Partial

TABLE 1 (cont'd)

Crop/Pest	Natural Enemy	Control Status
Vegetables		
Nezara viridula (green vegetable bug)	*Trissolcus basalis* (Hymenoptera: Scelionidae)	Substantial
Fruits		
Dacus passiflorae and *D. xanthodes* (the fruit flies)	*Opius oophilus* *O. longicaudatus* (Hymenoptera: Braconidae)	Substantial
Weeds		
Lantana camara	*Ophiomyia lantanae* (Diptera: Agromyzidae)	Partial
	Strymon bazochii (Lepidoptera: Lycaenidae)	
	Teleonemia scrupulosa (Hemiptera: Tingidae)	
	Syngamia haemorrhoidalis (Lepidoptera: Pyralidae)	
	Hypena strigata (Lepidoptera: Noctuidae)	

TABLE 1 (cont'd)

Crop/Pest	Natural Enemy	Control Status
Lantana camara (cont'd)	Uroplata girardi (Coleoptera: Hispidae)	
Clidemia hirta (Koster's curse)	Liothrips urichi (Thysanoptera: Thripidae)	Complete
Elephantopus mollis (tobacco weed)	Tetraeuaresta obscuriventris (Diptera: Tephritidae)	Substantial
Salvinia molesta (water fern)	Paulinia acuminata Samea multiplicalis	Substantial
Eichhornia crassipes	Neochetina eichhorniae	Partial (?)

insecticides. The interest in biological method of pest control was revived in the '70s (1969 onwards) in the light of success obtained with the substantial control of the coconut rhinoceros beetle by Baculovirus (Table 2).

PROBLEMS IN SELECTING AN EXOTIC NATURAL ENEMY

A review of successful cases of biological control has brought to light the fact that the introduction of an exotic natural enemy either of the same pest or an allied species from its native home offers greater possibilities than the mere mass-rearing and liberation of an indigenous species. In tackling any biological control problem, therefore, a preliminary survey for existing natural enemy species is very important. This helps in the subsequent selection of exotic natural enemies of the pest. The next step is foreign exploration for natural enemies of the pest in its native home. From experience, certain basic tenets have been established for purposes of selection of the biological control agents: (1) it is generally advisable to look for a natural enemy in a region with similar climatic conditions, as it is most likely to become established in the new home of the pest; (2) a host-specific, monophagous parasite or predator is likely to give immediate and obvious results and, thereafter, hold the host population at a low level. Nevertheless, the presence of alternate hosts as in the case of more polyphagous species can at times be

TABLE 2: Analysis of Biological Control
Introductions in Fiji

Period	No. Taxa Introduced	No. Established
1911-1960	83	37
1961-1968	14	nil
1969-1981	45	6

of help in maintaining populations of the natural enemy even when the major host species is in abeyance; (3) it must be understood that the most predominant natural enemy occurring in the native home at low host densities generally offers the greatest promise for introduction; (4) genetic races of a given natural enemy may be involved, so that one race has bioecological adaptations better suited to the host and the area of introduction than another; and (5) since the natural enemy may even show preference for hosts on a particular species of host plant, the host-plant preference must also be taken into consideration.

NEED AND SCOPE OF BIOLOGICAL CONTROL IN THE SOUTH PACIFIC

There is ample need and scope to pursue biological control measures against some common insect pests and weeds in the South Pacific.

There are a number of pest problems at present where detailed investigations in other areas to search for useful natural enemies might well prove economically rewarding as in the past.

The pests, including weeds, listed in Table 3 are common to some countries within the region; some are of major economic importance.

Need for a Scientific and Systematic Approach: Conclusion

To many of us, biological control may not mean much more than obtaining natural enemies, either indigenous or exotic, multiplying them in large numbers in the laboratory, and releasing them

TABLE 3: Pests, Including Weeds, in South Pacific Region with Potential for Biological Control

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Lepidoptera

Othreis fullonica - the fruit-piercing moth

Lamprosema octasema - banana scab moth

Heliothis armigera - the corn earworm

Plutella xylostella - the diamondback moth

Crocidolomia binotalis - the centre grub

Maruca testulalis - bean pod borer

Hellula undalis - cabbage worm

Agonoxena argaula - the coconut flat moth

Spodoptera spp. - armyworms

Diptera

Dacus spp. - the fruit flies

Melanagromyza phaseoli - bean leaf miner

Coleoptera

Papuana spp. - the taro beetles

Stephanoderes hampei - coffee berry borer

Brontispa spp. - the coconut hispid

Adoretus spp. - rose beetle

Phasmatodea

Graeffea crouanii - the coconut stick insect

TABLE 3 (cont'd)

Heteroptera

Nezara viridula - the green vegetable bug

Homoptera

Pentalonia nigronervosa - bunchy top aphid

Myzus persicae - the potato aphid

Toxoptera spp. - brown citrus aphid

Orchamoplatus mammaeferus - citrus whitefly
Family Aleurodidae - whiteflies
Family Pseudococcidae - wooly aphids

Acari

Tetranychus spp. - red spider mites

Polyphagotarsonemus latus - broad mite

Mollusca

Achatina fulica - giant African snail

Weeds - Terrestrial

Mimosa spp. - sensitive plants

Leucaena leucocephala - "Leucaena"

Cyperus rotundus - the nut grass

Kyllinga elata - Navua sedge

Mikania micrantha - mile-a-minute

Bidens pilosa - cobbler's pegs

Sida spp. - Sida

TABLE 3 (cont'd)

Weeds - Aquatic

Eichhornia crassipes - water hyacinth

Hydrilla verticillata - water elodea

in the field against a pest species. We know from experience that experiments or trials which have been based on such flimsy foundations have invariably ended in failure and consequent disillusionment in the biological control method. A serious study of the most outstanding successful cases of biological control, however, has shown that most of such attempts have been based on a thorough understanding of the ecology of the pest as well as the natural enemy involved. The natural enemy has been carefully selected and concerted efforts made to give it all possible opportunities to become established in the country of introduction. Therefore, it must be stressed that the need for approaching any biological control problem scientifically and systematically is utmost and, hence, the need for well-trained personnel.

An analysis of the successful cases and the factors responsible for these successes have proved without doubt that success has always been in proportion to the effort spent on tackling a problem. In general, the amount of money spent on biological control, hitherto, has been relatively very little, but the dividends drawn are high. A recent investigation in the State of California (USA) has revealed among others the fact that in a period of about 36 years the returns with respect to biological control were $30.00 (USA) for each dollar invested, while in the case of chemical control the nationally accepted figure was $5.00 for each dollar invested. This should be sufficient inducement for any developing nation to divert more funds and attention for research in biological control. I do not mean to say that chemical control should be entirely abandoned, because considering the extent and type of agriculture that we have in the world today, it would be ridiculous to suggest such an idea. Rather, attempts must be made to combine or integrate the two methods judiciously and with long-range effects in mind and an ecological approach to pest control be pursued.

We may, therefore, leave with a conviction that efforts in this field are a very sound investment of funds. With this I do not mean to imply that every project undertaken will produce worthwhile results; this certainly is not so. But, overall it is obvious that research in biological control can be extremely productive economically.

TABLE 4: Checklist of Natural Enemies Available for Biological Control Trials Against the Pests Listed in Table 3

Othreis fullonica

Egg: *Trichogramma* sp. nr. *papilionis* (Fiji)

Larval-Pupal: *Winthemia caledoniae* (New Caledonia)

Lamprosema octasema

Egg-Larval: *Chelonus striatigena* (Fiji introduced from Flores and Timor, Indonesia)

Larval: *Apanteles inquisitor*, *Elasmus philippinensis*, *Perilampus microgastris*, *Pristocelus fumipennis*, *Argyrophylax* (*Bactromyia*) *fransseni* - all parasites of the larvae of an allied species, *Lamprosema diemenalis* (Malaysia)

Angitia blackburni, *Casineria infesta*, *Chaetogaedia monticola*, *Ephialtes hawaiiensis*, *Eucelatoria armigera*, *Microbracon omiodivorum*, *Nesopimpla naranyae*, *Echthromorpha fuscator*, *Pimpla sanguineipes* - all parasites of species belonging to the allied genus *Omiodes*, especially *O. blackburni* (Hawaii)

Heliothis armiger

Egg: *Trichogramma achaeae* and *Trichogrammatoidea armigera* (India)

Larval: *Campoletis chlorideae*, *Eucelatoria* sp., *Drino imberbis*, *Eucarcelia illota* (India)

Plutella xylostella

Larval: *Angitia cerophaga*, *Apanteles plutellae* (India) *Thyraeella collaris* (New Zealand)

TABLE 4 (cont'd)

Maruca testulalis

Larval: Apanteles etiellae isolatus, Eiphosoma annulatum, Phanerotoma bennetti, Bracon cajani, B. thurberiphagae (Trinidad, West Indies) - on Ancylostomia stercorea having habits similar to those of M. testulalis

Pupal: Perisierola sp. (Trinidad, West Indies)

Agonoxena argaula

Larval: Bracon sp., Apanteles agonoxenae, Agathis sp., and Macrocentrus sp. (introduced from Java, established) (Fiji)

Pupal: Brachymeria agonoxenae and Tongamyia cinerella (Fiji)

Dacus spp.

Larval: Opius humilis, O. oophilus, O. longicaudatus, and O. vandenboschi (Hawaii)

Melanagromyza phaseoli

Larval: Opius importatus and O. phaseoli (introduced from East Africa and established in Hawaii giving excellent control)

Brontispa spp.

Egg: Trichogrammatoidea nana (New Guinea, Solomon Islands)
Haeckeliana brontispae (Marianas, Micronesia)

Larval: Tetrastichus brontispae (New Guinea, Solomon Islands)

TABLE 4 (cont'd)

Graeffea crouanii

Egg: *Paranastatus verticalis*, *P. nigriscutellatus* (Fiji)

Nymphs and Adults: *Mycteromyiella laetifica* and *M. phasmatophaga* (Solomon Islands)

Nezara viridula

Egg: *Trissolcus basalis* (Australia, Fiji)

Tetranychus spp.

Egg, nymph, and adult: *Phytoseiulus persimilis*, *Metaseiulus occidentalis*, *Amblyseius californicus*, *Typhlodromus occidentalis* (USA)

Date: Oct. 12
Time: 1335

THE GIANT AFRICAN SNAIL WITH SPECIAL REFERENCE TO ITS BIOLOGICAL CONTROL

R. Muniappan

DISTRIBUTION

The giant African snail (*Achatina fulica*) is a native of the east coast of Africa. Man has been responsible for its spread, and it has spread eastward along the tropical belt. Now, it has become a serious pest in the humid tropics of Asia and the Pacific.

It was first introduced into Madagascar from East Africa around 1760. From Madagascar, it spread to Mauritius in 1800, Reunion in 1821, Seychelles in 1840, and Comoro Islands in 1860. It was deliberately introduced into India in 1847. From India, it was introduced to Sri Lanka in 1900 and was reported to be abundant there in 1910.

By 1922, the snail had spread to Malaysia and Singapore. It reached South China in 1931, Siam in 1938, and Hong Kong in 1941.

It was introduced from Malaysia into Sarawak in 1928, Sumatra in 1933, and Java and Dutch Borneo in 1939.

During the Japanese occupation in 1931, the giant African snail was introduced into Taiwan and, thence, to the Philippines. It was introduced from Taiwan into Hawaii in 1936.

It reached the outer islands of New Guinea by 1946, New Ireland and New Britain in 1949, and the mainland of New Guinea in

1976-1977.

Even though it has been introduced many times into Japan since 1925, the cold weather has prevented its establishment. It has been accidentally introduced into California many times but has been destroyed as soon as discovered. In 1966, it was introduced into Florida; however, as a result of a strenuous quarantine program and clean-up work, it was eradicated in 1972.

An infestation of this snail was noticed in Gordonvale, 20 kilometers from Cairns, Australia, in 1977. An immediate clean-up operation eliminated the infestation.

The species made its first appearance in the Northern Marianas Islands of Rota, Tinian, and Saipan between 1936 and 1938. It was introduced into Pagan in 1939 and into Guam in 1945.

Around 1938, it was introduced into Ponape, Truk, and Palau Islands in the Carolines.

It entered New Caledonia in 1972. In Vanuatu, it was reported in the island of Efate in 1967; however, the establishment took place in 1972 at Port Vila.

This snail was introduced into Papeete in November 1967. In 1978, it was reported from Tahiti, Moorea, Huahine, Raiatea, Tahaa, and Bora Bora of the Society Islands and Hao and Mururoa of the Tuamotu Islands.

The giant African snail reached American Samoa in 1978.

ECONOMIC IMPORTANCE

As a Crop Pest

It is a serious pest of many cultivated plants. It will attack most vegetable and fruit crop seedlings. It will wipe out crops such as peppers, eggplants, and melon, etc., by scraping off the plants' bark.

As a Source of Food

Only in Taiwan has the giant African snail been successfully used for human consumption. In all other areas, it is only occasionally used as a human food item.

Use in Medicine

Mead (1979) reviewed its use in antimicrobial, antiviral, antitumor, blood group agglutinins, cosmetics, microbial identification, pharmacological, and radiobiological research.

Vector of Human Diseases

The giant African snail is known to transmit the rat lungworm, *Angiostrongylus cantonensis*, causing eosinophilic meningoencephalitis in human beings. It is also known to transmit a gram negative bacterium, *Aeromonas hydrophila*, causing a chronic bacteriosis. Dead snails become hosts for a number of disease-carrying flies. Empty shells serve as breeding sites for mosquitoes (*Aedes* sp.).

Vectors of Plant Diseases

The giant African snail is known to transmit *Phytophthora palmivora* in black pepper, coconut, betel nut, papaya, and vanda orchids; *Phytophthora colocasiae* in taro; and *Phytophthora parasitica* in eggplant and tangerine.

Use as Laboratory Animals

Because of their hardiness and wide host range, giant African snails have been used in laboratory experiments by many scientists.

BIOLOGICAL CONTROL OF THE GIANT AFRICAN SNAIL

Ants

Red ants and the fire ants, *Solenopsis geminata*, have been reported to trap and kill some giant African snails.

Beetles

The Indian glowworm, *Lamprophorus tenebrosos*, endemic to India and Sri Lanka, has been introduced to Mauritius, Indonesia, West New Guinea, Guam, and Hawaii since 1954, but none has established.

Several shipments of the carabids, *Damaster blaptoides blaptoides* and *D. rugipennis*, from Japan were introduced to Hawaii for *A. fulica* and armyworm control between 1958 and 1961, but none has established. The establishment of a number of carabids from East Africa introduced to Hawaii in the late 1950s and early 1960s is questionable or negative.

Birds

Ducks have been reported to kill giant African snails.

Centipedes

The common giant centipede of the Western Pacific has been occasionally seen in association with *A. fulica*, but there have been no reports of it attacking *A. fulica*.

Nematodes

Many nematodes infect terrestrial snails of which are juveniles of vertebrate parasites. Others are believed to be symbiotic or commensal with snails (CIBC, 1980).

Crustaceans

Hermit crabs of the genus *Cenobita* have been observed to kill the giant African snails and to use them as their shells.

Diptera

1. *Phoridae*. Most of them are saprophagous in dead snails. Adults of *Wandolleckia* sp. are ectoparasitic on *Achatina* spp. and breed in their feces.
2. *Ephydridae*. Most are carrion feeders. *Discomyza similis* has been reared on *Achatina* spp. in Africa.

3. *Sciomyzidae*. These are all parasites or predators of marshy or aquatic mollusks.

4. *Muscidae*. Some of the species of this family oviposit on dead or dying *Achatina* but none on live snails.

Mammals

The musk shrew, *Suncus marinus*, has been observed feeding on snails.

Millipedes

The millipede, *Orthomorpha* sp., has been reported to attack and feed on *A. fulica* in Andaman Islands.

Snails

For biological control of *A. fulica*, 25 species of snails were shipped to Hawaii, of which only 12 were field released.

Of the snails used for biological control, only *Euglandina rosea*, *Gonaxis quadrilateralis*, and *Gonaxis kibweziensis* have been important.

Euglandina rosea is endemic to the southeastern United States in an area from North Carolina to Louisiana. In 1955, the first introduction of *E. rosea* was made in Hawaii (Oahu). By 1958, it was well established, and by 1961, it reached its peak population. In May 1968, *E. rosea* was branded as a threat to the endemic species of snails. However, 1970 and 1971 surveys failed to confirm this.

Euglandina rosea was introduced into Guam in 1958. It established firmly, and its effect on A. fulica population has been evident in areas where there is less human activity. E. rosea has been harvested and shipped from Guam to CIBC in India, Andaman Nicobar Islands, Tahiti, New Caledonia, and American Samoa.

Gonaxis quadrilateralis is a native of Kenya. It was first introduced to Oahu and Maui in 1957. It has well established and has been reported as the most promising predator of A. fulica.

G. quadrilateralis was introduced into Guam in 1967 in the Navel Magazine area. No report of its establishment has been made.

Gonaxis kibweziensis is also a native of Kenya. It was first released in Agiguan Island in the Marianas chain in 1950. First release in Oahu was made in 1952. In 1954, this snail was harvested in Agiguan and released in Oahu. It is well established in Oahu and Maui.

G. kibweziensis was released in Guam in 1954 and established firmly mostly in and around the release sites.

Turbularians

Terrestrial turbularian flatworms are remarkable enemies of land snails and the giant African snail in particular. The activities of Geoplana septemlineata on A. fulica in Hawaii has been reported by Mead (1979). However, the use of G. septemlineata in biological control of A. fulica was viewed skeptically because of the infrequency with which the worms were encountered in the field.

In 1963, Schreurs reported the occurrence of a relatively large terricolous planarian at the Agricultural Research Station in Manokwari, West New Guinea, and accredited it for the complete disappearance of the A. fulica in some parts of Manokwari. The planarian was later identified as Platydemus manokwari.

Platydemus manokwari was first noticed in 1977 in Guam. Mr. Winsor of James Cook University of North Queensland, Australia, and Dr. Eudoxia Maria Froehlich of Universidade de Sao Paulo, Brazil, identified it as Platydemus manokwari.

Platydemus manokwari is nocturnal in habit and seen mostly on rainy nights.

In early 1981, the presence of these worms was reported from Saipan.

By 1981, over 95 percent of the giant African snail population in Guam had been reduced by P. manokwari.

The effective biological control program has had a significant economic impact in Guam. It has saved some $100,000 (USA) per year on snail pellets and has reduced crop losses by more than $0.5 million (USA).

REFERENCES CITED

CIBC. 1980. Possibilities for finding specific natural enemies for biological control of the giant African snail (Achatina fulica Bowdich). CIBC status paper 17.

Mead, A. R. 1979. Economic malacology with particular reference to Archatina fulica. Pulmonates Vol. 2B. V. Fretter and J. Peake (Eds.). Academic, New York.

Schreurs, J. 1963. Investigations on the biology, ecology, and control of the giant African snail in West New Guinea. Unpublished manuscript.

Date: Oct. 12
Time: 1500

INTEGRATED CONTROL OF THE RHINOCEROS BEETLE

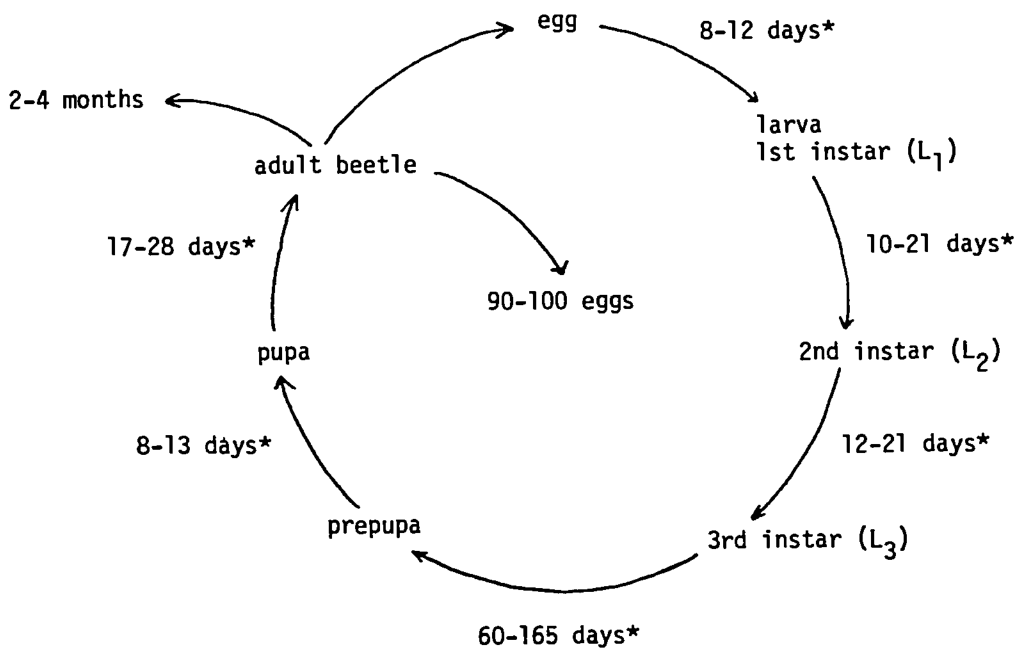
Christian Pertzsch

The rhinoceros beetle, Oryctes rhinoceros (L.), has been a major pest of the coconut palms of many Pacific islands since its introduction into the area (Samoa in 1909) from Southeast Asia. The life cycle of the insect is shown in Figure 1.

In the first years after its introduction in the Pacific islands, the pest was controlled primarily by sanitation with the aim of destroying breeding sites of the larvae (like rotting coconut logs, compost, manure, and rubbish heaps). This method was quite successful where all coconut farmers in an area participated in keeping the number of possible breeding areas low.

Friedrichs noted as early as 1913 (Friedrichs, 1913) that there seemed to be a relationship between the number of breeding sites and the rhinoceros beetle damage on trees when he visited some Asian countries. The combination of a radical sanitation program and catching and trapping of beetles made it possible to eradicate a rhinoceros beetle infestation in one of the Tongan islands during the period 1920-1929 (Dumbleton, 1952). These control methods, however, have become more and more expensive as the costs for labor have increased. Many farmers and governments therefore asked for better and cheaper solutions for the rhinoceros beetle pro-

Figure 1: Life Cycle of the Rhinoceros Beetle, <u>Oryctes rhinoceros</u> (L.)



* Bedford (1980)

blem. Over the years, researchers found a number of methods for controlling the pest that have or might have an impact on the beetle population. No method by itself, however, proved to be the final solution.

The result, therefore, has been to include all the possible methods into a concept of an integrated rhinoceros beetle control program. This program can be described as "a system of pest management which utilizes all feasible control methods in a compatible way to maintain pest populations at levels low enough so that serious damage to the crop does not occur" (Peterson, 1977).

The procedures may be listed as follows (UNDP/FAO, 1978):

1. Reduction of potential breeding sites
   a. environmental sanitation
   b. use of cover crops on potential breeding sites
2. Biological agents
   a. *Baculovirus oryctes*
   b. *Metarhizium anisopliae*
   c. parasites--species of *Scolia* wasps
   d. predators--the predatory larvae of certain click beetles
3. Insecticides
   a. to protect the living palm against adult beetle attack
   b. to prevent breeding in certain sites
4. Miscellaneous, e.g., trapping

A fifth point should be added:

5. Plantation improvement--creation of large, uniform plantations without open areas.

The combination of these control methods, especially 1, 2, and 5, should normally be sufficient to keep the damage by the rhinoceros beetle within low limits. If a whole plantation or some areas within it shows an increasing or very high damage level, the farmer should try to find out whether one of the components of this program is out of balance.

Before going into details of the single components of the control program, the term "damage level" should be discussed in greater detail.

One important aspect of integrated pest control is the establishment of the "economic threshold levels," the amounts of damage within a field or plantation that does not affect the crop yield significantly or only to such a degree that control methods would be more expensive than the loss of crop caused by the pest. It is relatively difficult to get clear results that show the influence of the loss of leaf area caused by the rhinoceros beetle on the number of nuts or copra harvested. One method may be to use a survey of the central crown damage: within a plantation, about 100 palms are surveyed. Only the apical four or five fronds are examined for the presence of the characteristic "v-shape" damage signs associated with the rhinoceros beetle infestations. The palm is recorded accordingly as damaged or undamaged, without taking into account the numbers of leaves damaged or the degree of damage per leaf.

Combined data from some researchers indicate the following relation between central crown damage and nut loss (UNDP/FAO, 1978):

10-20 percent central crown damage gives 4 percent nut loss

40-60 percent central crown damage gives 12 percent nut loss

80-100 percent central crown damage gives 23 percent nut loss.

According to these figures, a central crown damage of 20 percent would be below the level at which a successful rhinoceros beetle control program could be economically possible. (Even the very high damage levels seem to be tolerable; however, if the infestation becomes too severe, the repeated beetle attacks might kill the trees. So, not only the loss of nuts but also the loss of trees or whole plantations have to be considered in such cases.)

Results from Western Samoa show an average damage level for Upolu of 15.8 percent (24 locations) and Savai'i of 11.5 percent (15 locations). However, local outbreak areas show much higher damage levels and, even in some larger plantations, damage levels of more than 30 percent can be found.

In the following paragraphs, the procedures that may be combined to form an integrated rhinoceros beetle control program are discussed in detail:

1.a. Environmental sanitation

- The breeding sites of rhinoceros beetle larvae in plantations and in their environment, like villages or industrial sites, should be destroyed

- Rotting coconut logs and dead standing palms should be cut, piled up, split longitudinally when they are dry, and burned
- Rubbish heaps should be burned
- Palm stumps should be burned or treated with *Metarhizium anisopliae*
- Heaps of decaying material should be dispersed on the land or treated with *Metarhizium*
- Manure heaps should not be allowed to stand long before the contents are used; they can be treated with *Metarhizium*
- Sawdust heaps should be treated with *Metarhizium*, burned, or dispersed.

In Western Samoa, the environmental sanitation is enforced by a "beetle gang," a group of eight workers who go around the island, check the plantations for possible breeding sites, collect larvae from rotten coconut wood, and advise and assist farmers in sanitation methods. They require a car, two chainsaws, axes, and bush-knives for the job. They are responsible for the correct application of the insect killing fungus *Metarhizium anisopliae*.

1.b. Use of cover crops on potential breeding sites

Bearing in mind that the cutting and correct disposal of larger plantation areas are very labor-intensive and expensive, a second way to prevent these places from becoming breeding sites is the use of a "cover-crop" like Pueraria. The objective of the cover crop technique is to plant a crop such as Pueraria in the coconut plantations to conceal potential rhinoceros beetle breeding sites. It has been shown (Wood, 1969) that when logs are densely covered with vegetation they are unlikely to be used as breeding sites by the female beetles. It might be that the beetles do not find these rotting logs during their flight, or they might find it difficult to fly through the vegetation. The additional benefits of a cover crop are: The Pueraria is a legume which collects the plant nutrient nitrogen, the plant is a good food for cattle after the old logs have rotted, and the soil is protected against heavy exposure to sunshine and rain.

2.a. Baculovirus oryctes

After the discovery of this virus disease in Malaya (Huger, 1966), it was introduced into almost all the Pacific islands where the rhinoceros beetle problem existed. The virus, which affects both larvae and adults, proved next to environmental sanitation to be the most effective method against rhinoceros beetles. Shortly after the introduction of this virus into beetle populations, very often a strong decline of beetle damage on the new fronds of the palm trees could be noticed. An example is the island Viti Levu, one of the Fiji islands (UNDP/FAO, 1978), where the following data were obtained on percentage by new fronds damaged by the beetles before and after the introduction of the virus:

Observation Places	Before	After
Tamavua	76%	5%
Caboni	79%	16%
Lautoka/Nadi	88%	12%

After the virus is introduced into a beetle population, it seems to maintain itself adequately within the population, being transmitted from one beetle to another, without any further requirement. It spreads rapidly throughout a beetle population and suppresses the population by decreasing the life span of adults and reducing the number of eggs laid (Zelazny, 1973). The virus has only a limited effect on larval populations and cannot prevent the localized damage to palm plantations that results from a concentration of suitable breeding sites in so-called "outbreak areas." Outside the living insect, the virus has only a short time of survival. In Western Samoa, no further releases of virus-infested beetles have been made since 1979-1980. However, the virus level within the beetle population is monitored regularly. For that purpose, beetles are trapped in traps using chemical attractants and checked for virus disease using gut smear tests. The virus level was found in 1980-1981 to be 38 percent (300 beetles tested) of the female and 51 percent (out of 80 beetles) of the male beetles in Upolu, and 42 percent (150 beetles) of the female and 55 percent (29 beetles) of the male beetles of Savai'i.

2.b. *Metarhizium anisopliae*

In contrast to the virus disease, this fungus disease is primarily associated with larvae, although it also attacks the adult beetles. Again, in contrast to the virus, the fungus is spread only to a limited extent, because the fungus spores appear outside the insect only after the insect has died. And thirdly, in contrast to the virus, the spores of the fungus can survive for a very long time in the soil or in breeding places of the rhinoceros beetle, up to two years (Latch and Falloon, 1976). It therefore can be used as a biological insecticide on compost heaps, rubbish sites, and stumps (especially in places where the presence of domestic animals exclude the use of chemical insecticides).

The Metarhizium is mass produced in the laboratories at Nu'u in Western Samoa. The spores are first isolated and multiplied on potato dextrose agar, then brewery waste with the additives 10 percent milk powder and 2 percent sugar is used as substrate. A disadvantage of the use of Metarhizium in rhinoceros beetle control programs must be mentioned: its production is relatively labor-intensive and expensive.

2c.&d. A number of parasites and predators have been introduced into Western Samoa. Some of them have not been recovered; and others were found in small numbers. However, it is hardly possible to estimate their value as controlling agents against rhinoceros beetles, adults or larvae.

3.a. At present, insecticides are not being used for the control of the rhinoceros beetles in Western Samoa. Previous experiments have proven to be unsatisfactory, mainly because of the cryptic life habit of the beetle and of high labor costs. The use of insecticides might be justified in special plantations like hybridization nurseries or in palm trees used as ornamentals.

3.b. Because of the danger to domestic animals, no trials involving the use of insecticides on breeding sites have been carried out.

4. Trapping is used only as a method to get beetles for virus tests. Trapping as a control method would be too expensive and ineffective.
5. Because it can often be seen that the borders of open areas within coconut plantations are severely damaged by rhinoceros beetles, it seems to be important to obtain a constant, uniform plantation stand. This method would not help to decrease the number of beetles, but it would disperse them more evenly within the plantation. A palm tree would not die from a single beetle attack. However, if the attacks occurred too frequently, the palm might be so much damaged that it would die, producing new open areas and new breeding places. Therefore, if palms are killed within a plantation, they should be cut down, the logs destroyed, and new palms replanted.

SUMMARY

What rhinoceros beetle program is actually carried out (besides the release of the Baculovirus, which should be considered in all islands where rhinoceros beetles can be found and no virus has yet been distributed), is often up to the decision of the farmer.

In many cases, when the damage in a plantation is low,

between 10 and 25 percent central crown damage, and no actions are taken or planned which would drastically increase the number of possible breeding places, it might be uneconomical for a farmer to spend much money in efforts to reduce the beetle population even further.

The creation of large numbers of breeding sites within or around plantations, however, will quite certainly result in a local outbreak of rhinoceros beetle activities and the farmer should act accordingly to protect his own plantations as well as his neighbors.

REFERENCES CITED

Bedford, G. O. 1980. Biology, ecology, and control of palm rhinoceros beetles. Ann. Rev. Entomol. 25:309-339.

Dumbleton, L. J. 1952. Rhinoceros beetle control in the Kingdom of Tonga. South Pacific Commission Technical Papers No. 34. Nov. 1952.

Friedrichs, K. 1913. Uber den gegenwartigen Stand der Bekämpfung des Nashorn Käfers (Oryctes rhinoceros L.) in Samoa. Dr. Tropenpflaner, Berlin 17.

Huger, A. M. 1966. A virus disease of the Indian rhinoceros beetle, Oryctes rhinoceros (Linnaeus), caused by a new type of insect virus, Rhabdionvirus oryctes gen. n., sp. n. J. Invertebr. Pathol., 8:38-51.

Latch, G. C. M., and R. E. Falloon, 1976. Studies on the use of Metarrhizium anisopliae to control Oryctes rhinoceros. Entomophaga 21:39-48.

Peterson, G. D. 1977. Research on the control of the coconut palm rhinoceros beetle, Fiji, Tonga, Western Samoa. Review of Project Results UNDP/FAO, Rome.

UNDP/FAO. 1978. Research on the control of the coconut palm rhinoceros beetle, Phase II, Fiji, Tonga, Western Samoa. Technical Report.

Wood, B. J. 1969. Studies on the effect of ground vegetation on infestations of *Oryctes rhinoceros* (L.) in young oil palm replantings in Malaysia. Bull. Entomol. Res. 59:85-96.

Zelazny, B. 1973. Studies on *Rhabdionvirus oryctes*. II. Effect on adults of *Oryctes rhinoceros*. J. Invertebr. Pathol. 22: 122-26.

Date: Oct. 12
Time: 2010

SHOWING OF THE FILMS "INSECT ALTERNATIVE" AND "BIOLOGICAL CONTROL"

Two 16-millimeter films were shown at this evening session. "Insect Alternative," produced in the USA in 1978 by NOVA, illustrated some of the problems that have been brought on by heavy insecticide use in agriculture. It showed that the development of insecticidally resistant strains of cotton insect pests in southern Texas and northeastern Mexico has economically crippled production of the cotton crop. The status and problems of using some of the promising control alternatives, insect hormones and pheromones, for example, were discussed.

The film on biological control was produced by the Australian government over 20 years ago. Examples from Australia were used to illustrate the principles and techniques of manipulating "beneficial" living organisms for the reduction of pest organism populations. The film emphasized the technique of classical biological control, that is, the introduction and establishment of natural enemies in areas where they did not previously occur. This approach has been used largely against pests of foreign origin and has been quite successful and economical.

Date: Oct. 13
Time: 0925

REPORTS OF WORKING GROUPS TO REVIEW TRADITIONAL CROP PROTECTION TECHNIQUES IN TARO AND COCONUT IN THE SOUTH PACIFIC

The objectives of the working groups' exercise were given in a section above (refer to page 194).

TARO

With taro, many traditional methods are associated with plant protection. Where corms or suckers are the preferred planting material, this is often seen as a way of avoiding any of the pests (used here in the wide sense) being carried over from the parent plant. After taste, disease resistance is given next importance when selecting preferred varieties. In some places, deliberate interchange of planting material between villages occurs, and this presumably serves to give a wider genetic base from which to make selections. Where leaves are trimmed from planting material, this is usually done as part of a conscious effort to reduce carry-over of pests. Pest problems of leaves, corms, and roots can all be ameliorated by careful selection of planting material.

Choice of planting site in relation to variety is important, and special growing methods such as on terraces or raised beds have a bearing on root diseases. The addition of sand to planting holes in Cook Islands and French Polynesia is reported to control Pythium root rot. Burning before planting can partially sterilize the soil, and mulching with coconut leaves or other materials is often seen as a method of weed control. Smoke may be used to repel insects, and hand picking and rogueing are often practiced. Chickens are everywhere considered to provide good control of caterpillars and some other insect pests. Rotation is commonly practiced, and sites with a history of serious disease are avoided for future replanting.

COCONUT

Although, of course, there is much tradition associated with all stages of coconut growth and utilization, participants were able to mention very few practices related to plant protection. Burning is used for weeds, and to provide smoke for stick insect control. Cooked shark liver was considered to be a rat poison and repellant in Tokelau. No other traditional pest control practices could be identified with certainty.

Date: Oct. 13
Time: 0945

LEGISLATIVE AND REGULATORY METHODS IN THE PACIFIC

Ivor D. Firman

We are mainly concerned here with "plant quarantine." Common usage has broadened the meaning of the term to embrace all aspects of the regulation of movement of plants between or within countries. Quarantine in this sense signifies a legally enforceable restriction imposed by a constituted authority whereby the movement of plants, plant products, insect pests, diseases, soil, etc., is brought under control by various regulations.

It is not the intention here to discuss the strictly legal or organizational aspects of plant quarantine. This should be covered in special training courses for quarantine officers, and in any case, the publication Plant Quarantine Procedural Manual for Island Countries of the South Pacific (O. O. Stout, 1978, FAO/UNDP/SPEC) has been made available for this purpose and distributed in the region. Also, during the course of the UNDP/FAO Agricultural Pests and Disease Survey, Dr. Stout critically reviewed the quarantine regulations of the seven countries concerned (Cook Islands, Fiji, Kiribati, Niue, Tonga, Tuvalu, and Western Samoa) and suggested the changes and amendments which should be made in a series of detailed reports to those countries. Then again, in 1981, Mr. Baird, Assistant Director of Agricultural

Quarantine in New Zealand, visited all these countries again and:

- inspected the quarantine facilities and equipment available in each country, recorded them, and recommended improvements
- examined the procedure and systems operating in each country and recommended modifications and improvements
- recorded the staffing levels and capabilities in each country and recommended possible training courses and programs.

Plant quarantine is the front line of defense against plant diseases and insect pests and so is a control method which should be considered during this training course. There is much confusion and misunderstanding about quarantine in the region. In particular, it seems that officials in many countries believe quarantine to be a serious and unreasonable hinderance to agricultural development and to trade. It is certainly not intended to be so. Indeed it is intended to aid agricultural production by reducing the risk of new and damaging diseases and insect pests spreading into and around the region. It was to try and promote a general awareness of the subject that two articles were published in the South Pacific Bulletin, The Need for Plant Quarantine [1979, 29(2):7-11] and National and International Action in Plant Quarantine [1979, 29(3):18-21]. These articles appear, respectively, as Appendix 2 and Appendix 3. The main points from these two articles will be discussed. A few aspects will be selected for extra attention.

TRADE IN AGRICULTURAL PRODUCE

There has been a feeling in some parts of the South Pacific region that quarantine legislations were out of date, too restrictive, and prevented trade. Although legislations may sometimes seem to be out of date, this is very rarely the cause of trade restrictions. The actual regulations are usually discretionary rather than prohibitive. If there is a real intention to export a commodity, an import permit is applied for and the importing country will inform the exporting country of any quarantine requirements. The requirements for individual crops differ and the insect pest and disease status of countries also differs. To decide whether the quarantine requirements are reasonable and based on sound biological grounds can therefore be decided only with reference to specific commodities being traded between specific countries. In some cases, a total prohibition may be justified, in other cases a treatment such as fumigation may be needed, and yet in other cases free entry (subject to inspection from serious insect pests and diseases) may be allowed.

In 1981, Mr. Travis Flint, New Zealand's Regional Agricultural Quarantine Officer, visited Fiji to advise and train quarantine staff in aspects of quarantine inspection and especially to pay attention to producing outturns acceptable for export. The Trade Commissioners of both Australia and New Zealand expressed their interest in the work and provided specific examples of acceptable and unacceptable produce which also indicated areas where more research might be useful on commodity treatments.

Although the problem of trade in agricultural produce has recently been much discussed, it is probably not an area which impinges much on the practicing agricultural staff at this training course. They might be more immediately concerned with obtaining and trying out new and possible insect pest or disease resistant varieties or in implementing local quarantines or eradication attempts.

IMPORT OF GERM PLASM

The FAO guidelines, International Transfer of Germplasm, (H. C. Phatak, 1981) noted that "such movement has played a key role in the distribution and conservation of germplasm" and "played a pivotal role in crop improvement through breeding programmes." But at the same time, international exchange of germ plasm "is associated with some inherent risk--that of spreading pathogenic microorganisms, viruses, mycoplasmas, and insects."

We are now well aware of such risk and can take steps to minimize them. The International Board for Plant Genetic Resources (IBPGR) in collaboration with FAO has published Plant Health and Quarantine in International Transfer of Genetic Resources (1977). The FAO Plant Protection Committee for the Southeast Asia and Pacific region regularly publishes "Recommended measures for regulating the importation and movement of plants" and has elaborated on those measures in "Plant Quarantine in Asia and the

Pacific: Plant Quarantine Recommendations: Agricultural and Biological Basis." But all this is still not enough.

The information needs to be interpreted locally, and clear national (or more widely acceptable Pacific regional) procedures and policies should be developed. Examples of this type of approach were given at the SPEC regional conference on coconut interests in 1982 (paper on coconut quarantine, pests, and diseases by I. D. Firman) and the IFS regional meeting on edible aroids in 1981 (Guidelines for the movement of germplasm of taro and other aroids within the Pacific, G. V. H. Jackson and I. D. Firman).

In all cases, expert advice should be sought, and only competent authorities should be allowed to make the imports. The dangers of uncontrolled imports of planting material needs to be well publicized among the public and agricultural staff alike.

LOCAL QUARANTINE AND ERADICATION

If an important new disease or insect pest enters the country, it may be feasible to launch an eradication campaign. A successful campaign would depend on appropriate legislation being in effect and prompt action being taken. Countries should have contingency plans and might profitably study the experiences of Papua New Guinea in eradicating coffee rust and of Western Samoa in eradicating outbreaks of the giant African snail. It may be the agricultural extension staff who detect the outbreak and help organize the eradication so it is not only a matter for quarantine officers.

In some circumstances and especially in countries which consist of groups of widely scattered islands, there are often opportunities for preventing spread by imposing local quarantines. The rhinoceros beetle and citrus canker in Fiji, Marasmiellus cocophilus of coconut in Solomon Islands, and cocoa vascular streak dieback in Papua New Guinea are some examples.

Date: Oct. 13
Time: 1100

PESTICIDE LEGISLATION: RATIONALE AND STATUS

Ivor D. Firman and Dale G. Bottrell

Firman discussed the responsibility of organizations and individuals and legislative control when dealing with pesticides. He stressed that the responsibility of government is to make regulations and provisions to ensure, as far as possible, that pesticide sale and use do not present undue hazards to humans, domestic animals, and wildlife. He said that the purpose of registration schemes is to ensure that only suitable pesticides are available to the public and to encourage their safe and efficient use. Active ingredients, formulation, packaging and labeling, safety, toxicology, residues, etc., will be taken into account by the registering agency in deciding whether to allow the pesticide to be sold.

The responsibility of the manufacturers and distributors of pesticides is to ensure that statutory requirements for their sale are complied with and that products are adequately labeled and packaged.

The responsibility of the extension worker is to inform the user of the products which can be used for a particular purpose and to advise on the correct use of these products.

Firman discussed the status of pesticide legislation in the island countries of the Pacific. American Samoa, Guam, and the Trust Territory of the Pacific Islands come under United States law and must comply with provisions of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). In Fiji and Tonga, legislation exists to regulate the registration and sale of pesticides, along the lines recommended by FAO/WHO in the Guidelines for Legislation Concerning the Registration for Sale and Marketing of Pesticides. French Polynesia and New Caledonia benefit from the advice of L'Association de coordination technique agricole in Paris which publishes lists of pesticide products and summarizes French legislation. Cook Islands imports only pesticides that have been registered for use in New Zealand.

Bottrell summarized the United States pesticide law as it affects those Pacific countries noted above. FIFRA has been amended several times since it went into effect in 1947. The most significant amendment was in 1972; it created a most ambitious and comprehensive regulatory structure for pesticides. Known as the Federal Environmental Pesticide Control Act (FEPCA), the 1972 amendment placed pesticide regulation in an environmental context, taking into account the economic, social, and environmental costs and benefits of pesticide use. Pesticides sold in the USA or in any of the countries under USA law are classified in two categories: general use materials or restricted use materials. Pesticides in the restricted category can be applied only by or under the supervision of applicators who have been certified. The FEPCA now requires that certification of applicators must include provisions for making instructional materials concerning integrated pest management to individuals at their request.

A new document (1982, Pesticide Regulations Compendium, Editions Agrochimie Ltd., Geneva, Switzerland) outlines the pesticide laws of more than 80 countries and would be of value to anyone interested in the international status of pesticide legislation.

Date: Oct. 13
Time: 1125

PANEL DISCUSSION OF ON-GOING EFFORTS AND NEEDS IN PESTICIDE AND QUARANTINE REGULATIONS IN THE SOUTH PACIFIC

Tom Simiki, Ivor D. Firman, Edwin C. Pickop,
Niels von Keyserlingk, and Dale G. Bottrell

Each panel member expressed views concerning the problems of pesticide and quarantine regulation in the island countries of the South Pacific and needs for improved regulation. Then, during the open discussion that followed, the course trainees and lecturers identified additional problems and needs. One of the real problems identified was the lack of adequately trained individuals in the South Pacific for carrying out programs related to pesticide and quarantine regulations and enforcement. There was a general feeling that training requirements could best be met if some regional organization in the South Pacific (probably SPC) were mandated with this responsibility, and provided the personnel and economic resources necessary for carrying out the training.

Date: Oct. 13
Time: 1335

PHEROMONES, HORMONES, AND GENETIC METHODS OF INSECT CONTROL

D. F. Waterhouse

When the synthetic organic insecticides became generally available for pest control in the mid-1940s, they were used against almost every sort of medical, veterinary, and agricultural insect pest. At first they gave spectacular results, and other methods of control were largely neglected. But it gradually became evident that pesticides were not the ideal solution and, indeed, were sometimes doing more harm than good. More and more insect pest species evolved genetic resistance to insecticides. It also became increasingly apparent that some populations of harmless or beneficial insects were more severely affected than the pests: they were unable to evolve resistance as rapidly, if at all.

Such considerations as well as the unanticipated environmental hazards sometimes caused by pesticide chemicals have reawakened interest in old techniques, such as cultural and biological control and in newer approaches, such as the use of pheromones, hormones, and genetic methods.

PHEROMONES

A pheromone is a substance produced by one member of a species that brings about a response in another member of that species. There are two types, "releaser" and "primer" pheromones. Releaser pheromones produce a rapid change in the behavior of the recipient, whereas primer pheromones (which are most highly exploited in social insects) trigger off, or control, a chain of physiological events such as the regulation of caste structure. An example is the queen substance of queen bees or termites.

Releaser Pheromones

Most attention has been paid to developing the use of releaser pheromones that cause insects to aggregate for mating, feeding, or oviposition, although the possibility of manipulating trail-following and alarm behavior is also being investigated.

Aggregation Pheromones

Aggregation pheromones include (1) sex pheromones that are released by one sex (either the female or the male) and result in behavior in the other sex designed to facilitate mating and (2) general aggregation pheromones that may be released by only one sex, but which influence both sexes to approach the source.

Sex Pheromones

Sex pheromones are commonly secreted by the female and are often somewhat misleadingly referred to as sex attractants in that this implies, incorrectly, that they do no more than attract. For example, depending on concentration, they will cause males to become activated, to land, or to display mating behavior. It is generally accepted that the pheromones switch on orientation to, and movement into, the wind, and this leads the male towards the odor source. Responsiveness to pheromone may also lead to considerably increased catches when virgin females are placed near light traps. The mechanism for this effect is not clear, although moths that are active for any reason are more likely to respond to light than inactive ones, but it is possible that increased responsiveness to light may be involved.

By early this century, it was well known that females of many moths release materials to attract the males and that these substances tend to be quite specific in their attraction. The attractant pheromone is usually produced by glands in the tip of the abdomen, and females emitting it adopt a characteristic "calling" posture. Extraction of half a million silkworm abdominal tips led to the identification of the sex pheromone "bombycol" (Figure 1). The chemical composition of at least the major component of the pheromones of over 600 insect species is now known.

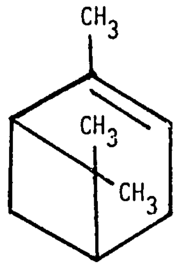
Because the response of the male moths to calling females is generally very specific, it was at first thought that attractant pheromones would be species specific. This is not always so, and a particular compound may affect more than one species. For example, *cis*-11-tetradecenol acetate has been identified as a component of the sex pheromone of 10 different moth species and is attractive in the field to males of 12 other species. In 13

FIGURE 1: Insect Pheromones

$$Ch_3.\overset{O}{\overset{\|}{C}}.(CH_2)_5.\underset{H}{\underset{|}{C}} = \overset{H}{\overset{|}{C}}.COOH$$

9-ketodecenoic acid

The 'queen substance' of honey bees and termites



α.pinene

The alarm pheromone of termites of the genus *Nasutitermes*

$$CH_3.(CH_2)_2.CH = CH \cdot CH = CH(CH_2)_9.OH$$

trans·10,*cis*·12·hexadecadienol

Bombycol

The sex attractant of the female silkworm moth

$$CH_3.(CH_2)_2.CH = CH.(CH_2)_7.O\overset{O}{\overset{\|}{C}}.CH_3$$

cis 8·dodecenyl acetate

Sex attractant of the female oriental fruit moth of these 22 species, at least one other compound is needed for maximum attraction. Indeed, in many instances precise ratios of two or more components are necessary.

Sex pheromones may attract over considerable distances. For example, in one instance a marked male moth was captured in a trap baited with synthetic pheromone 7.5 kilometers from where it had been released the day before.

Pheromones are active in very small amounts. For example, a female silkworm contains in her abdomen about one-hundred-millionth of a gram of bombycol. The male's antennal receptors are so sensitive to this compound that he is stimulated by as few as 200 molecules of it. A single female has sufficient pheromone to stimulate a hundred thousand million males, probably far more than are alive at any one time.

The moth attractants that have so far been identified are long chain (10-18 carbon atoms) compounds of relatively simple structure, usually with one or two double bonds. Acetates are commonest, but alcohols and aldehydes are also well represented.

In insect orders other than Lepidoptera, the chemicals are often more complicated and the sex pheromone may be produced by the male. For example, certain male cockroaches produce an unidentified volatile secretion called "seducin" which initiates a behavior pattern in the female that leads to mating.

Other Pheromones

There are several types of releaser pheromone in addition to sex pheromones, including trail pheromones, alarm pheromones, and host-marking pheromones.

Trail pheromones are used by ants and termites, either to mark their way back to the nest, or to lay a recruiting trail when returning to the nest from a rich source of food, so as to guide others to the location of the food.

Alarm pheromones are common in social insects, and the response to them may vary, depending on circumstances, from greatly increased activity and moves to escape, to attraction, or to attack.

Some parasitic wasps mark host eggs or larvae in which they have laid eggs with a pheromone that inhibits further egg-laying, so preventing over-parasitization and enhancing the chance of survival of eggs already laid.

Pheromones and Insect Control

Pheromones may be used in control programs in two ways: (1) to detect the presence and sometimes the abundance of a species, allowing an informed decision on whether or not to initiate control measures and (2) to control its behavior.

Pheromones and Monitoring

Where pheromones are now being used in monitoring, their principal use is to detect the appearance of the first spring generation, and this permits the accurate timing of a pesticide application.

Pheromones and Behavior Control

Where the aim is to control pest behavior, there are two approaches: (1) to attract sufficient individuals from the population into a trap and so remove them, leading to control or, (2) to prevent effective orientation to the opposite sex (a) by providing a very large number of pheromone sources or (b) by flooding the atmosphere by evaporating very large amounts of pheromone into it.

Pheromone Trapping

Some of the early work with trapping employed virgin females as the source of the pheromone in the trap, and this had the advantage that the pheromone was emitted over the particular limited period of the day which corresponds with the time of maximum male responsiveness.

If synthetic pheromone is available, possible lack of synchrony, caused by the artificial caged conditions, can be overcome since it is then possible to provide the pheromone continuously. However, another difficulty may arise, that of adaptation. Thus, even brief exposure of males of the light brown apple moth to the female sex pheromone during their quiescent period may greatly reduce responsiveness during the succeeding period of regular male activity.

When synthetic pheromone is available, it becomes possible to use in a trap the equivalent of hundreds or even thousands of females. This, however, may also lead to problems. Males may only respond normally to a pheromone concentration that is typical of a single female and, hence, may not approach more closely than a few meters away from a concentrated source of pheromone. Further movement towards the odor source may cease in the region surrounding the source where the message is received that a single female is present. Copulatory motions have been described well away from the pheromone source under these conditions. Whether or not this effect occurs apparently depends upon the species concerned and perhaps upon the conditions, particularly the emission rate of the pheromone from the source.

Thus, with increasing amounts of pheromone, gypsy moth traps remained effective over progressively longer periods and, at the highest pheromone level used, amounting to 500 female equivalents, no inhibition was observed.

Many kinds of trap have been designed for use with pheromones, a common type being a surface covered with some sort of sticky substance having the dispenser of pheromone placed in the center, the whole being protected from the rain and capable of being suspended at an appropriate height.

The main pest species for which mass trapping is promising are the spruce bark beetle, the gypsy moth, the Japanese beetle, and the boll weevil. That male annihilation can work was demonstrated in the Pacific region by means of methyl eugenol, a non-pheromonal attractant, against the oriental fruit fly, *Dacus dorsalis*. Methyl eugenol is applied together with malathion, naled, or another insecticide to fiber-board wafers or twisted cotton cords and scattered over the areas inhabited by the fruit fly. This is a practical method of control in, and even for eradication from, areas such as moderate-size islands and is more effective than any of the pheromone-trapping treatments so far investigated for other pests.

Mating Disruption

Pheromones, or pheromone analogues, may be used in an attempt to prevent effective orientation of males by "saturating" the atmosphere with pheromone or by providing an overwhelming number of pheromone sources. This general approach, which has been considered mainly in relation to Lepidoptera, has also been termed the "male confusion" technique. The continuous presence of high concentrations of pheromone is probably effective in preventing males from locating females, primarily because the increase in odor needed to evolve a response must be significantly above the background. In clean air, the amount of pheromone produced by a female is readily detected by the male but, if there is already in the air an all-pervading high concentration of pheromone, the increment of pheromone produced by a female cannot be perceived. This effect is presumably reinforced by a state of adaptation to high concentrations of pheromone mentioned earlier.

Whatever the mechanism of action, this is a promising approach to the control of some pest Lepidoptera, especially those that do not migrate far after mating. An Australian colleague of mine showed that, if at least 6 milligrams/hectare/hour of its synthetic sex pheromone was released in a peach orchard, the oriental fruit moth did not cause its customary economic damage. The control achieved was, indeed, better than in orchards receiving a full seasonal schedule of six insecticide applications. The synthetic pheromone was exposed in fine, hollow, polythene tubes, two of them in every eighth tree in the orchard. To save labor, they could be hung in the trees at the time of pruning and remain effective over a period of about 200 days. The six sprays of parathion cost $56 (Australian) per hectare, whereas the pheromone cost $40 per hectare, and the increased protection conferred was estimated to be worth $30 per hectare resulting in savings of $46 per hectare.

More or less encouraging mating disruption data are available for about 40 lepidopterous pests, including the pink bollworm, peachtree borer, codling moth, gypsy moth, western pine shoot moth, Douglas-fir tussock moth, and spruce budworm.

At present, there appears to be little likelihood that mating disruption will be adopted in situations where crops are attacked by a complex of pests, particularly where these include insects that are not Lepidoptera and where they can be controlled only by pesticides. This is the situation in many Asian rice growing areas where the Asiatic rice borer (the caterpillar of a moth), only one of a complex of borers, consistently causes a low- to medium-level of damage, the effects of which are masked by the spectacular damage resulting from pests such as planthoppers. When all of the major pests in a complex are Lepidoptera, it may be possible to disrupt mating of several species simultaneously by using a mixture of materials. This has been attempted only on a very small scale for orchard tortricids and for noctuid pests of field crops.

The greatest likelihood of success and rapid adoption will be in situations where there is only one important species, and secondary pest problems arise through pesticide treatments directed at the major pest. Codling moth and oriental fruit moth are two examples of a major pest which at present can be satisfactorily controlled through the judicious use of pesticides. However, should they become resistant to the only acceptable chemicals available, use of their pheromones may prove to be of great value.

HORMONES

Definition

Hormones are substances which are produced by an organism and exert their effects in the same organism away from their site of production.

Nature

The possibility of using hormones for insect control has been discussed for several decades, and a term "third generation pesticides" was even suggested for them when it was thought that they might prove spectacularly effective.

The hormones that have attracted most attention are the lipid-soluble juvenile hormone (neotenin or juvabione) and the water-soluble molting hormone (ecdysone). Both of these occur as related, but different, compounds in different insect groups so that there is a considerable degree of specificity between insects.

Juvenile Hormone

Juvenile hormone, being lipid-soluble, penetrates into the insect body if applied to the cuticle. It inhibits metamorphosis and must be present at the time of all larval molts but absent at the time of molting to the adult. It must be secreted again in the adult, since it also activates the ovarian follicle cells of the adult female and, in some insects, is necessary for pheromone production. If present at the time of the last larval molt, it inhibits normal metamorphosis, resulting in a supernumerary larval instar. In some instances the insect dies, but in others the insect survives and feeds, so that no control is achieved and indeed greater damage may result.

More than 5,000 chemical analogues have been synthesized in the hope of obtaining materials that would prove selectively toxic to insects either by inhibiting or hyperactivating the juvenile hormone, but this hope has only been realized, in practical terms, in a very limited way.

Only one such compound, methoprene, is yet licensed for use in the United States against floodwater mosquitoes. It is effective, in a microencapsulated form, at less than one part per hundred million in the water in which they breed. At this concentration, it has no effect on other aquatic insects or on vertebrates. Methoprene is also active in the higher Diptera and has been used as a feed-through insecticide (usually as an additive to licking salt) to control manure breeding flies, such as the buffalo fly. A similar material, Kinoprene, is specific for aphids and is capable of acting both directly on the aphid and systemically through the plant. Epofenonane has a somewhat different chemical structure and is effective against aphids, scale insects, and Lepidoptera, but does not harm bees. Precocenes, originally isolated from the plant ageratum, affects only bugs and other hemimetabolous insects but have little effect on the holometabola, with the exception of some Coleoptera.

Molting Hormone

The molting hormone, as its name implies, must be present for an insect to go through the complex series of steps resulting in the shedding of the old cuticle. It is capable of breaking both larval and adult diapause and of inducing molting in the intermolt period. There are several closely related ecdysones and a number of more distantly related natural or synthetic compounds with molting hormone activity. The aim of producing the synthetic compounds was to obtain a material that could be used to produce unnatural molting leading to death, or that would inhibit molting with a similar outcome. Ecdysone and its mimics cannot penetrate the waxy layer of the cuticle and must be fed. In general, very high concentrations are required to cause precocious molting and none of these materials has yet found a practical application.

Summary

One attractive feature of the hormone analogues is that many of them act rather specifically on a given group of insects. This provides the possibility of being able to control insect pests by means that would be completely harmless, not only to man and higher animals, but also to useful insects, such as biological control agents.

It was earlier hoped that insect pests would not be able to develop resistance to a material so necessary for the insects' own survival. However, this belief has not been confirmed and resistance to synthetic juvenile hormone has been reported, for example, in the flour beetle Tribolium castaneum is a strain known to be resistant already to DDT, lindane, and a large number of organophosphate and carbamate insecticides.

Interestingly enough, the oral administration of juvenile hormone at a particular period during the last larval instar led to a significant increase in the quality and weight of the silk of the silkworm, and this method is used commercially in Japan to increase silk yield.

GENETIC METHODS OF CONTROL

The impetus for research into genetic control systems stems largely from the spectacular success of the sterile-insect-release method (SIRM) in eliminating the New World screwworm fly from parts of the Caribbean and the United States, and also from a zone across northern Mexico.

The method depends upon the observation that many insects can be made sterile without gross interference with either their longevity or their mating ability. When introduced into a natural population, these sterile insects mate with the normal insects present, but no progeny results from the matings. The probability that a given normal female will be found first by, and mate with, a normal male and so leave progeny decreases as the ratio of sterile to normal males increases. In many species, the female mates once only, so a mating with a sterile male prevents her from leaving offspring.

Two ways of utilizing sterile males are available: (1) the rearing, sterilization, and release of large numbers of insects into the population and (2) the production of sterility in the natural population.

The Release Method

SIRM has one inherent advantage over most other methods of pest control, the efficiencies of which diminish as the population declines: it becomes more efficient as the population declines. This is illustrated by a simplified model (Table 1). The calculations are based on a natural five-fold increase per generation, which is fairly realistic for many species, even though their reproductive potential is far higher. The model provides for an insecticide treatment that kills 90 percent of each generation and for steady liberations of the same number of sterile insects so that, in the first generation, there are 90 sterile for every 10 fertile flies. Note that, with the sterile male method, a constant release rate will result in a higher and higher ratio of sterile to fertile insects as the population declines and that, in this model, the population is eliminated after three generations. On the other hand, the effect of each insecticide treatment on the population trend remains constant, regardless of population density. When the population density is high, the insecticide treatment is highly effective in terms of actual numbers killed. But the number killed by each treatment becomes lower and lower as the population declines. From this it follows that the cost of eliminating the last 5 percent of an insect population with insecticides is just as high as, or may be higher than, the first 95 percent. In this model, the population is not eliminated by insecticides for 10 generations.

TABLE 1: Theoretical Model Showing the Trend of

Insect Populations Subjected to Two Treatments

(basic model developed by E. F. Knipling)

Generation	No Treatment	Insecticide Treatment that Kills 90% Each Generation	Release of Constant Number of Sterile Insects that Initially Overflood the Natural Population by a Ratio of 9:1			
			Natural Population	Sterile Population	Ratio: Sterile to Fertile	Progeny
Parent	1,000	1,000	1,000	9,000	9:1	500
F1	5,000	500	500	9,000	18:1	132
F2	25,000	250	132	9,000	68:1	10
F3	125,000	125	10	9,000	900:1	0
F4	125,000 x 5	62	0	-	-	-
F5	125,000 x 5^2	31	-	-	-	-
F6	125,000 x 5^3	16	-	-	-	-
F7	125,000 x 5^4	8	-	-	-	-
F8	125,000 x 5^5	4	-	-	-	-
F9	125,000 x 5^6	2	-	-	-	-
F10	125,000 x 5^7	1	-	-	-	-

The effective and practical use of released, sterile insects depends on many factors, including:

1. An ability to rear enough insects to flood the natural population
2. A capacity to produce sterility without seriously affecting the ability of the released males to compete with normal males in the natural environment. It has been found possible in the Australian sheep blow fly to produce, through translocation between chromosomes, laboratory strains of the fly that leave no offspring when they mate with wild flies, although they are able to interbreed satisfactorily. These are more fully competitive than radiation-sterilized flies, but require some lethal condition to be incorporated into their genetic makeup, so that they are eventually eliminated by climatic or other conditions rather than simply replacing the wild population.
3. The natural population of the insect must reach a very low level at some stage of the year, or it must be reduced by some means (e.g., insecticides) to such a low level that swamping it with sterile males will be practicable. SIRM is most likely to be effective in comparatively small areas such as small and relatively isolated islands.

4. The released, sterile insects must not cause significant damage to crops, livestock, or man at the level required to achieve control or eradication of the natural population.

The method employed to produce sterility is exposure to ionizing radiation (e.g., from a cobalt source), but radiation sufficient to produce sterility always results in substantial reduction in sexual vigor and competitiveness. Indeed, in some insects, vigor is reduced to such an extent that the males are of little value if the more radiation-resistant females present in the mass rearings have to be sterilized also, which of course is necessary unless means are developed for separating them from the males.

Production of Sterility in the Natural Population

Some years ago, great hopes were held for the use of chemicals that are capable of sterilizing both males and females either by swallowing or by surface contact. These chemosterilants did not interfere seriously with the mating ability or general vigor of either sex. However, their major disadvantage is that all of the effective chemosterilants so far known are very hazardous to man, and work on them has largely been suspended.

Successful Use of Sterile Males

So far, SIRM is only being used successfully in field campaigns for the screwworm and for several species of fruit fly.

The first success with the latter group was the eradication of the melon fly (Dacus cucurbitae) from the island of Rota in the Western Pacific. Irradiated flies were released at the rate of about 9 million per week. Within three weeks, the reproductive rate of the normal females on the island had been reduced to zero, and in six months eradication had occurred. No precise information is available about the number of melon flies on Rota before releases began, but the island is small (about 33 square miles) and hosts for melon fly were mainly in the vicinity of a small native settlement at one end of it. Thus, the population was undoubtedly very small compared with most natural populations of pest insects.

Before this success on Rota, there had been a failure to eradicate the much more abundant Oriental fruit fly, Dacus dorsalis. Sterilized adults of this species were released at about 10 million per week for about 80 weeks without much apparent effect on the population. It is interesting that this same population of Oriental fruit fly was later eradicated in less than eight months by means of a mixture of the specific male lure, methyl eugenol, with an insecticide and dropped from aircraft over the island on 15 occasions.

A major operation has been in progress now for some years to eradicate, progressively, those two same fruit fly species from a chain of Japanese islands southwest from Kyushu and steady progress is being made. Sterile Mediterranean fruit flies (Ceratitis capitata) are also being used in an attempt to eradicate an infestation which became established in about 1980 in California (USA).

SIRM is being, or has been, investigated for a number of other major pests including the codling moth, the boll weevil, and various species of mosquitoes.

Population suppression has often been demonstrated, but the logistics of an eradication campaign and the costs involved are major problems.

The value of SIRM does not, of course, depend solely on its use for eradication. However, the problems and costs involved in maintaining a mass production facility simply for population reduction have deterred its use in most instances. One example, however, of the adoption of this approach is the buffer zone of irradiated adult Mexican fruit fly, *Anastrepha ludens*, in Baja California. This buffer zone is claimed to be responsible for the exclusion of gravid females from Mexico into southern California.

Date: Oct. 13
Time: 1450

ENVIRONMENTAL DIVERSITY AND INSECT PEST ABUNDANCE WITH REFERENCE TO THE PACIFIC

James A. Litsinger

HISTORICAL

From the relatively recent colonization of the Pacific islands by man (Bellwood, 1980), the original forest and grassland communities have been gradually replaced with agricultural crops leading to less diverse ecosystems. At first, small patches were cleared by slash-and-burn agriculture, and numerous subsistence crops were grown. This was a highly mixed system of fruit trees and root crops. As the human population increased, the natural forest and grassland communities gradually gave way to larger areas of slash-and-burn subsistence farming.

In recent times with a further increase in human population and development of markets, opportunities for cash crops have changed the manner in which crops were grown. Because of limitations in size of individual land holdings, cash crops were grown mainly as monocrops to maximize economic investments. First came low-management crops such as coconut, banana, cocoa, citrus, and root crops, which were long maturing but required less investment in labor and capital over time. Then as land became more limiting, high management, short-turnaround vegetable and cereal row crops were cultivated (Peters, 1973).

As the cropping systems evolved from slash-and-burn subsistence crops to early-maturing cash crops, the pest problems increased substantially. There is a widely held belief that because the original mixed agricultural systems were more stable and less prone to attack by pests, components of the environmental diversification of the mixed crop systems could be incorporated into the modern agricultural systems to stabilize pest populations (Perrin, 1977; Risch, 1980a).

Let us examine the components of environmental diversification to see which ones may hold promise in promoting insect pest stability for the Pacific region. This section has been adapted from Litsinger and Moody (1976), van Emden (1977), and Risch (1981).

INSECT PEST SUPPRESSING MECHANISMS FROM ENVIRONMENTAL DIVERSIFICATION

Crop Species

The choice of crop species that are cultivated is one aspect of regulating environmental diversity in an area.

Pest Spectra: In any location, crops differ in the number of pests that attain pest status. In the Pacific, root crops have few recorded insect pests while coconut, banana, crucifers, and cucurbits have more. This factor is not static as more pests will emerge in a location over time. The longer a crop species is grown in an area and the greater the area is cultivated to the crop, there is an increased probability that new pests will arrive in an island and become more established (coconut and banana are examples of this phenomenon).

Aspects of island biogeography dictate the eventual number of key pests that any one island can sustain (MacArthur and Wilson, 1967; MacArthur, 1972). Insect pests have dispersed over the Pacific island "stepping stones" from west to east, gradually becoming filtered out over the long distances involved between neighboring islands. With airplanes and cargo ships, these distances are becoming less of a barrier than before.

Those pests such as trypetid fruit flies, which dispersed quickly throughout the Pacific island archipelago, have undergone speciation and have changed host preferences due to factors of isolation and interspecific competition (Drew, 1975). Each Pacific island has a unique composition of trypetid fruit fly species, each with a unique array of plant host preferences.

Pest distribution between islands is highly variable, even for crops such as coconut, taro, and banana, which have been cultivated from the time man first arrived on the islands.

Larger islands will support more pest species than smaller islands. Nearby islands will share a more common pest complex than more remote islands because the greater the distance between islands, the lower is the probability of insects becoming transferred.

In addition, as each crop species expands in area, the greater are the chances that new pests will transfer from native hosts to attack crop species. Examples are fruit flies and fruit-piercing moths.

Introduced crop species such as temperate vegetables that have undergone extensive breeding over many decades lose their natural chemical defenses. Yam and cassava, for example, are more similar genetically to the original wild plants than the highly bred crucifer, cucurbit, and solanaceous crops.

Annual vs. Perennial: Annual crops suffer more than perennial crops from insect pests. Annual plants that are actively growing are more likely to receive fertilizer and undergo high rates of photosynthesis in order to compete with weeds and escape predation by insect pests (Risch, 1981). Such plants are high in the energy resources that insect pests require and, therefore, insects feeding on these plants develop faster, produce more progeny, and attain higher survival than those feeding on slower growing perennial species. Perennial crops, because they are not under a time constraint, except during early growth, can allocate more of their photosynthate to chemicals antagonistic to pests once they have overcome their competitiveness to neighboring plants.

Coconut stick insect would be a much greater pest if it attacked old as well as young coconut trees. Older trees perhaps are able to produce chemicals that are antagonistic to the stick insect.

Perennial crops, because of their greater stability over time, allow natural enemy populations to become established. It is due to stability that more successes have occurred with natural enemies in perennial crops than in the highly disturbed and unstable annual crops

(Hall et al., 1980). Natural enemies have difficulty in becoming established in short-duration crops. This is less true, however, in wetland rice, as the aquatic environment, with its diverse invertebrate fauna attracts more predators than would exist in dryland culture.

Plant Architecture: Tree crops such as coconut, citrus, and cocoa provide more ecological niches suitable for the establishment of natural enemies than short standard erect crops. Decumbent crops such as sweet potato increase humidity and shade at ground level, providing more favorable habitat for soil-dwelling predators or insect pathogens than do the erect crops. The sweet potato hornworm populations are kept in check by insect pathogens.

Crop Variety: Susceptible, resistant, tolerant varieties: Wild plants have evolved mechanisms to combat insect pests; these mechanisms include chemicals that are detrimental to pests and production of greater leaf areas to tolerate defoliation. Development of resistant rice varieties by the International Rice Research Institute against several key insect pests (brown planthopper, green leafhopper, and stem borers) has provided a breakthrough in integrated pest management of this crop (Heinrichs et al., 1979). Without this resistance, greater insecticide usage would have to be relied upon with the inevitable consequences of insecticide resistance, pest resurgence, and environmental problems on nontarget organisms including man.

Natural enemies of rice pests have been allowed to survive because of the limited need for insecticide usage, and chronic pests can now be readily managed. Development of resistant varieties has only just begun for other crops such as cotton, which are attacked by a multitude of pest species throughout their growth cycle, or for crops such as sweet potato, crucifers, and maize, where insect pests cannot be readily controlled by other means. It would be more time consuming but not impossible to develop resistant varieties in perennial tree crops.

Maturation period: Insect pests multiply exponentially with time. Choosing crop varieties that mature earlier reduces the carrying capacity of the crop to insect pests. This tactic has been used with great success in rice, cotton, and maize (Litsinger, 1982). Reducing the growing period of a crop so that one less generation of a pest species can develop has drastically reduced the damage from insects. Breeders can reduce duration without sacrificing yield potential.

CROP ARRANGEMENT IN TIME

Sequence of Rotation

Alternation of annual crop species in time has long been known to lessen the incidence of pests. The success lies in choosing (usually by experience) sequences of crops having the fewest pests in common. The best results are usually achieved by combinations of botanically unrelated crops following one another. The effect is to break pest cycles by eliminating the food source. Cucumber should not be planted after watermelon; cabbage should not be planted after radish.

The long rainy seasons in the Pacific Islands allow for long growing seasons involving sequences of annual crops, and crop rotation should play a role in pest suppression.

Continuous vs. Discontinuous: Monoculture is growing the same crop species on a field over time. Rice can be cropped one to four times a year, the number of times depending on climate, water availability, and variety. Sweet potato grown on the same field year after year results in greater populations of sweet potato weevil. Banana plantations grown year after year result in greater banana weevil (Litsinger, 1974). Ratooning sugarcane over years results in greater insect pest buildup. Insect populations can be reduced if the right crop species are rotated over time to break pest cycles.

Asynchronous vs. Synchronous: Most insect pests can readily disperse to neighboring fields, and studies have shown that their effective range of flight is only 1-2 kilometers (Loevinsohn et al., 1982). Long-distance migrants that can disperse in the wind over hundreds of kilometers are less of a threat to the present crop than short-distance migrants. Asychronous planting of crops among neighboring farms extends the effective crop maturation period for insects that can disperse by wind. Rainfed farmers usually suffer lower pest incidence (because they have to plant at once) than farmers who have irrigation and spread out their planting times. The consequences of asynchronous planting in rice in terms of insect pest buildup has recently been demonstrated (Loevinsohn et al., 1982). Farmer groups should become organized to regulate members in choosing the time to plant. Islands can be zoned such that farmers in each zone plant together. Zoning would overcome the problem of not having a constant supply for the island as a whole.

Seasonal Position of Each Crop: The effect of season on pest abundance is well known, and adjustment of planting or harvesting times of annual crops has proved to be an inexpensive means of preventing problems from pests, whose activity is triggered by weather-related responses. Delayed planting of host crops after the initiation of the rainy season can result in a suicidal emergence of pests (moths or beetles) that lie dormant during the dry season. Other pests such as seedling maggots or shootflies become abundant during certain months in the rainy season, and shifting planting time will escape their damage (Litsinger, 1982). Other pests such as aphids, thrips, and beanfly are held in check by heavy downpours. Their damage is greater in the dry season when their populations are higher and the crop is less tolerant of their feeding because of moisture stress.

CROP ARRANGEMENT IN SPACE

Sole Crop, Intercrop, Mixed Crop

A number of reports show the beneficial effect of pest population reduction when crop species coexist in a field, either in an irregular (mixed crop) or a regular (intercrop, strip-crop) arrangement. The examples are not many, and their beneficial effect is highly species and location specific. The degree of pest suppression, furthermore, is not great in any of the known examples (Cromartie, 1981; Risch, 1981). Some intercropping or mixed cropping combinations may even lead to greater pest problems. Mixing fruit tree species that bear fruit at different times, for example, will enhance trypetid fruit flies. Placing hedge rows of Erythrina trees near citrus or tomato will enhance populations of the fruit-piercing moth. The effects of intercropping and mixed cropping, therefore, are highly location specific and depend on the composition of pest species in a particular area.

From the examples that have been studied in detail, the causal mechanisms of associational resistance, which reduce particular pest species, have been classified by Root (1973) and summarized by Risch (1981) as the "natural enemies mechanism" and "resource concentration mechanism."

Natural enemies mechanism: Insect predator and parasite abundance increases in species-rich associations by three means:

1. Diversified crop arrangements offer greater temporal and spatial distribution of nectar and pollen sources, both of which attract natural enemies and increase their reproductive potential.

   Flowers are important sources of adult food for many beneficial insects. Females of beneficial species need to feed on nectar or pollen before they can deposit viable eggs. Parasites and predators are attracted to coconut and maize flowers, and these crops benefit more from their presence than do nonflowering crop plants such as leafy vegetables.

2. Increased ground cover provided by decumbent crops creates a microhabitat and shelter favorable for natural enemies particularly ground dwellers (Dempster and Coaker, 1974). Perrin (1977) cites examples where ground-dwelling predators

in crucifers and cereals were increased by intercropping decumbent legumes.

3. Increased plant species richness provides alternative hosts for beneficial insects when the main hosts are scarce. Two crops side-by-side in strips may maintain the population equilibrium of host-natural enemy relationships in a way a sole crop cannot. Alternative hosts to natural enemies in one crop may maintain a reservoir of beneficial insects when the second crop is cleared of hosts by harvesting, maturation of plants, or use of insecticides. Stern (1969) reported less Lygus bug injury to cotton when strip-cropped with alfalfa. Robinson et al. (1972) found that grain sorghum strip-cropped in cotton provided a reservoir of predators that ultimately moved into cotton to seek prey. Laster (1974) reported that sesame interplanted in cotton attracted higher numbers of Heliothis than did cotton alone, but that Heliothis larvae in the intercrop were largely controlled by predators and parasites.

Crop diversity, however, does not always ensure a greater enhancement of natural enemy effectiveness. Natural enemies that have to colonize a crop in the same manner as pests may be as negatively affected as are pests to aspects of host plant responses in intercrop systems (Perrin, 1977). Ryan et al. (1980) reported that ground cover did not increase ground-dwelling predators. Cromartie (1981) also reported instances of a lack of natural enemy response.

Resource concentration mechanism: The resource concentration mechanism involves behavioral mechanisms in the pests themselves for locating host fields and successfully colonizing and remaining on the host plants. Pests respond to visual and chemical stimuli or cues from host and nonhost plants that affect both the rate of colonization of habitats and their behavior once within the habitat. The total strength of the attractive stimuli for any pest is the result of the following interacting effects: (1) the number of host species present and the relative preference of the pest for each, (2) the absolute density and spatial arrangement of each host species, and (3) interference effects from nonhost plants. A pest approaching a habitat will have greater difficulty locating a host plant when the relative resource concentration is lower (Risch, 1981).

Trap or Diverting Crop

In an intercrop, two crops that are common hosts of a pest may be used to divert that pest from the main crop. Maize and cotton are both hosts of *Heliothis*, maize being more preferred. *Heliothis* is diverted from the more valuable cotton crop to a maize variety that silks before the cotton sets flowers. Sesame acts as a trap crop for *Heliothis* in cotton interplantings (Pair et al., 1982).

Barriers

Planting tall hedge rows at intervals along the borders of fields interferes with the horizontal air currents, causing wind-dispersed small insects such as aphids to settle out on the leeward side, resulting in smaller populations in the center of fields.

Nonhost, Antiarrestant Effect

Insects that locate their plant hosts by taste alight at random on the taller plants in a field. If a tall nonhost plant is intermixed with a short host plant of a particular pest species, fewer individuals will be able to locate their food plants. They will tend to alight on tall plants; if, after tasting them, they find out the plants are not to their liking, they will continue to disperse and leave the field. Insect pests remain longer in sole crops than in polycultures (Bach, 1980). Only when they physically alight on their preferred host will their dispersal behavior be arrested. In Costa Rica, chrysomelid beetles that attack sweet potato and beans were less abundant on these crops when maize, a nonhost, was intercropped (Risch, 1979). The bean-fly pest of cowpea and mungbean in the Philippines was less abundant during the early growth stages of these crops when tall rice stubble was present (Ruhendi and Litsinger, 1980).

Crop Background

Many pests, particularly day-flying long-distance migrants that utilize visual cues to find their hosts--aphids, thrips, leafhoppers, and whiteflies--are highly attracted to green crops set against a bare soil background (Smith, 1976). The greater the area of bare soil between crop rows, the more the crop becomes attractice to them. These insects utilize optomotor responses (Johnson, 1974) passing rapidly over their retinas. The optomotor response allows the insect to judge its motion relative to the ground (Kennedy and Thomas, 1974). To slow down, the insect descends close to earth in the boundary layer of stiller air where the wind speeds are lower (Taylor, 1974). Friction caused by wind passing over vegetation or the ground surface slows wind speeds, and insects seek this boundary layer before alighting on a crop plant.

This group of day-flying insects is adapted to colonize seedling host plants that grow in disturbed soil such as a plowed field. They will tend to fly over crops with closed canopies and weeds or mulch covering the bare ground. Fewer of these dispersing insects will land on an older crop that densely covers the soil. Straw mulch or stubble left over in minimum tillage from the previous crop is also effective. A weedy crop is less attractive for the same reason, but leaving weeds is not an acceptable agronomic practice (Dempster and Coaker, 1974), although van Schoonhoven et al. (1981) suggested searching for less competitive weeds in interplanting systems.

Aluminum foil placed in bands on either side of a crop row also repels this same group of pests (Schalk et al., 1979; Wyman et al., 1979). This method, although expensive, has been the only known mechanism of controlling insect vectors of viruses in crops such as cucurbits and legumes. The reflected sunlight interferes with their strong attraction to light of longer wave lengths as they descend. Dispersing insects are first strongly attracted to light of short wave lengths which causes them to rise higher in the air (Kennedy et al., 1961). After their energy reserve is depleted from prolonged flight, they became attracted more to light coming off the earth's surface, which is of longer wavelengths. This causes them to descend. Aluminum foil, by reflecting skylight of shorter wavelengths causes these insects to be repelled.

Olfactory Inhibition

Insects that locate their hosts by the odors (Chemicals) emitted by plants are less attracted to fields emitting many kinds of odors. Crucifers emit chemicals that attract insect pests and, if other aromatic plants are grown in association with crucifers, the attractant odors become diluted and even masked. Organic gardeners have intercropped aromatic plants such as basil, garlic, and marigold to repel pests. Whether they are repelled or simply not attracted has not been determined. Researchers who have tested these have not always achieved beneficial results (Lateef and Irwin, 1979).

Microclimate

Intercropping tall and short plants changes the microclimate in the crop. Most reports cite shade created by the tall crop repelling certain insects such as sun-loving beetles from the short undercrop (Risch, 1980b, 1981). But, other beetle species are attracted to shade (Smith and Webb, 1970).

Plant Density

Dense planting through narrowly spaced rows provides a quicker canopy cover of the bare ground between rows and reduced infestation of pests that are attracted to plants set against bare soil (crop background effect). Pests that utilize olfactory cues to locate plants such as crucifers are more greatly attracted to dense plantings. This advantage gives way in time as insect pests build up rapidly on a per plant basis.

Large vs. Small Fields

Two situations arise regarding the size of fields and the resulting insect pest buildup. Insects that respond to olfactory or visual plant cues and which are distributed evenly in a field will be more attracted to larger fields proportional to their area on a per plant basis (Cromartie, 1975). This is the resource concentration hypothesis (Root, 1973). Oriental maize borer, for example, attains larger populations in larger fields (Hasse, 1981). Other pests that disperse on the ground, such as banana weevil borer (Litsinger, 1974), or wind-dispersed pests, such as the maize delphacid, which settle proportionally more along the borders, will attain greater numbers in small fields because of their larger perimeter area relative to field size (Johnson, 1969).

Regional Host Crop Area

For insects to successfully colonize a newly planted crop, there must be a sufficient pest population generated from a previous source--the greater the area planted to the previous host crops within the effective range of dispersal (which for most insects is several kilometers), the greater will be the pest buildup to invade a newly planted field. The quantity of land area devoted to host crops is a contributing factor for pest buildup. The greater the area devoted to a crop, the greater the probability of a dispersing insect to locate its host plant. In contrast, however, to the dimension of time in which insects build up exponentially with increased crop duration in the area, the dimension of space is described in terms of population increase in an algebraic (additive) fashion. In the Pacific islands, where crop land is limited, insect pest populations attain lower levels than is common in continents.

Distribution of Host Crop Fields

Field distribution in space is also a factor that affects pest population buildup. Aggregated fields will attain higher pest numbers than scattered fields. With the exception of coconut and banana, the Pacific islands typically have widely scattered fields that act to decrease pest abundance. Pests dispersing from scattered fields will have a lower probability of finding host crops among nonhost crops.

CROP DIVERSIFICATION AND INSECT PEST DAMAGE

Intercropping is a common response of farmers to minimize risks from crop stress. Devoting a field to more than one crop species spreads the risk of crop failure as not all crop species will be affected equally by a particular stress. Placing several crops together sets up competition between them, leading many people to believe that yields will be lower than for sole crops. For certain species this is true, but for other combinations this is not true as both crops together will yield higher than either alone, as measured by land equivalent ratio (Trenbath, 1976).

In intercropping combinations, insect pest damage to one crop is compensated by the increased growth of the second crop (IRRI, 1977, 1978).

CONCLUSION

The South Pacific islands, because of their recent origin in geological time, small size, and isolation from continents and each other, show a progressive decline in plant and insect richness from west to east (van Balgooy, 1971). Their depauparate or fragile ecosystems have made them particularly vulnerable to the introduction of exotic pest species because few natural enemies exist to challenge them (Hall et al., 1980). Island isolation has enabled exotic species to exploit existing habitats and broaden host ranges under low interspecific competition with eventual speciation as an outcome. Trypetid fruit flies are a prime example of this phenomenon.

Strict ;uarantine and treatment of produce shipped between islands is a must before interisland trade can be established. Facilities to treat produce should be established to allow expanded agricultural markets so necessary in these island economies.

Pest problems have been accentuated with the increased expansion of agricultural land in response to increased population pressure. Because of the small size of the islands and, consequently, small land holdings, agriculture is shifting to high-value row crops, creating pressure to export these to neighboring islands. Pests quickly become introduced and pesticide usage has just as quickly increased because the farmers cannot afford yield loss on the high-value crops.

Root crops typical of mixed-cropping systems in subsistence agriculture were grown in small isolated plantings. These crops are slow growing and have not been greatly altered genetically from their original wild parents; thus, they have suffered little from insect pests. Temperate and subtropical introduced crops, however, have inherently greater insect problems even if they are grown in subsistence mixed cropping systems because the insect resistance in the original wild types has been bred out of them.

Coconut and banana have been grown extensively from the time man first colonized the Pacific islands. The large area devoted to these perennial crops and the great number of years that the crops have been grown has resulted in high numbers of pest species that became established on them.

Aside from quarantine, I have discussed various methods of decreasing pest pressure by creating changes in the environment.

Perennial crops have lower carrying capacities for insect pests, and methods such as the introduction of biocontrol agents and creation of crop diversity through mixed or intercropping offer the greatest promise.

Pest management of annual crops that have higher carrying capacities for insect pests should focus on isolation of the crop in time (synchronous planting in zones, crop rotation, and early-maturing varieties) and in space (small isolated fields), use of mulches, and development or introduction of pest-resistant varieties.

REFERENCES CITED

Bach, C. E. 1980. Effects of plant diversity and time of colonization on an herbivore-plant interaction. Oecologia (Berl.) 44:319-326.

Bellwood, P. S. 1980. The peopling of the Pacific. Sci. Amer. 243(5):138-147.

Cromartie, W. J., Jr. 1975. The effect of stand size and vegetational background on the colonization of cruciferous plants by herbivorous insects. J. Appl. Ecol. 12:517-533.

Cromartie, W. J., Jr. 1981. The environmental control of insects using crop diversity. p. 233-251. In: Pest Management. D. Pimental (Ed.). Vol. 1. Chemical Rubber Co. Handbook Series in Agriculture. C.R.C. Press, Florida.

Dempster, J. P., and T. H. Coaker. 1974. Diversification of crop ecosystems as a means of controlling pests. p. 106-114. In: Biology of Pest and Disease Control. D. Price Jones and M. E. Solomon (Eds.). 13th Symposium British Ecological Society Blackwell Scientific Publ.

Drew, R. A. I. 1975. Zoogeography of Dacini (Diptera: Tephritidae) in the South Pacific area. Pacific Insects 16:441-454.

Hall, R. W., L. E. Ehler, and B. Bisabri-Ershadi. 1980. Rate of success in classical biological control of arthropods. Bull. Entomol. Soc. Amer. 26:111-114.

Hasse, V. 1981. The influence of vegetational diversity on host-finding and larval survival of the Asian corn borer, Ostrinia furnacalis Guenee (Lepidoptera: Pyralidae). Ph.D. dissertation, Justus-Liebig Univ. Giessen, W. Germany (unpubl.).

Heinrichs, E. A., R. C. Saxena, and S. Chelliah. 1979. Development and implementation of insect pest management system for rice in tropical Asia. p. 208-248. In: Sensible Use of Pesticides. Food and Fertilizers Technical Center (FFTC) for the Asian and Pacific Region (ASPAC). FFTC Book Series No. 14. FFTC, Agriculture Building, 14 Wen Chow St., Taipei, Taiwan.

International Rice Research Institute. 1977. Cropping Systems Program. p. 354. In: Annual Report for 1976. IRRI, Los Banos, Philippines.

International Rice Research Institute. 1978. Cropping Systems Program. p. 467-468. In: Annual Report for 1977. IRRI Los Banos, Philippines.

Johnson, C. G. 1969. Migration and dispersal of insects by flight. Methuen, London.

Johnson, C. G. 1974. Insect migration: aspects of its physiology. p. 279-334. In: The Physiology of Insecta. M. Rockstein (Ed.). Vol. 3.

Kennedy, J. S., C. O. Booth, and W. J. S. Kershaw. 1961. Host-finding by aphids in the field. III. Visual attraction. Ann. Appl. Biol. 49:1-21.

Kennedy, J. S., and A. A. G. Thomas. 1974. Behavior of some low-flying aphids in wind. Ann. Appl. Biol. 76:143-159.

Laster, M. L. 1974. Increasing natural enemy resources through crop rotation and strip-cropping. p. 137-149. In: F. G. Maxwell and F. A. Harris (Eds.), Proc. Summer Inst. Biol. Control of Plant Insect and Disease. Univ. Mississippi Press, Jackson.

Lateef, M. A., and R. D. Irwin. 1979. The effects of companionate planting on Lepidopterous pests of cabbage. Can. Entomol. 111:863-864.

Litsinger, J. A. 1974. Final report of the Entomologist 1972-1974. Ministry of Agriculture, Kingdom of Tonga.

Litsinger, J. A., and K. Moody. 1976. Integrated pest management in multiple cropping systems. p. 293-316. In: Multiple Cropping. R. I. Papendick, P. A. Sanchez, and G. B. Triplett (Eds.). Amer. Soc. Agron. Spec. Publ. No. 27.

Loevinsohn, M., J. Litsinger, J. Bandong, A. Alviola, and P. Kenmore. 1982. Synchrony of rice cultivation and the dynamics of pest population: experimentation and implementation. Saturday Seminar, 28 August 1982. International Rice Research Institute, Los Banos, Philippines.

MacArthur, R. H. 1972. Geographical Ecology. Patterns in the Distribution of Species. Harper and Row, New Jersey.

MacArthur, R. H., and E. O. Wilson. 1967. The theory of island biogeography. Princeton University Press, Princeton, New Jersey.

Pair, S. D., M. L. Laster, and D. F. Martin. 1982. Parasitoids of Heliothis spp. (Lepidoptera: Noctuidae) larvae in Mississippi associated with sesame interplanting in cotton, 1971-1974: implication of host-habitat interaction. Environ. Entomol. 11:509-512.

Perrin, R. M. 1977. Pest management in multiple cropping systems. Agroecosystem 3:93-118.

Peters, C. W. 1973. A preliminary review of the prospects for intraregional trade in fruits and vegetables in the South Pacific Region. UNDP, Suva, Fiji.

Risch, S. J. 1979. A comparison, by sweep sampling, of the insect fauna from corn and sweet potato monocultures and dicultures in Costa Rica. Oecologica (Berl.) 42:195-211.

Risch, S. J. 1980a. The population dynamics of several herbivorous beetles in a tropical agroecosystem: the effect of intercropping corn, beans, and squash in Costa Rica. J. Appl. Ecol. 17:593-612.

Risch, S. J. 1980b. Fewer beetle pests on beans and cowpeas interplanted with banana in Costa Rica. Turrialba 30:229-230.

Risch, S. J. 1981. Insect herbivore abundance in tropical monocultures and polycultures: an experimental test of two hypotheses. Ecology 62:1325-1340.

Robinson, R. R., J. H. Young, and R. D. Morrison. 1972. Strip-cropping effects on abundance of Heliothis-damaged cotton squares, boll placement, total bolls, and yields in Oklahoma. Environ. Entomol. 1:140-145.

Root, R. B. 1973. Organization of a plant-arthropod association in simple and diverse habitats: the fauna of collards (Brassica oleracea). Ecol. Monogr. 43:95-124.

Ruhendi and J. A. Litsinger. 1980. Effect of rice stubble and tillage method on preflowering insect pests of grain legumes. Proc. Symposium on Cropping Systems 3-7 March 1980. International Rice Research Institute.

Ryan, J., M. F. Ryan, and F. McNaeidhe. 1980. The effect of interrow plant cover on populations of the cabbage root fly, Delia brassicse Wiedemann. J. Appl. Ecol. 17:31-40.

Schalk, J. M., C. S. Creighton, R. L. Fery, W. R. Sitterfly, B. W. Davis, T. L. McFadden, and A. Day. 1979. Reflective film mulches influence insect control and yield in vegetables. J. Amer. Soc. Hort. Sci. 104:759-762.

Smith, F. F., and R. E. Webb. 1970. Soil mulches for repelling Mexican bean beetles. Proc. 9th Natural Agric. Plastics Conf. p. 59-61.

Smith, J. G. 1976. Influence of crop background on aphids and other phytophagous insects on Brussels sprouts. Ann. Appl. Biol. 83:1-13.

Stern, V. M. 1969. Interplanting alfalfa in cotton in control Lygus bugs and other insect pests. Proc. Tall Timbers Conference on Ecological Animal Control by Habitat Management. 1:55-69.

Taylor, L. R. 1974. Insect migration, flight periodicity and the boundary layer. J. Anim. Ecol. 43:225-238.

Trenbath, B. R. 1976. Plant interactions in mixed crop communities. p. 129-169. In: Multiple Cropping. R. I. Papendick, P. A. Sanchez, and G. B. Triplett (Eds.). Amer. Soc. Agron. Spec. Publ. No. 27. Madison, Wisconsin.

van Balgooy, M. M. J. 1971. Plant-geography of the Pacific. Blumea. Suppl. 6.

van Emden, H. F. 1977. Insect-pest management in multiple cropping systems - a strategy. p. 325-343. In: Proceedings, Symposium on Cropping Systems Research and Development for the Asian Rice Farmer, 21-24 September 1976. International Rice Research Institute, Los Banos, Philippines.

van Schoonhoven, A., C. Cordova, J. Garcia, and F. Garzon. 1981. Effect of weed covers on Empoasca Kraemeri Ross and Moore populations and dry bean yields. Environ. Entomol. 10:901-907.

Wyman, J. A., N. C. Toscano, K. Kido, H. Johnson, and K. S. Mayberry. 1979. Effects of mulching on the spread of aphid-transmitted watermelon mosaic virus to summer squash. J. Econ. Entomol. 73:139-143.

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Time: 0930

CHEMICAL CONTROL: PRINCIPLES AND TECHNIQUES

Niels von Keyserlingk

Pesticide use in recent history began in 1867 with the chemical Paris green (copper acetoarsenite) to control the Colorado potato beetle (Leptinotarsa decemlineata) in the United States. Soon after that, the usefulness of Bordeaux mixture was accidentally discovered to control fungal diseases in vineyards in France. At the beginning of this century, very toxic compounds based on fluorides and heavy metals became available. Some of them are still in use. Lindane or BHC was discovered in 1933 and DDT in 1935. DDT's founder, Paul Müller, received the Nobel prize for giving the world one of the most controversial chemicals ever.

Today, to market a new pesticide, intensive basic research is required not only to determine its effect on agricultural crops and the target pests but also on human health and ecological systems. A period of 10-12 years or more may elapse from the time the laboratory work is started until the pesticide is marketed to farmers. The cost to develop a new chemical has continued to rise and is now around $20 million (USA). For that reason, the number of new pesticide chemicals will likely be limited in the future. Further, some of the existing pesticides will likely be withdrawn from the market as new information on their harmful effects on human health and the environment become available.

TYPES OF PESTICIDES

What is a pesticide? Derived from the words "pest" and "cide," a Latin derivative meaning "killer," pesticide describes the various chemicals used in crop protection and pest control. Broadly, the term means any chemical used to control any kind of pest in any agricultural or nonagricultural situation, except, here, it excludes chemicals used to control internal parasites of man and animals.

The term pest includes any living organism which is somewhere that man does not want it to be. The main pests of economic importance are weeds, fungi, and insects and, therefore, the main groups of pesticides are classified as herbicides (weedicides), fungicides, and insecticides. All these words combine the prefixes meaning plants, fungi, and insects with the suffix cide. Other pesticides include acaricides, bactericides, rodenticides, nematicides, and molluscides, for example, each being named according to the group of organism which it is used against.

MODE OF ACTION

Pesticides are also classified according to their "mode of action," that is, they are grouped according to what they do to the pest. For example, a "contact" pesticide kills pests simply by contacting them; a "stomach poison" kills when swallowed; and a "fumigant" kills as the pesticide (a poisonous gas) is inhaled or otherwise absorbed by the pest. It is known that many pesticides can act in several ways: for example,some insecticides act as contact and stomach poisons and also as vapor toxicants. The classification therefore should concern the toxicological action of the pesticide on the vital tissues and enzyme systems and not just the mode of entry and means of transfer in the target organism.

Insecticides and fungicides can be broadly classified as "volatile," "superficial," or "systemic" compounds, and herbicides as "contact" or "systemic" compounds. Volatile compounds are the fumigants--the toxic ingredient reaches its target as a gas. Superficial and systemic compounds differ in the way they are absorbed and translocated by the plant. Systemics are taken into the sap of a plant and move throughout it. Superficial compounds are neither absorbed nor translocated by the plant.

To be of value in the control of pests in agriculture, systemic pesticides must not damage the crop. Ideally, they should be completely free of physiological effect on the crop plants. All compounds effectively systemic in plants are much more soluble in water than in oils. For translocation within the plant, the water/oil partition ratio must be high.

Systemic pesticides are applied as granules or sprays to the soil or foliage, or in the case of woody plants, they are directly injected into the phloem system with special injectors. Sap-feeding insects such as aphids are more readily killed by systemic than contact insecticides. Parasites and predators are normally not affected unless they come into contact with the insecticide during spraying (Green et al., 1977).

Systemic insecticides are mainly effective against leaf-feeding and stem-sucking insects. They usually are not effective against insects that feed on roots. They are mainly useful for rapidly growing crop plants, which have an adequate water supply. The net water movement is upward and outward (evaporation) which results in the tendency for systemic chemicals to accumulate in rapidly transpiring young leaves that have developed fully. There is no net movement of the pesticide downward into the root. Even when applied onto the soil, there is no accumulation in the roots--only in the leaves.

Superficial pesticides are the more oil-favorable chemicals. They are not transported in the plant's phloem system, but they can diffuse short distances before decomposition. Thus, even highly oil-favorable compounds applied to one side of a leaf can kill insects that feed on the other side. However, they are only effective on those leaves to which applied. Superficial insecticides are commonly used to control leaf miners (Green et al., 1977).

NOMENCLATURE OF PESTICIDES

By the time a pesticide is marketed, it has been identified by four names:

- Test number assigned by the pesticide's manufacturer
- Chemical name
- Common name
- Trade name.

The test number is used by researchers and others working with the chemical when it is still in an experimental stage of development.

The chemical name is a description of the pesticide's chemical structure. For example, the chemical name of gamma BHC, or lindane, is: gamma - 1, 2, 3, 4, 5, 6 - hexachlorocyclohexane.

For practical reasons, the chemical name has to be shortened to an internationally acceptable common name. And here is where the problem of pesticide nomenclature begins. Although the International Standards Organisation Technical Committee 81 (ISO) attempts to standardize the usage of common names, the Organisation is not supported by the USA and the USSR, for example. The Organisation tries to get agreement on common names for pesticides between the national standards organizations of the various participating countries. Getting agreement among the various countries is often a long and tedious procedure.

The Organisation specifies that a short common name selected must:

- Be easily pronounced in any language
- Not closely resemble any existing word in any language

- Not conflict with any trade name in any country
- Desirably, have some relationship to the chemical name.

The Organisation's designated common name of gamma BHC, or lindane, is HCH.

Manufacturers market pesticides under trade names, which refer to particular formulations and not specifically to the active ingredients. One active ingredient may be marketed in several different formulations under several different trade names with different trade names in different countries. Some trade names of gamma BHC, or lindane, are Agrocide, Gammalin, Lindex, and Kokotine. Trade names must be registered. In the USA, there are some 1,200 registered active ingredients sold under about 40,000 different trade names.

To distinguish common names from trade names, the ISO has specified that the common name be written only in small letters of the alphabet (e.g., lindane) and the trade name begin with a capital letter (e.g., Lindex). Another way to identify the trade name is by the registered trademark sign, ®, that appears by the trade name. Nearly all pesticide registration authorities now require that the labels bear, in addition to the trade name, the percentage composition of active ingredient of the common name product (Green et al., 1977).

PESTICIDE FORMULATIONS AND CHEMICAL ADDITIVES

Active ingredients are the chemicals in a pesticide product that do the work. They are usually crystalline solids or oily liquids which can rarely be used in this form. They usually must be changed or mixed with something else. Other ingredients may be added to make them convenient to handle and safe, easy, and accurate to apply. These are the inert ingredients. This mixture of active and inert ingredients is called a "pesticide formulation." Some formulations are ready for use, but others must be diluted with water or a petroleum solvent.

Many solid substances that will not dissolve in water can be ground and formulated as a "wettable powder" formulation. Various additives (dispersants) can be added in the formulation of wettable powders to delay the process of sedimentation.

Pesticides insoluble in water may be dissolved in various organic solvents forming an "emulsifiable concentrate" which can be diluted in water to an appropriate spray strength. The breaking of the emulsion is the usual way in which the toxic dispersed phase comes into play, with breakage occurring after most of the water has evaporated.

A "solution," a mixture of one or more substances in another in which all ingredients are completely dissolved, is not the same as a "suspension," which is finely divided solid particles mixed in a liquid. Various additives are required to obtain the desired solution or suspension.

Spray Additives (after Hill, 1975)

The following additives are sometimes added to sprays:

1. Spreader (wetter or surfactant)--a material added to a spray to lower the surface tension and to improve its distribution over the plant's foliage
2. Dispersant--a chemical with highly colloid properties to delay sedimentation in suspensions to ensure a uniform concentration in the tank
3. Emulsifier--a spray additive which permits formation of a stable suspension of oil droplets in aqueous solution or aqueous solution in oil
4. Penetrant--an oil added to a spray to enable it to penetrate an insect's waxy cuticle or a plant's leaf surface more effectively
5. Sticker--a material of high viscosity used to make powdered seed dressings stick to the seed's coat or a material such as methyl cellulose added to increase a spray's retention on plant foliage
6. Lacquers--some insecticides are formulated in a spirit varnish, such as shellac (paint is sometimes used also) in order to achieve a slow release from the surface to which applied (baseboards in homes, for example, to control various household insect pests)
7. Synergist--a substance that increases the killing power of a pesticide. Synergists are sometimes called acti-

vators. The way that a synergist acts is not always fully understood, but some synergists inhibit the enzymatic degradation of the toxicant to which added.

8. Warning material--a color additive (bright red, for example), odorant (offensive smell), or vomit inducing agent added to signal warnings to highly toxic pesticides.

Dust

Sometimes dust formulations have certain advantages, especially since their application does not require the use of water. Dusting equipment is usually lighter and easier to manipulate than the spraying equipment.

To make a dust formulation, the active ingredient is diluted with a suitable carrier powder such as talcum. The trade product is usually concentrated between 1 and 10 percent active ingredient. Knapsack power dusters use a powerful fan or blower to propel the dust to the target. The dusters can be used quite effectively, but they have certain limitations. During very wet conditions, for example, the powder "cases" through absorption of atmospheric moisture or "balls" in the sprayer's hopper. Also, the application is generally less uniform than with sprays. Dusting is most efficient during calm weather and when the crop plants are covered with dew. The presence of dew is very important, otherwise only a small percentage (10-15) of the dust may adhere to the plant foliage.

Fumigants

The toxicity of a fumigant is proportional to its concentration and to the time of exposure against the pest. Research into gas properties has shown that fumigation is usually only successful in completely closed spaces. For stored products, the material to be fumigated must be treated in special chambers, in sealed drums, or under large gas-proof sheets (plastic, for example).

Soil can be fumigated by injecting volatile liquids directly into it at frequent intervals. The "DD" soil injector, for example, is effectively used to control nematodes and other soil pests, but this is a tedious process and practical only when small areas are treated.

Seed Dressings

Seed dressing is a coating (either dry or wet) of protectant pesticide applied to seeds before planting. Dry seed dressings are often physically stuck to the testa of the seed by a sticker such as methyl cellulose. The earliest technique of seed dressing consisted of steeping the seeds in liquids such as urine or wine. The object of dressing the seed is to protect it in the soil against fungal, bacterial, or insect attack and also to protect the seedling for a short time after germination. The dressing forms a protective zone around the seed; the extent of the zone depends on whether the pesticide acts as a fumigant or systemic.

In the past, seed dressings were used mainly to protect against smuts and other diseases. However, there now are many insecticides which can be successfully formulated as seed dressings against such insect pests as wireworms and shoot flies. The use of seed dressings containing systemic insecticides will protect against aphids and other sap-sucking insects on the young plants.

Granules

Granular formulations are made by applying a liquid formulation of the active ingredient to coarse particles (granules) of some porous material--clay, corn cobs, or walnut shells are commonly used. The granule particles are much larger than dust particles. The amount of active ingredient ranges from 2 to 40 percent.

Granular formulations of systemic organophosphorous insecticides are becoming increasingly popular to control insect pests attacking seedling plants. The main advantage of granules is that the insecticide can be placed in such a manner that it gives maximum protection to the plant with minimum danger of large scale soil pollution and negligible danger to the operator. This is of particular importance with highly toxic chemicals. Another major advantage of granules is that the active ingredient does not break down rapidly in the soil. The rate at which the active pesticide ingredient escapes from the granule formulations is influenced by the dosage and the size of the granule as well as the soil moisture, temperature, and other environmental conditions. Granules are commonly used against such insect pests as fly maggots, beetle larvae, and aphids. Granules are applied over the plant rows or as spot treatments to the base of individual plants by using hand applicators supplied by the manufacturers.

Encapsulation

A recent development in insecticide formulation is a technique known as "microencapsulation." The insecticide is encapsulated in a nonvolatile envelope. The capsules are very small--the formulation appears to be somewhat like a coarse powder. The capsules are nontoxic upon contact but toxic to insects that ingest them. This type of formulation would appear to be promising against many leaf-feeding insects. In theory, the formulation should be safer to handle than various other pesticide formulations and less hazardous to beneficial insects such as predators, parasites, and pollinators.

METHODS OF APPLICATION

The object in the application of pesticides to control crop pests is to direct the materials to those parts of the crop plants or the crop field where the materials will produce a desirable effect without undue harm to the crop plants or the environment. The application technique selected must suit a particular need. The pest's life cycle, behavior, distribution, etc., will influence the choice of application procedure, as illustrated by the following examples of insect pest control: When controlling a leaf-feeding insect such as rose beetle, the pesticide toxicant has to be deposited on the leaf surface or it has to penetrate the leaf tissues. For a sap sucker, such as an aphid, the poison must move within the phloem system. For a leaf miner, the poison must penetrate the leaf tissues. A soil inhabiting, root-feeding pest can be attacked through the tissues of the roots or by applying a contact insecticide into the soil around the roots. Many caterpillars and fly maggots bore (during the late larval stages) into the plant fruits or stems. It is very difficult to control the larvae once inside the plant structures, hence chemical control is generally effective only when the pesticides are directed against the early instar larvae which live on the outside parts of the plants.

Spraying

Spraying is probably the most common form of applying pesticides. The spray application is categorized as high volume (HV), low volume (LV), or ultra low volume (ULV), depending on the amount of water used per hectare.

High Volume

Definitions vary considerably, but the term high volume generally applies when spray rates greater than 400 liters/hectare (36 gallons/acre) are used. In practice, with a field crop that is less than 70 centimeters in height at the time of spraying, the usual volume of water is 600 liters/hectare (50 gallons/acre). As the crop grows, the volume of water has to be increased to at least 1200 liters/hectare (100 gallons/acre). If the plants must be thoroughly drenched, the HV method of application is a requirement.

High volume spraying has several major limitations, the first being the problem of transporting large quantities of water in areas where water is not easily accessed. Furthermore, the cost of the HV spraying equipment is considerable, and the HV operation requires bulky equipment.

Because of these limitations, alternatives to the HV technique have been sought for the treatment of large areas. The idea has been to reduce the droplet size and blow the droplets through an air stream onto the crop. For ground spraying, the air stream is produced by a horizontally mounted fan or by a turbine fan. Such techniques that rely upon fans for reducing the droplet size and dispersing the spray are referred to as "atomization."

The atomized droplets are generally much smaller (100-150 microns) than droplets of the conventional high volume sprayers (150-250 microns). Because of the smaller droplet size, smaller volumes of spray per hectare are required. But the amount of active ingredient required per unit area to kill a certain pest on a certain crop is constant and does not depend on the volume of water. The amount of active ingredient per unit of water concentration increases correspondingly with the decrease in the quantity of water (Hill, 1975).

PESTICIDE TOXICITY

It is important to differentiate the hazard from the toxicity of a chemical.

From a chemical point of view, various attributes of hazard are related to the chemicals physiochemical properties. From a toxicological and hygenic point of view, the route of exposure, the methods of use, and the inherent toxicity of the chemical are the important variables.

Three fundamental principles of toxicologv need to be emphasized:

1. All chemicals, whether natural or synthetic, can be toxic if large enough doses are taken in over a specified period of time
2. Unless the chemical in question reaches a vulnerable site, no toxic effect will occur
3. As the dose of the chemical increases, so does the toxic effect increase.

Together these principles may be utilized to reduce the hazards of exposure, even when dealing with very toxic pesticides.

The relative toxicity of a pesticide can be found by examining its LD_{50} value. The LD_{50} is the dose of an active ingredient taken by mouth (orally) or absorbed by the skin (dermally) which is expected to cause death in 50 percent of the test animals so treated. The LD_{50} is expressed in milligrams per kilogram of body weight. If a chemical has an LD_{50} of 10 milligrams per kilogram, it is more toxic than one having an LD_{50} of 100 milligrams/kilogram.

Actual statistics of human poisoning correlate reasonably well with the LD_{50} values derived from laboratory tests involving rats or rabbits. The following shows the amounts of pesticide toxicant (probable lethal dose) of various LD_{50} values that an average adult person would be expected to swallow before dying:

Acute Oral LD_{50}	Amount of Pesticide Needed to Cause Death
5	a few drops
5 - 50	1 teaspoonful
50 - 500	1 tablespoonful
600 - 5000	1 pint (about 0.5 kilogram)
5000 - 15000	1 quart (about 1 kilogram)

It is important to remember that no matter how toxic the chemical, there will be no effect if there is no exposure. Thus, by minimizing the level of exposure, the effect is also minimized if not eliminated entirely. It is important that all who handle pesticides understand this principle.

Route of Exposure

The route of exposure largely determines the pesticide hazard. Ingestion, inhalation, and dermal contact are the primary means of pesticide entry into the human body. In general, toxic effects are seen most rapidly after ingestion, most slowly after dermal exposure, and at an intermediate time after inhalation (Davies et al., 1982).

SELECTED REFERENCES

Davies, J. E., V. H. Freed, and F. W. Whittemore (Eds.). 1982. An agromedical approach to pesticide management--some health and environmental considerations. USAID/CICP.

Firman, I. D. 1981. Pesticide handbook. South Pacific Commission. Noumea, New Caledonia.

Green, M. B., G. S. Hartley, and T. F. West. 1977. Chemicals for crop protection and pest control. Pergamon Press, London.

Hill, D. 1975. Agricultural insect pests of the tropics and their control. Cambridge Univ. Press, Cambridge.

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CHEMICAL CONTROL: USE IN IPM PROGRAMS

Dale G. Bottrell

HISTORICAL PERSPECTIVE

For many centuries human settlements have had to contend with a variety of unwanted and sometimes harmful insects, micro-organisms, weeds, rodents, and other organisms--collectively, "pests." Many biological, physical, cultural, and chemical methods have been developed to combat these organisms. One of the oldest methods is the use of chemical preparations to kill the pests or in some other way diminish or stop their actions.

The earliest reference to the use of chemicals to control pests dates back to about 2,500 B.C. when the Sumerians used sulfur compounds to control insects and mites. Thousands of miles east of Sumer, and some 1,000 years later, the Chinese developed plant-derived insecticides for protecting plant seeds and for fumigating plants infested with insect pests (Flint and van den Bosch, 1981). Chemicals were also used to control plant diseases at least 1,000 years before the Christian era; at the time of Homer, sulfur was used as a therapeutic agent (Walker, 1950).

The late 1800s and early 1900s witnessed significant developments in chemical control in the United States of America (USA) and in Europe. Use of chemical insecticides in the USA dates from

1867, when Paris green (an arsenic compound) was used to control outbreaks of the Colorado potato beetle (Leptinotarsa decemlineata). Within a decade, Paris green and kerosene oil emulsion were being used against a variety of insect pests. Common salt (sodium chloride)--the USA's first chemical herbicide--was being used extensively to control field bindweed (Convolvulus arvensis) in Kansas in the late 1800s. Copper sulfate was used toward the turn of the century for control of weeds in wheat in the USA (Timmons, 1970).

Around 1882 the use of Bordeaux mixture (quicklime and copper sulfate) as a fungicide (with some insecticidal properties) was accidentally discovered in France, adding further impetus to use of pesticides. This discovery was soon followed by fluorine-based insecticides and insecticidal compounds derived from plants (NAS, 1969).

Introduction of Synthetic Organic Chemicals

The emergence of synthetic organic chemicals--such as the insecticide DDT and the herbicide 2,4-D--after World War II began a new era in pest control. After the War, dozens of synthetic organic pesticides (carbon-based compounds synthesized from petroleum derivatives) were introduced commercially, and a major chemical industry developed and marketed these new materials. Although agriculture was the primary market for the pesticide industry, pesticide products and equipment for their application were also created for the home, garden, and recreational markets.

The postwar pesticides had a major impact upon control of agricultural pests, particularly insects and weeds. With significant success at a relatively low cost, synthetic organic insecticides and herbicides rapidly became a primary means of pest control in productive agricultural regions. They provided season-long protection for crops and complemented the benefits of fertilizers.

The synthetic organic pesticides also had a major impact upon the concept and implementation of the "Green Revolution" by providing a major mode of pest control for the new high-yielding varieties of wheat, rice, maize, and other food grains introduced into the developing countries. They produced equally spectacular results against pests that directly affected human health and comfort. Wide-scale employment of DDT, for example, resulted in the temporary riddance from entire countries of serious public health pests, such as malaria mosquitoes.

LIMITATIONS TO CHEMICAL CONTROL

Chemical pesticides are of considerable importance in food and fiber production, forest management, public health, and urban pest control programs. Despite the gains realized from using the materials, however, technological and biological limitations are becoming increasingly apparent. (Appendix 4, Limitations to Pest Control Methods by D. G. Bottrell, discusses limitations that are also known for various nonpesticidal methods).

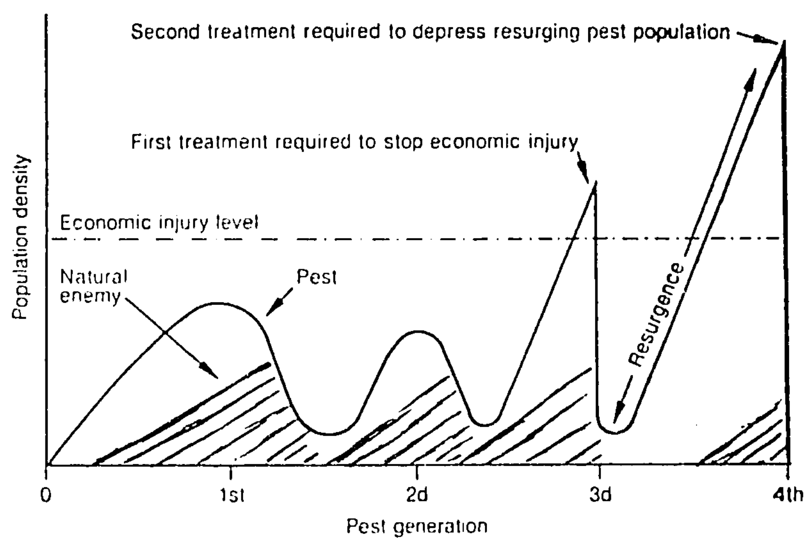
By virtue of the nature of their use and the fact that they are designed to be biologically active, pesticides often present many potential hazards to human health. Also, some of the materials may seriously harm important beneficial nontarget organisms--fishes, birds, other wildlife, honey bees and other important pollinators, natural enemies such as insect predators and parasites, economic and noneconomic plant species, and livestock--resulting in ecological disruptions, deterioration of environmental quality, and economic losses. One of the serious limitations to the use of chemical pesticides in pest management programs results from their disruptive effects on natural control agents.

Disruption of Natural Control

Chemical insecticides applied to control insects and mites frequently have deleterious effects on the natural enemies (i.e., beneficial predators, parasites, or disease-causing organisms) that regulate the "target" pests. They may also disrupt the actions of natural enemies that regulate nontarget organisms sharing habitats with the target pests. The resulting effects are referred to as "target pest resurgence" and "induced secondary pest outbreak" (Smith and van den Bosch, 1967; Smith, 1970).

Target pest resurgence is the rapid increase of the target pest population following application of an insecticide, often to a level higher than existed prior to the control measure, as illustrated in Figure 1. The insecticide may destroy a high per-

FIGURE 1: Hypothetical examplc of the effect of insecticides on insect pest resurgence (Bottrell, 1979)



centage (often 99 percent or more) of the target population, but it rarely eliminates all members--and it frequently destroys a large portion of the target pest's natural enemies as well. In addition, the insecticide may disrupt food chains important to the target's natural enemies, thus causing the enemies to starve, migrate, or cease to reproduce. In the absence of their natural enemies, then, the few members of the pest population surviving treatment continue to increase as long as environmental factors are favorable or until the natural enemy population recovers. Because the natural enemies usually recover considerably more slowly from pesticide treatment than do the pests, the pest population may reach a much higher level than before the treatment. In some cases, it may even be a year or more before the beneficial organisms recover fully from treatment (Smith, 1970).

Induced secondary pest outbreak refers to the flareup of potentially harmful nontarget organisms to pest status following pesticidal destruction of their respective natural enemies which occurred incidentally to the attempted destruction of the primary pest target. Such organisms are sometimes called "potential" pests. The potential for their reaching pest status always exists, but this potential is realized only following an ecological disruption such as that resulting from pesticide use (Smith and van den Bosch, 1967).

The serious consequences of chemical disruption of natural enemies are illustrated by the control of insect and mite crop pests. In efforts to depress resurgence of target insects and mites and to control outbreaks of secondary pests, farmers have often increased the dosages to extremely high levels and the frequency of application. Over the long term, however, this "treadmill" chemical approach has proved to be self-defeating, only engendering such serious problems as insecticide resistance, human poisonings, and environmental pollution (Smith and van den Bosch, 1967).

Fumigating the soil with the nematicide MB has caused destruction of symbionts (mycorrhizal organisms) necessary for the development of most tree and vine crops, consequently reducing plant growth (Gerdemann, 1974). Fumigating the soil with nematicides may also interfere with soil nematode predators or competitors of plant parasitic nematodes, although this effect has not been carefully studied (Van Gundy and McKenry, 1977).

The interactions of herbicides with plant pathogens, insect pests, predators, parasites, and beneficial pathogens are not well known. However, studies have demonstrated that some herbicides may increase the risk of attack by pathogens in many crops (Altman and Campbell, 1977). Treatments of 2,4-D have been shown to favor the growth of the southern corn leaf blight pathogen, *Helminthosporium maydis*, and the insect corn leaf aphid, *Rhopalosiphum maidis* (Oka and Pimentel, 1976). Some herbicides may reduce the incidence of plant disease as well (Altman and Campbell, 1977).

Other Limitations

Other limitations to chemical pesticides are apparent.

First, the price of synthetic organic pesticides and the cost of their applications have risen significantly, placing an increasing financial burden on those farmers and others who use large quantities of the materials.

Second, tremendous losses to pests are occurring despite the advances in modern chemical control. In the USA, for example, although pesticide use has increased dramatically (about 10-fold) during the past 30-35 years, annual crop losses from all pests appear to have remained constant. Losses caused by weeds may have declined slightly, but those caused by insects may have nearly doubled (Pimentel, 1978). Of course, yields of USA crops also increased during this period, and pesticides undoubtedly contributed substantially to the increase. Further, the ratio of losses from pests would probably be much higher than it presently is on many crops if it were not for pesticides or suitable alternatives. The fact remains, however, that pests continue to rob an enormous portion of potential food and fiber crop yields in the USA, and increasing the use of pesticides has apparently not decreased the portion of crop loss caused by pests. Further increase in use of available pesticides therefore would not be expected to ensure increased yields of major USA crops.

Third, and potentially of even more concern, significant groups of pests have developed strains that are genetically resistant to chemical pesticides. Worldwide, in 1980, 432 species of insects, mites, and ticks, about 50 species of plant pathogens, five species of weeds, and two species of nematodes were known to possess strains resistant to one or more chemical pesticides (Georghiou, 1980). The resistant groups include some of the most serious insect pests affecting agriculture and public health.

IPM: A MORE RATIONAL APPROACH

If the world's food production system is to meet the pace of human population growth and a good quality of life is to be achieved and maintained, pests must be managed. Pesticides must also be managed so as to protect human health and the environment and to maximize benefits from their use. Integrated pest management (IPM), as discussed by W. C. Mitchell (Definition, Objectives, and Features of Integrated Pest Management) at this training course, has the dual objective of economically managing pests and maximizing the benefits from the control methods, including pesticides.

IPM represents an important trend toward rational management of crop pests in the developing countries. It emphasizes a broad interdisciplinary approach that addresses economic, ecological, and social concerns. By spreading the burden of crop protection over a combination of effective pest control methods, IPM reduces the probability of crop failure. Even if one of the methods fails, one or more of the others may still provide protection. Therefore, IPM should be less risky for developing country farmers than crop protection programs based on single methods such as pesticides or pest-resistant crop varieties. Also, by drawing heavily from natural biological and environmental controls, improved varieties with pest-resistant characteristics, and traditional methods of control, and using pesticides selectively, IPM should reduce costs of control in those crops now treated heavily with pesticides. By using pesticides selectively and judiciously, IPM promises to prevent needless insult to the environment and human health at minimal costs. In fact, IPM has already achieved this objective on some crops in various areas of the developing world (Brader, 1979; IOBC, 1981).

PRINCIPLE AND APPLICATION OF ECOLOGICAL SELECTIVITY

As apparent from the discussion above under Disruption of Natural Control, a major drawback to use of pesticides in IPM programs owes to their broad spectrum of biological activity. Few select only the target pests, and many are broadly toxic, multiple-use materials that operate against numerous groups of organisms. In general, narrowly specific pesticides have not been available, and there has been relatively little effort to develop them. Because broader-spectrum pesticides permit control of several pest species with a single application, they may be more economical in that there may be fewer failures caused by erroneous diagnosis of the pest problem. Further, because of the high volume and the spread of production costs over many units, they are less costly than narrow-spectrum materials (Glass, 1975). However, many pesticides can be used to enhance their own "ecological selectivity," involving much less effort and expense than development of physiologically selective compounds.

Application of the principle of ecological selectivity requires an understanding of the ecology of the pest problem and the ecological consequences of using a pesticide. The objective is to use the pesticide in such a way that it poses the least risk potential to nontarget organisms. In other words, pesticides are used in ways which selectively kill unwanted organisms (pests), leaving the other organisms unharmed (Flint and van den Bosch, 1981). Some of the ecologically selective methods of pesticide use are as follows.

Use of Economic Thresholds

As discussed in another paper at this training course (D. G. Bottrell, Analysis of the Economic Status of Diseases, Insects, and Other Pests in Question), realistic economic thresholds that relate crop damage to pest population densities are the "keystones" of IPM programs. Economic thresholds serve to identify when and where remedial measures such as pesticide treatments are truly justified. Observance of the economic thresholds and applying the pesticides only when the pests exceed these levels may lead to a significant reduction in the amount of pesticide used in a given field and the amount of cropland treated in a given area (Stern, 1973). In Brazil, use of economic thresholds in soybean insect pest management programs reduced insecticide use 78-93 percent with no sacrifice in crop yield (Kogan et al., 1977).

Strategic Timing

Use of the economic threshold is the first step to strategic timing, but there are also other methods in this category which will enhance the ecological selectivity in pesticides.

Many insecticides are highly toxic to bees and are especially harmful if applied during the bloom period when the crops are inhabited by large populations of honey bees or important wild bee pollinators. Applying the insecticides to crops after bloom or in the evening when bees are not visiting blossoms is therefore an important conservation measure.

Some insect predators and parasites may utilize crops only during a portion of the 24-hour period or when the pest hosts are in a particular life stage (egg, for example). Thus, avoiding the applications of pesticides when the predators and parasites are most abundant in the fields is another important measure for achieving ecological selectivity.

Timing the applications to avoid drift of the pesticide particles out of the target area is also important. Applying the pesticide on windless days or early in the morning or evening may greatly reduce problems of wind drift.

Minimum Effective Dosages

Experience has shown that achieving 100 percent control of a pest population is rarely a desirable goal, and in fact it may have harmful side effects. Low-level infestations of some pests may be highly desirable. Noninjurious levels of agricultural insects and weeds, for example, may provide important sources of food, reproductive hosts, or shelter for natural enemies; complete annihilation of these organisms may therefore cause the natural enemies to starve or force the enemies to emigrate (Smith and van den Bosch, 1967). In IPM programs, an insecticide that kills 75 percent of the pest insects may be more valuable than one which kills 95 percent or more of these insects (Reynolds et al., 1975).

In insect pest management, the philosophy of "overkill" has prevailed for many years (Smith, 1976). As a result, insect control recommendations developed by the extension services or the chemical companies often prescribe unnecessarily high dosages of insecticides (Metcalf, 1980). Recommendations for control of weeds, plant disease organisms, and other pests may also prescribe unnecessarily high dosages. Therefore, an important step in the use of pesticides in IPM programs is to determine the "minimum effective dosage"--the lowest application rate required to hold pests just below economic threshold levels. Use of the low rates may produce spectacular results. Cate et al. (1973), for example, obtained excellent control of the greenbug (*Schizaphis graminum*) on grain sorghum with several organophosphorus insecticides applied at rates containing 2-10 times less toxicant than suggested by their manufacturers. Most of the compounds exhibited some level of ecological selectivity at the lower rates but little or none at the manufacturers' suggested rates. Use of the lower rates therefore reduced the costs of control and also lessened the chance of target pest resurgence and secondary pest outbreak.

Pesticide Formulation and Application Equipment

The manner in which a pesticide is formulated (granular, dust, bait, emulsifiable liquid, etc.) and the equipment used for its application (aircraft, hand-held sprayer, hand duster, etc.) affect both its effectiveness against the target pests and its impact on nontarget organisms.

Granular insecticides are generally more selective than sprays, less hazardous to the applicator, and often reduce the dosage required for effective control (Metcalf, 1980). Poison baits, used against a variety of insect pests, snails, slugs, rodents, and pest birds, are also generally selective. "Controlled-release" formulations of herbicides (and insecticides) offer another potential means of ecological selectivity.

Many chemical pesticides are extremely inefficient from an ecological standpoint, because of the limitations to the application equipment used. It has been estimated (von Rümker et al., 1974), for example, that only one percent or less of the ingredients of some insecticide sprays applied by aircraft intercepts the target insects. No more than 25 to 50 percent may even land in the target area (e.g., crop field). The remaining 50 to 75 percent may be lost through volatilization and drift may be carried many miles away. The problem of spray drift can be reduced by using ground application equipment (hand-held sprayers, tractor-driven sprayers), but the potential for drift is still high for sprays, especially when the sprays are applied during windy conditions.

Reducing the Area of Application

Development of techniques that precisely direct the pesticide deposits in the habitat of the target pest, thereby minimizing drift and contamination outside the target area, offers great promise for achieving ecological selectivity. "Spot-treating"--applying insecticides only to areas of the crop fields where insect infestations are determined to be the heaviest--is widely practiced in IPM programs in China (NAS, 1977). Knowledge of the behavior of dispersing and aggregating populations is requisite to effective application. Restricted chemical treatments, made in the loci of the aggregating populations, effectively control the target insect pests while sparing natural enemies in the rest of the field, thus minimizing both costs of application and adverse effects of nontarget organisms. Application of post-emergence herbicides to restricted areas of a crop field infested with weed species that occur in "clumps" is another example of the principle.

Many insect pests restrict their activity to well-defined portions of the plants--ventral surfaces of the leaves, pods, stems, etc. Selective application of insecticides toward the portions most frequently utilized by the pests may therefore be feasible when hand-held equipment is used.

Use of seed treatments for control of soil-inhabiting insects and plant disease organisms is probably the best example of chemical control which reduces the area of application. Often, seed treatments at very low rates provide adequate protection against insect pests or plant diseases.

CONCLUDING REMARKS

In many countries, concern about impacts of pesticides on health and the environment has led to more stringent regulation of their use and to complete prohibition of specific compounds. Although regulations are necessary to protect society and the environment against external costs, undesirable side effects have not been demonstrated for all chemical pesticides, and they will continue to be valuable. However, the undesirable side effects of these materials, discussed in this paper, demonstrate the fact that they must be employed judiciously, and ecologically selective approaches must be sought.

REFERENCES CITED

Altman, J., and C. L. Campbell. 1977. Effect of herbicides on plant diseases. Annu. Rev. Phytopathol. 15:361-385.

Bottrell, D. G. 1979. Integrated pest management. Council on Environmental Quality. U. S. Govt. Printing Office., Washington, D. C.

Brader, L. 1979. Integrated pest control in the developing world. Annu. Rev. Entomol. 24:225-254.

Cate, J. R., Jr., D. G. Bottrell, and G. L. Teetes. 1973. Management of the greenbug on grain sorghum. 1. Testing foliar treatments of insecticides against greenbugs and corn leaf aphids. J. Econ. Entomol. 66:945-951.

Flint, M. D., and R. van den Bosch. 1981. Introduction to integrated pest management. Plenum, New York.

Georghiou, G. P. 1980. Implications of the development of resistance to pesticides: basic principles and consideration of countermeasures, pp. 116-129. Proc. Seminar and Workshop, Pest and Pesticide Manage. in the Caribbean, E. G. B. Gooding (Ed.). Vol. 2. U. S. Agency for International Development, Consortium for International Crop Protection, Berkeley.

Gerdemann, J. W. 1974. Mycorrhizae, p. 205-217. In E. W. Carson (Ed.), The plant root and its environment. Vol. 8. Univ. Virginia Press, Charlottesville.

Glass, E. H. 1975. Integrated pest management: rationale, potential, needs and implementation. Entomol. Soc. Amer. Spec. Publ. 75-2.

IOBC. 1981. IOBC Special Issue, Int. Organ. Biol. Control Noxious Animals and Plants. Centre Overseas Res., London.

Kogan, M., S. G. Turnipseed, M. Shepard, E. G. de Oliveira, and A. Borgo. 1977. Pilot insect pest management program for soybean in southern Brazil. J. Econ. Entomol. 70:659-663.

Metcalf, R. L. 1980. Changing role of insecticides in crop protection. Annu. Rev. Entomol. 25:219-256.

National Academy of Sciences. 1969. Principles of plant and animal pest control. Insect-pest management and control. Nat. Acad. Sci. Pub. 1695(3). 508 p.

National Academy of Sciences. 1977. Insect control in the People's Republic of China. CSCPRC Rep. No. 2. Nat. Acad. Sci. 218 p.

Oka, I. N., and D. Pimentel. 1976. Herbicide (2,4-D) increases insect and pathogen pests on corn. Science 193:239-240.

Pimentel, D. 1978. Socioeconomic and legal aspects of pest control, p. 55-71. In E. H. Smith and D. Pimentel (Eds.), Pest control strategies. Academic, New York.

Reynolds, H. T., and P. L. Adkisson, and R. F. Smith. 1975. Cotton insect pest management, p. 397-443. In R. L. Metcalf and W. H. Luckmann (Eds.), Introduction to insect pest management. Wiley, New York.

Smith, R. F. 1970. Pesticides: their use and limitations in pest management, p. 103-118. In R. L. Rabb and F. E. Guthrie (Eds.), Concepts of pest management. North Carolina State Univ., Raleigh.

Smith, R. F. 1976. Insecticides and integrated pest management, p. 489-506. In R. L. Metcalf and J. J. McKelvey, Jr. (Eds.), The future for insecticides--needs and prospects. Wiley, New York.

Smith, R. F., and R. van den Bosch. 1967. Integrated control, p. 295-340. In W. W. Kilgore and R. L. Doutt (Eds.), Pest control--biological, physical, and selected chemical methods. Academic, New York.

Stern, V. M. 1973. Economic thresholds. Annu. Rev. Entomol. 18:259-280.

Timmons, F. L. 1970. A history of weed control in the United States and Canada. Weed Sci. 18:294-307.

van Gundy, S. D., and M. V. McKenry. 1977. Action of nematicides, p. 263-283. In J. G. Horsfall and E. B. Cowling (Eds.), Plant disease: an advanced treatise. Vol. 1. How disease is managed. Academic, New York.

von Rümker, R., E. W. Lawless, and A. F. Meiners. 1974. Production, distrbution, use and environmental impact potential of selected pesticides. Environmental Protection Agency, Offc. of Pesticide Programs, and Council on Environmental Quality. 439 p.

Walker, J. C. 1950. Plant pathology. McGraw-Hill, New York.

Date: Oct. 14
Time: 1330

PRACTICAL EXERCISES IN USING AND TESTING PESTICIDES

Coordinated by Konrad Englberger and Hubert Stier

The objective of these exercises was to give the trainees practical experience in the correct use of pesticides and to review various aspects of experimental techniques used in the testing of pesticides.

In the field, Mr. Englberger reviewed the basic steps to the correct use of pesticides, including the safety procedures. With assistance from the course participants, he demonstrated the procedures for calibrating pesticide sprayers typical of those used by Tongan farmers and showed how to calculate the proper pesticide and water mixture for use in the sprayer.

In the classroom, Mr. Stier discussed various kinds of experimental procedures used to determine the performance of pesticides (efficiency in reducing the pest population, effect on crop yields).

The following papers by Englberger and Stier served to supplement the practical exercises.

METHODS OF CALIBRATION AND APPLICATION

Konrad Englberger

Calibration of the spraying equipment is the key to uniform application of pesticides. Before spraying, one must détermine:

1. The correct amount of pesticide and the volume of spray liquid recommended for a particular crop and pest. Either follow the label on the pesticide container or consult an advisory officer
2. The most suitable application technique.

There are three important variables involved in calibration:

1. Size of the nozzle
2. Pressure applied to the spray tank
3. Forward travel speed of the person or vehicle doing the spraying.

THE MAIN OBJECTIVE IS TO DETERMINF THE VOLUME OF SPRAY LIQUID TO BE APPLIED OVER A GIVEN AREA

When the spray equipment has a pressure gauge, and the size of the nozzle orifice is given, calibration is relatively easy since only the speed of travel has to be adjusted. Usually in Tonga, and most probably in other islands of the South Pacific, farmers use simple hydraulic knapsack sprayers or motorized knapsack mistblowers that do not have pressure gauges or special nozzles.

Before we discuss the calibration, we must decide on our equipment: Shall we use a hydraulic knapsack sprayer or a motorized mistblower?

With a hydraulic knapsack sprayer, the droplets are relatively large and a high volume is applied. With a mistblower, due to the fast airstream and small nozzle orifice, a fine mist is produced and therefore a low volume can be applied.

Some pesticides. i.e., weed killers, should always be applied with large droplets and a high volume (500-1000 liters/hectare). Others can be applied with a low volume (50-250 liters/hectare).

A mistblower should not be used for herbicide application because the fine mist is easily carried away by wind (drift) and can cause serious damage to the crop itself or to neighboring crops. Also, breathing in the fine spray droplets from the mistblower is dangerous to health.

There are several methods to determine the spray output of a particular sprayer. The simplest way, if no pressure gauge is available and the speed is not known, is as follows:

1. Fill spray tank with a known quantity of water
2. Walk over any selected test area and spray the tank empty
3. Measure the sprayed area.

Assuming for example, the volume used was four liters and the sprayed area was $80m^2$, the volume required for any given area (i.e., 1 hectare) can be calculated from the following relationship:

$$\frac{\text{Volume required}}{\text{Area to be sprayed}} = \frac{\text{Test volume applied}}{\text{Test area to be sprayed}}$$

In this example:

$$\frac{\text{Volume required (x)}}{10000m^2 \text{(1 hectare)}} = \frac{\text{4 liters}}{80m^2}$$

So,

$$\frac{4 \times 10000}{80} = \text{500 liters}$$

The spray output of that particular sprayer is 500 liters per hectare, if the tank pressure and the walking speed of the operator remain constant.

By comparing the calculated volume with the recommended amount of water as printed on the label an adjustment might be necessary. The label may say: "Use high application rates for spraying dense weeds or first treatment, using 60 gallons water per acre. Use low application rates for spraying under heavy shade or treating re-growth, using 40 gallons water per acre".

Converted into l/ha the rates are:

a) 675 l/ha

b) 450 l/ha.

In addition to following the recommendation on the label, attention must be paid to ensuring a good spray coverage and avoiding excessive run off of the spray liquid.

Again, we must follow the recommendation on the label.

Assuming we are dealing with a liquid formulation and the label says: "Use four liters of product per hectare", we now have to calculate the quantity of product per filling of the knapsack sprayer.

If the knapsack sprayer holds 12 liters, how many liters of product are required per filling?

500 liters of water require 4 liters of product

12 liters of water require x liters of product

$x = \frac{12\ \ell. \times 4\ \ell.}{500\ \ell.} =$ 0.096 liters or 96 milliliters of product per knapsack sprayer are required.

It might be useful to know the number of tank fillings for the area (1 hectare):

$$\frac{500\ \ell./ha}{12\ \ell./tank} = 41.6 \text{ knapsack sprayers}$$

So for 1 hectare we need 42 fillings.

The situation may be different in the field. Do we need the four liters of product, if we only apply spot treatment or practice interrow spraying? For spot treatment and interrow spraying we need less product and less volume and therefore must deduct the percentage of the area not being treated.

Assuming that we work with 500 liters of spray volume and 4 liters of product per hectare, how much product would we need to treat only 25 percent of the area?

VOLUME

Divide the volume of 500 liters by 4: (or multiply by $\frac{25\%}{100\%}$) = 125. The new volume required is 125 liters.

PRODUCT

Divide the 4 liters of product by 4 (or multiply by $\frac{25\%}{100\%}$).

The new amount of product is 1 liter.

How much product is required to fill one knapsack sprayer (12 liters in our example)? The required number of fillings for the reduced area is:

$$\frac{125\ \ell.}{12\ \ell.\ \text{sprayer}} = 10.4 \text{ knapsack sprayers}$$

To obtain the amount of product per knapsack sprayer, divide the total amount of product per area by the number of tank fillings:

$$\frac{1.0 \text{ liter of product}}{10.4 \text{ tank fillings}} = \text{0.096 liter or 96 milliliters of product are required per tank filling}$$

Note that the spray concentration has not changed and remains at 96 ml per tank. Simply the number of tank fillings has been reduced from 42 to 10.

Spot spraying is often used in crops with a wide spacing. This is very important for extension workers to consider in their work.

The same procedure can be followed by an extension officer who wants to examine whether a farmer uses the right concentration and the right spray volume.

For example, suppose a farmer has 2025m^2 of cabbage and sprays five knapsack sprayers (12 liters/tank). He used 10 tablespoons of Ambush (1 tablespoon of Ambush = 8 grams per sprayer). The extension officer wants to recheck whether the concentration and the spray volume used is correct.

The Ambush label says:

"For the control of the following pests of vegetables: diamond-back moth, large cabbage moth, centre grub apply at rate of 300 gm/ha (4.25 oz/acre). For knapsack sprayers add 6 gm per 14 liters water (knapsack) and apply 49 knapsacks per hectare."

What volume and how much Ambush should the farmer use?

Volume: 49 knapsacks x 14 liters/knapsack = 686 l/ha

For $10000m^2$ (1 hectare), 686 liters water are required

For $2025m^2$, x liters water are required

$$X = \frac{2025m^2 \times 300 \text{ grams}}{10000m^2} = 60.75 \text{ grams Ambush}$$

So, for $2025m^2$ the farmer needs 61 grams of Ambush.

The farmer, however, had used:

Volume: 5 knapsack sprayers x 12 liters/tank = 60 liters water

Ambush: 10 tablespoons (80 grams) x 5 tanks = 400 grams

He had used 60 liters of water and 400 grams of Ambush for $2025m^2$, but he should have used 140 liters of water and 150 grams of Ambush.

What advice should the extension officer give to the farmer? The farmer must calibrate his spray equipment and determine the recommended rates on a small test area before spraying this cabbage. HOW?

The knapsack sprayer has no pressure gauge and the nozzle size is not known. The farmer wants to apply 686 liters of spray volume per hectare (1 ha = $10000m^2$):

With 686 liters he should cover $10000m^2$

With 5 liters he should cover x m^2

$$X = \frac{5 \times 10000m^2}{686 \text{ liters}} = 72.9m^2$$

The farmer measures a test area of 72.9 square meters. His area is five meters broad and 18.22 meters long. He has to adjust his equipment or his walking speed until he covers the test area with exactly 5 liters of water.

QUESTION

If the five liters of water have been sprayed before covering the $72.9m^2$, what procedure must follow?

ANSWER

He has to: 1. Increase walking speed, or

2. Decrease tank pressure, or

3. Use a nozzle with smaller orifice.

QUESTION

If the area of $72.9m^2$ is covered and there is still water left in the tank, what procedure must follow?

ANSWER

He has to: 1. Reduce walking speed, or

2. Increase tank pressure, or

3. Use a nozzle with larger orifice.

Once the farmer has calibrated his equipment and he knows that the output of his sprayer is 5 liters per $72.9m^2$ (686 liters per hectare) then he has to calculate the spray concentration.

The Ambush label recommends the use of 300 grams Ambush in 686 liters of water per hectare. To obtain the correct concentration per sprayer the farmer has to use the following equation:

$$\frac{\text{required concentration x}}{\text{volume of 1 sprayer tank}} = \frac{\text{recommended concentration}}{\text{recommended spray volume}}$$

$$\frac{x}{12\ \ell.} = \frac{300\ g}{686\ \ell.}$$

$$x = \frac{300 \times 12}{686} = 5.25\ g$$

The farmer puts 5.3g of Ambush into one knapsack sprayer holding 12 liters of water.

RECOMMENDED LITERATURE

Firman, I. D. 1981. Pesticide Handbook, South Pacific Commission, Noumea. 102pp.

Lambert, M. 1978. Weed Control in the South Pacific, Handbook No. 10 (1973); South Pacific Commission, Noumea. 119pp.

Kasasian, L. 1971. Weed Control in the Tropics, Leonard Hill, London. 307pp.

FIELD EXPERIMENTS FOR RESEARCH AND EXTENSION

Hubert Stier

DEFINITION

Different definitions are available for the word "experiment." For our purposes, we will consider an experiment as a planned as a planned inquiry to:

- obtain new facts
- confirm or deny the results of previous experiments, where such an inquiry will aid in an administrative decision such as recommending:
    1. a variety
    2. a procedure
    3. a pesticide.

OBJECTIVES

In designing an experiment, state the objectives clearly, as questions to be answered, hypotheses to be tested, and effects to be estimated.

Consider:

- ecological conditions of the region
- economical conditions of the region
- rural development
- policy.

The experimenter should be in contact with:

- farmers
- administrators
- research personnel.

PLANNING OF EXPERIMENTS

Selection of Treatments

When selecting a set of treatments, it is important to define each treatment carefully. It is necessary to consider each treatment with respect to the other treatments to assure that the set provides efficient answers to the objectives of the experiment. Another aspect which needs to be considered when selecting treatments is comparing promising new methods or otherwise previously untested methods with known agricultural methods. New varieties, pesticides, and other agronomic practices need to be compared with those varieties, pesticides, and other agronomic practices already being used by the farmers.

To avoid research with impractical results, it is important that the methods (treatments) to be tested are really available and practical for use by farmers. The research results can hardly be expected to have value to the farmers unless they can be applied to the farmers' actual situation.

Selection of Assessments

Besides assessments for yield and quality it is important to to observe those parts of the plant which are closely related to yield and quality, in respect to insect pest and disease density. Knowledge of how the treatments affect the yield will be very helpful for further selection of treatments if the trial must be repeated.

Location

A trial should be located where all factors which may influence the results, such as soil, landscape, climate, and other environmental factors, are similar to farmers' conditions.

DIFFERENT KINDS OF TRIALS

Demonstration Trials

For extension workers or farmers, these trials compare a new treatment or treatments with a standard.

Preliminary Trials

These trials scrutinize a large number of treatments in order to obtain leads for future work.

Critical Trials

These trials compare responses to different treatments using sufficient observations of responses to give reasonable assurance of detecting meaningful differences.

EXPERIMENTAL TERMS

Plot = the smallest unit in a trial.

Treatment = all plots which are treated in the same way.

Replication = when a treatment appears more than once in a trial.

Block = includes one replication of all treatments.

Randomization = every treatment should have an equal chance of being assigned to any plot.

PLOT SIZE

The plot size will vary from one experiment to another. The size of the plots will depend on:

- crop
- treatment
- homogeneity of soil
- technique of setting up
- education of technicians and laborers.

RESEARCH PROFILE

One means of collecting all of the relevant information concerning an experiment is by writing a profile of the experiment. The following information should be recorded by the researcher:

- title of experiment
- objective
- background:
    1. description of diseases/insect pests
    2. control methods
    3. description of problems

- review of existing information
- description of activity/trial outline:
    1. treatments and rates
    2. field activities
    3. field design
    4. recording
    5. commencement and duration of the trial
- requirements:
    1. area
    2. machinery
    3. materials
    4. manpower/labor
    5. cooperation with other sections and divisions
- cost estimates
- justification.

TECHNICAL SETUP

Selection of Trial Area

Consider:

- the area should be representative for the region
- similar soil conditions within the area
- similar microclimatic conditions
- previous crop
- previous trial (fertilizer trial).

Soil Preparation

Consider:

- adapted to crop
- machinery and methods according to progressive farmers
- equal soil preparation
- soil preparation should be finished during the same weather conditions.

Fertilizing

Consider:

- equal application (except in fertilizer trials) adapted to crop.

Pesticide Application

Consider:

- sufficient plant protection for the whole area, except pesticides to be tested
- avoid drifting in other plots
- proper calibration of equipment
- weather conditions (e.g., rain, wind).

Plot Marking

Consider:

- plot marking in an easy, understandable way, e.g., treatments 1, 2, 3, etc.; replicates A, B, C, etc.
- plot numbers are fixed before in plot layout in the trial profile

Plot Marking cont'd

Consider:

- never change the plot numbers during the whole trial period
- plot numbers always on the left side of the plot
- use weatherproof markers.

Seed/Planting Material

Consider:

- same spacing
- same number of plants per plot
- same conditions for germination.

Maintenance Work

All additional work has to be done in the same way for all plots. Weeding, herbicide application, and all plant protection should be done in the best way possible.

ASSESSMENTS

Measuring

Different ways of measuring are used to obtain information about the variation within the treatments and/or the treatments and the check (untreated).

Measures:

- height of plants
- size of leaves, fruits, etc.

Counting:

- germinated plants
- leaves, flowers
- fruits, seeds, etc.

Weighing:

- yield
- tubers, roots, etc.

Analyzing:

- protein
- contents of different plant parts (tubers, stems, leaves, etc.)

Observing

All measured results are objective, so comparisons within the treatments are possible. But observations as an instrument for gaining figures about density of a disease symptom are always subjective.

Before starting an observation it is necessary to get a visual idea about the disease/insect pest density in different treatments.

Consider:

- all observations should be done by the same person during the whole trial period
- the assessor should be unprejudiced and not influenced.

Observation Systems

- scale 1-9: 1 = not infested
  9 = high infestation
- percentage control/percentage damage = degree of control/damage is rated in percentage
- combination measuring and observing: special numbers of leaves are observed and the density of damage rated.

STATISTICAL ANALYSIS

The measured and observed plot results depend not only on the treatments which are tested but also on the differences between plots that are unrelated to the treatments, due to:

- soil differences
- border influences
- technical mistakes.

With the help of the analysis of variance it is possible to differentiate the effect caused by the treatment and error of the experiment.

Least Significant Difference (LSD)

The LSD indicates the probability that the same trial shows the same results again. Differences between two treatments should be higher than the LSD to be significant.

Use of Calculators

Most modern calculators (costing $30 USA or more) are programmed to calculate standard deviation which makes the analysis of variance easy for anyone who is interested in this analysis.

Final Trial Report

In addition to the project profile, the following information should be included in the trial report:

- results in tables and graphs
- LSD (0.05 level of probability)
- discussion of final results
- irregularities
- emphasis of "best and worst"
- interpretation of results
- any side effects
- recommendation for future trials
- weather conditions during trial period.

For the interested reader of the final trial report, it should be possible to find out all information about each particular trial. Do not forget an acknowledgment to thank those people involved in the work.

PLOT LAYOUT

The following five pages show various kinds of plot layouts for experimental work (Lochow and Schuster, 1961).

SELECTED REFERENCES

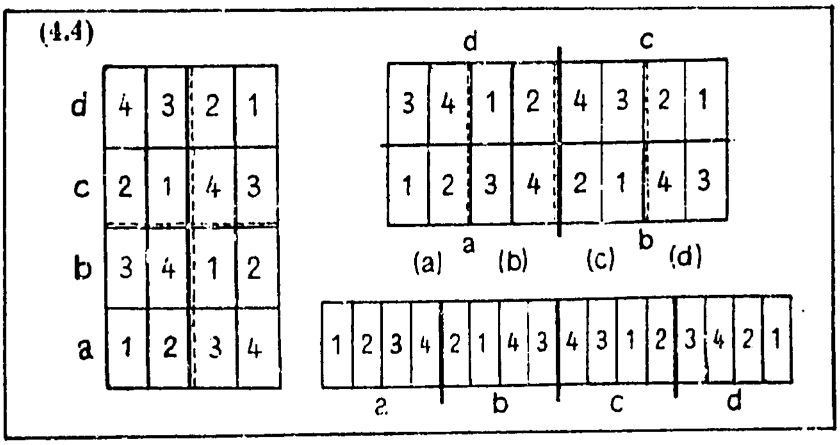
Bailey, M. T. J. 1959. Statistical methods in biology. The English Universities LTD., London.

Cox, R. R. 1958. Planning of Experiments. Wiley Publications in Statistics, New York.

Lochow, J. von, and W. Schuster. 1961. Anlage und. Auswertung von Feldversuchen. DLG - Verlag, Frankfurt (Main).

Rohrmoser, K. 1981. Kompendium fur Feldversuche. Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH, Eschborn.

(4.4)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d
c
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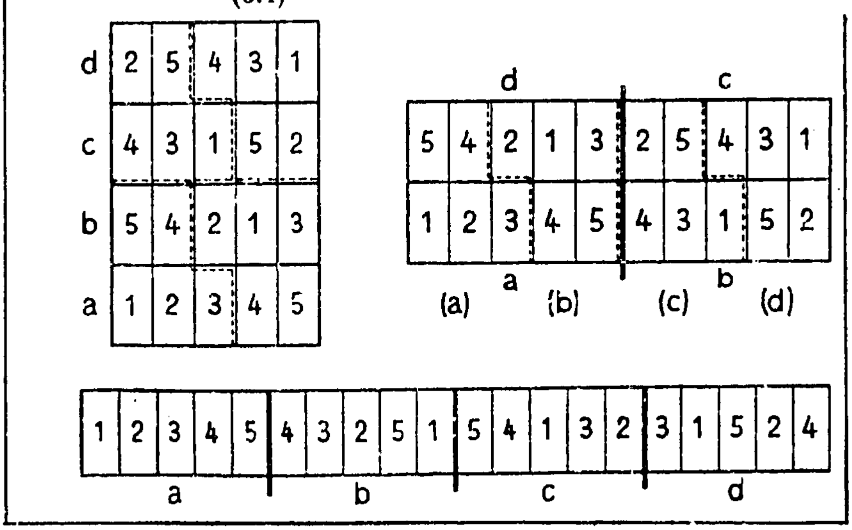
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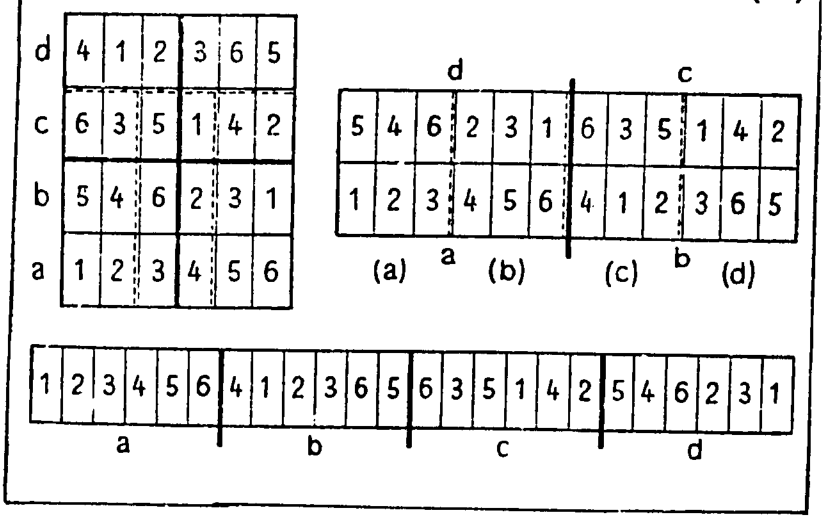
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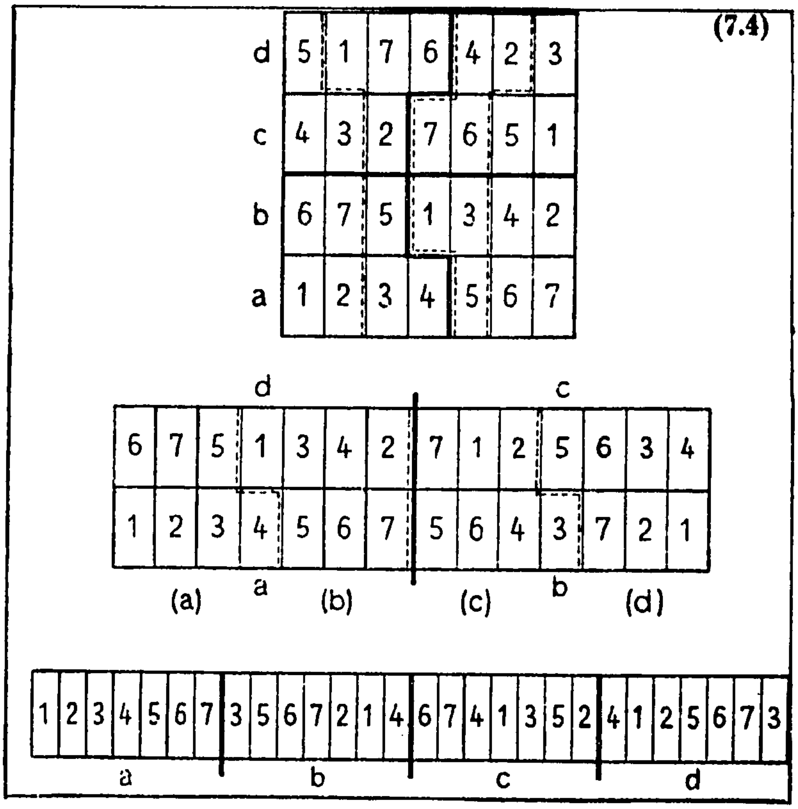
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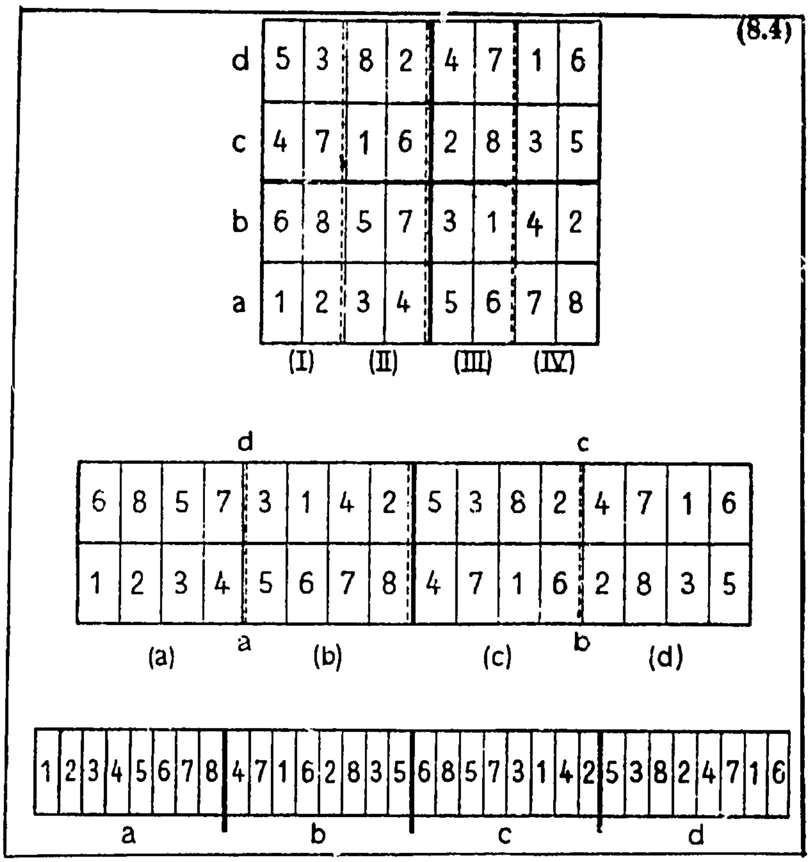
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d c
6 8 5 7 3 1 4 2 5 3 8 2 4 7 1 6
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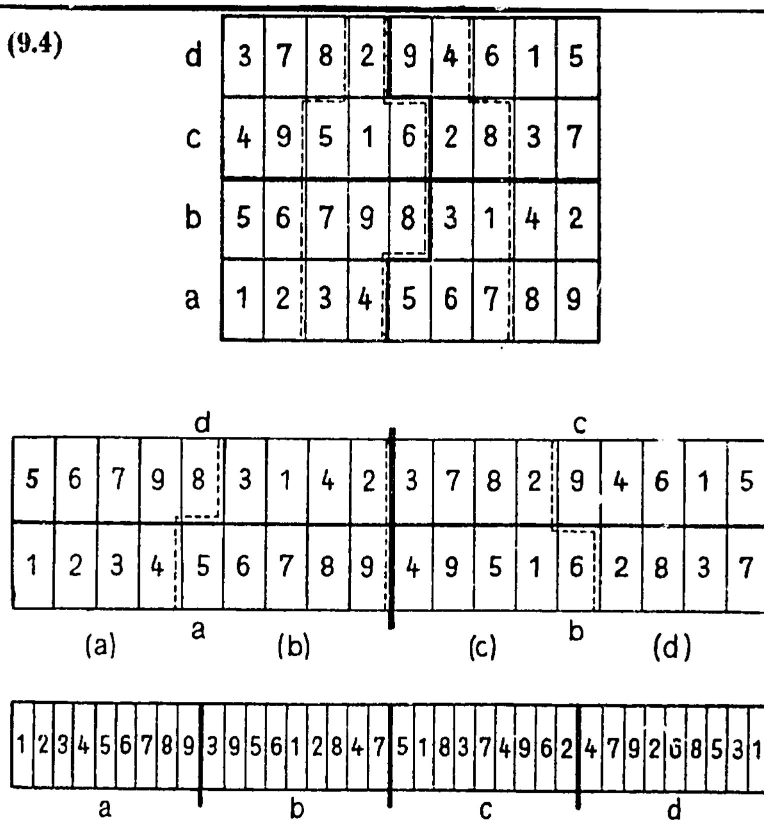
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(b)
(c)
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(d)
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a
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Date: Oct. 14
Time: 2000

EVENING WORKSHOP: DISCUSSION WITH A REPRESENTATIVE OF THE PESTICIDE INDUSTRY

F. Sumich

Mr. Sumich reviewed for the course trainees and lecturers some of the recent developments in the agrichemical industry--manufacture of new pesticide products, change in registration and marketing practices, etc., as related to the South Pacific region. Then, during the open discussion that followed, Mr. Sumich responded to questions concerning problems of pesticide registration, reformulating, repacking, and labeling in this region.

Date: Oct. 15
Time: 0925

RESISTANCE TESTING IN INSECTS, TICKS, AND MITES

Luc-Olivier Brun

INTRODUCTION

Since 1945 synthetic insecticides and acaricides have played a major role in reducing insect-borne disease and increasing agricultural production. In spite of the increased emphasis on integrated pest management (i.e., the integration of all available control techniques: biological control using predators, parasites, etc., cultural practices, strategic application of pesticides, and use of specific insecticides, such as bacterial insecticides), traditional pesticides are still the most important means of pest control and will probably remain so, at least until the year 2000. All agriculturists should be fully aware of the value of pesticides and should strive to use them safely and effectively.

There are several problems associated with the use of pesticides, namely:

1. Residues in plant and animal produce, particularly associated with the use of persistant organochlorines (e.g., DDT, dieldrin, etc.)
2. Side effects on nontarget organisms

   Wildlife build up pesticide levels in food chains. This is a major problem with the use of organochlorines, but very toxic insecticides, such as parathion, can have a direct effect on wildlife. Spillage of insecticides into streams or irrigation ditches can seriously affect fresh water life. Probably the most important effect on nontarget organisms in regards to agriculture is the elimination or reduction of beneficial species (predators and parasites), leading to the outbreak of secondary pests which they regulate. The use of DDT or synthetic pyrethroids to control Heliothis armiger in cotton fields eliminates the predators of spider mites, which then may themselves require chemical control. Control of the codling moth in apple orchards with azinphosmethyl eliminates Stethorus spp. and other predatory mites, unleashing the two spotted mite (Tetranychus urticae) and the European red mite (Panonychus ulmi) which may become very serious problems and require acaricides.

3. Resistance in the pest populations to the chemical materials.

RESISTANCE

The development of resistant strains of insects and mites is one of the most important problems facing world health control authorities and agriculturalists.

One of the first failures of an insecticide to control a pest as a result of resistance was recognized as long ago as 1908 with the use of lime sulfur to control San José scale (Quadraspidiotus perniciosus). By 1966, resistance to one or several insecticides, in one or more areas, had been reported in some 180 species of agricultural pests. Today, the number of resistant species of insect pests alone is over 300.

I would like to define resistance as "a decreased response of a population of animal or plant species to a pesticide or control agent, as a result of its application." The factors which confer resistance in the pest have been found to be genetically controlled so that the progeny of resistant parents tend also to be resistant. For this reason, resistance in pest populations can persist in the fields for many generations even after the use of the pesticide to which resistance has developed has been stopped. In practical terms, many of you may be faced with control failures that can be traced to genetic resistance in the pest population. However, all failures are not due to resistance. Other factors that may be involved include:

1. Bad timing of application in relation to the life cycle of the pest, stage of growth of the plant, or season
2. Disregard of the manufacturer's instructions on mixing the formulated pesticide or on the correct concentration to be used
3. Deterioration of one or more of the ingredients of the formulation
4. Inefficient, maladjusted, or worn application machinery
5. Inefficient or careless application procedures, resulting

in poor coverage or the delivery of a dosage too low to be effective

6. Unsuitable weather either during or after application
7. Poor quality water used for diluting pesticides.

DETERMINATION OF RESISTANCE

If the control failure is not due to any of these factors and there is a history of pesticide usage by the growers, resistance must be suspected. To confirm resistance it is necessary to carry out a series of tests in the laboratory. I will give you a brief outline of the procedures used to test for pesticide resistance.

To detect resistance, we must first establish a base line of data. That is, we must define the response of a susceptible reference strain to the pesticide involved. To do this, we usually try to collect insects, ticks, or mites that have never been exposed to pesticides and then set up a laboratory culture under controlled conditions (temperature, humidity and light, food supply). These conditions are also made available to the organisms to which resistance is suspected; both groups should be of the same age, sex, weight or size, etc. All of these variables may affect the results.

We then expose batches of the test organisms to a series of concentrations of the pesticide, usually graded on a logarithmic scale of 100.

e.g., first step:

Range in Concentration	Mortality Results
1.0%	100%
0.1%	100%
0.01%	0%
0.001%	0%

second step:

Range From	Mortality Range
0.1%	100%
0.05%	70%
0.025%	40%
0.0125%	10%

About three repetitions should be made for each concentration.

We assess mortality at each concentration and then plot the results to obtain a dose-response line. For resistance testing we try to achieve a range of mortality of from 5 to 95 percent. If the results are plotted on normal graph paper, we obtain a sigmoid curve, but using log probability paper, there is a linear relationship between dose and mortality. This straight line can be either fitted by eye (in using a celluloid ruler) or drawn after calculation with a computer.

From this dose-response line we can obtain a discriminating dose or concentration = LD (lethal dose) 99.9 percent or LC (lethal concentration) 99.9 percent. This is the dose that normally kills all (99.9 percent plus) susceptible individuals or, sometimes, two times the dose that kills all the susceptibles in the test.

I must emphasize that the test organisms must not only be reared in controlled conditions but also held under controlled conditions after testing and mortality assessed after a standard holding period, using a specific criterion for mortality. Unless the tests are carried out exactly as specified, the results will be meaningless. It is why the WHO and FAO have promoted standardized test methods on many major pests.

The suspected resistant strain is then tested with the discriminating dose and if there are any survivors we use a series of concentrations to obtain a dose-response line. The line can be either flatter than that of the susceptible strain or parallel. The flatter line may indicate a heterogenous population which is often found in the field (i.e., a mixture of resistant and susceptible individuals).

Following pesticide usage, a pest may have developed resistance to one or several insecticides. It therefore is important to look for the possibility of "cross resistance." In the case of cross resistance, the pest may resist not only the pesticide to which it first became resistant but one or more closely related compounds of the same class (e.g., organochlorines) or, in some cases, several classes of compounds (e.g., organochlorines, organophosphorus compounds, and carbamates).

ILLUSTRATION OF TESTING METHODS

This section of the course paper, which is not included here, involved the showing of a large number of slides which illustrated the various kinds of techniques and procedures for testing for resistance in the laboratory.

CONCLUSION

The main question remains: how do we prevent resistance from occurring or at least delay it? Unfortunately there is no simple solution, but there are a number of counter measures that should be considered:

1. Introducing an alternative pesticide to which there is no cross resistance: We can use a pesticide of an unrelated group, but this still could lead to the onset of cross resistance.
2. Using mixtures and synergists: In some cases the use of two chemicals mixed together may give better results than if either chemical is used by itself--in fact, the results may be more than additive. The mechanism of resistance, in many cases, has been identified as an enzymatic detoxication of the absorbed insecticide. If the detoxifying enzyme can be inhibited by adding a suitable enzymatic poison or "synergist" to the pesticide formulation, the original effectiveness of the pesticide may be restored.

3. Methods not involving chemicals

These methods include:

a. Consideration of the time of planting - It is important to have a good knowledge of the life cycle of the pest and its susceptibility to weather, parasites, and predators as required to select a planting time that is most disruptive to the pest.

b. Soil fertilization will sometimes reduce the pest damage

c. Cultivation and harvesting

d. Rotation of crops

e. Eradication of alternative plant hosts (noncrop hosts)

f. Trap cropping

g. Crop residue sanitation and suppression of shelter

h. Modification of crop storage practices (in the case of postharvest pests)

i. Use of resistant plant varieties

j. Use of biological control such as predators and parasites

All of these various alternative methods, plus many more, are discussed in papers presented at this course.

Date: Oct. 15
Time: 1045

REPORT OF THE TRAINEES' REVIEW OF THE COURSE

Presented by Edwin C. Pickop

At the request of the course organizers, the trainees commented on some of the deficiencies in the course and how future courses could be carried out more efficiently. The organizers agreed that the comments were useful and that they should be carefully studied in the planning of future courses that may be carried out as follow-ups to the present course.

Date: Oct. 15
Time: 1145

SHOWING OF THE FILMS: THE COCONUT RHINOCEROS BEETLE CONTROL PROGRAM IN WESTERN SAMOA, AND ANOTHER, "PESTICIDES AND PILLS-- FOR EXPORT ONLY" (PART I)

The film on the coconut rhinoceros beetle, produced by the GTZ in Western Samoa, traced back to the introduction of the insect pest into Western Samoa, described the economic problems that resulted, and reviewed the development and implementation of the biological control program used successfully against the pest.

The other film, produced by Robert Richter, Inc., New York, pointed up the problems of USA and Western European nations exporting pesticides that have been suspended, prohibited, or greatly restricted in their countries of origin to the nations of the developing world.

Date: Oct. 16
Time: 1400

TOUR OF TONGATAPU ISLAND WITH DEMONSTRATION OF DISEASES, INSECTS, AND OTHER PESTS IN CROPS

Coordinated by Konrad Englberger

1400	Departed International Dateline Hotel, Nuku'alofa
First stop	Captain Cook Landing Place
Second stop	Royal Tomb
Third stop	Farmer Sioni Tualau in Alaki Crops inspected • capsicum • taro (Colocasia, Xanthosoma) • tomato • findings or problems--insect infestations on capsicum and tomato, mainly Heliothis; armyworm and taro hornworm on taro
Fourth stop	Farmer Asaeil Village Koonga, visit to a vanilla plantation (demonstration plot)
Fifth stop	Ha'amonga tourist spot
Sixth stop	Farmer Fili Hufanga Village Lapaha, mixed cropping taro with different taros (Xanthosoma, Colocasia, and Alocasia) Kava plantation and vanilla

Seventh stop	Farmer Sikifi Ma'afu Village Lapaha, banana plantation (demonstration plot)
1800	Returned to International Dateline Hotel

Date: Oct. 18
Time: 0915

DEFINITION, OBJECTIVES, AND FEATURES OF INTEGRATED PEST MANAGEMENT

Wallace C. Mitchell

INTRODUCTION

All of the trainees attending this course live in the tropical areas of the Pacific region. In our island ecosystem, the major pests--whether they are weeds, insects, or plant diseases--are generally exotic species accidentally introduced into this region. These pests arrived on our shores, leaving their natural limiting factors, specific parasites, predators, and diseases behind; thus, they were free to increase to large numbers and become serious deterrents to crop production. Pest problems now occur with little regard to seasonality and may be highly unpredictable. Insects are active throughout the year, and their generations overlap, forcing farmers and extension agents to find insecticidal sprays or dust applications that will give season-long control. Insecticide applications have been applied on a "calendar basis" or when the supply ship arrived with the materials. The tendency has been to apply them irrespective of the real need.

In the past, the widespread use of the newer organic synthetic pesticides took much of the uncertainty out of pest control and brought incalculable benefits to mankind, but it has now become apparent that the calendar spray schedule is no longer the answer (Smith, 1959). Through the widespread and sometimes indiscriminate use of pesticides, the ecosystem has been drastically altered, and a number of problems have occurred. Species of insects and mites have developed resistant strains, and secondary outbreaks of arthropods other than the target pests have occurred because of the interference of the pesticides with the nontarget pests' natural enemies. Toxic pesticide residues on food and forage crops have been a public health hazard and cause of concern for the qua-quality of food available in the markets. The high cost of petroleum-based pesticides, labor, and the hazard to the environment through the total reliance on pesticides have made people search for more economical, more effective, and safer alternatives to the chemical controls.

Your own experience in crop production has shown that a given crop is rarely confronted with a single pest problem but rather a complex of pest problems: different kinds of weeds, insects, and plant diseases. Your experience has also shown that no single arbitrary control method will give long-lasting or permanent control. Finally, your experience has shown that the development of effective long-term solutions for pest problems require an understanding of the actions, reactions, and interactions of the components of the crop to be protected.

It has become evident that the overreliance on pesticides, the root of major crisis situations in many crop protection programs, must stop. If we are to avoid the mistakes of the past, there has to be an integration of pest control technologies in a manner which will ensure effective management of the pests while simultaneously guarding against ecological disruptions and human health hazards. Pest control recommendations should not evolve independently for insects, weeds, plant diseases, and other pests; optimal control strategies must be developed considering the cropping system as a whole.

WHAT IS IPM?

Experience has shown that to provide effective long-term results a pest management scheme must be integral to and compatible with the overall management and economics of the forest, farm. orchard, greenhouse, or other resource for which it was developed. Increased yields and yield stability are more likely to occur if the crop protection technologies are systematically spread over a combination of genetic, biological, cultural, physical, and chemical control methods rather than relying on a single technique. The term "integrated pest management," or IPM, has been used to describe this approach. IPM is not an application of fertilizer or pesticide applied to a crop each week. IPM is a concept composed of many components, all of which taken together, provide the knowledge and resource bases necessary to implement an ecologically sound pest management system. The system must be flexible and offer a variety of options because pest problems, control technologies, economics, and human values are continually changing.

IPM is a strategy in which the pest control technologies are organized and integrated in a suitable mode after the basic information on the ecology of the pests, economic costs, and environmental suitability of the control methods are known. IPM is an integral part of the crop production system. Discussions on the various pest control technologies used in various countries of the Pacific region are covered in other papers in this training course.

The need for comprehensive ecologically oriented multipest management systems has given rise to the concept of IPM. Although the essential features of IPM were originally articulated by entomologists many years ago, all pest control disciplines -- plant pathology, weed science, entomology, nematology, etc., have shared in the development and implementation of IPM. Integrated pest management initially was considered to be the combination of biological and chemical control methods (Stern et al., 1959). Various authors (Stern et al., 1959; Huffaker, 1972; van den Bosch and Messenger, 1973; Watson et al., 1975; Metcalf and Luckmann, 1975; Smith, 1980; Smith and van den Bosch, 1967; Flint and van den Bosch, 1981; Bottrell, 1979; Bottrell, 1980; Bottrell and Smith, 1982) have attempted to define and delineate IPM from other approaches, but all agree on the broad ecological and multidisciplinary basis for pest control utilizing a variety of control technologies compatible in a unified single pest management system.

OBJECTIVES

The primary goal of IPM is to manage the pest populations in such a manner that crops can be produced economically and in an acceptable and ecologically sound manner. An effective IPM program will provide the following:

1. Improved control. The change to a new resistant variety, crop rotation, change in row spacing, use of mulch paper, change in fertilizer or pesticide use pattern, etc., which cause a shift in the status of the pest species, disease incidence, etc., are management components of an IPM program that will sometimes improve quality and yield of the crop. By implementing such control measures, one reduces the dependence upon pesticides and emphasizes the augmentation and conservation of beneficial organisms.
2. Pesticide management. Pesticides are an important component of IPM, but they are applied only when needed to reduce and maintain pest populations at acceptable levels. The more sensible approach with the judicious use of pesticides should increase their effectiveness and useful life span. Proper selection and proper use of pesticides reduce the chances of the building up of resistant strains of pests in the population as well as reduce other undesirable side effects.
3. Economical crop protection. Considerable savings in pest

control costs will be the outcome of an IPM program. Treating crops when pest populations require it rather than by the calendar reduces the amount and frequency of pesticide applications. The reduced number of applications also mean savings in the cost of fuel, labor, etc., necessary for the application of the pesticides.

4. Reduction of environmental pollution. Judicious use of pesticides will reduce the probability of harmful side effects associated with pesticides.

FEATURES OF AN IPM SYSTEM

1. Identification of pest species

The identity of the pests (insects, weeds, diseases, etc.) to be managed in the agroecosystem is a vital part of an IPM program. You must differentiate between the "real pests" and those that we perceive as real pests but actually are not. You should also be able to recognize the beneficial organisms within the cropping system. An organism should not be called a pest until it is proven to be a pest. A species may be a pest in some situations but not in others. Pest identification itself involves several subcomponents: the gathering of the specimens responsible for crop damage and having them positively identified; and searching the literature for relevant articles so as to learn about their distribution, biology, ecology, and control.

Pests interact with one and another, and this interaction may compound or offset their effects on the crop. Never assume that these effects are additive.

Scientists have classified the complex of pests within the cropping system into several basic units as follows:

"Key" pests: Integrated pest management programs are developed for lowering the average density of those pests that recur regularly at population densities exceeding economically damaging levels. Key pests are the focal point of any IPM system. They generally are few in number (usually one or two) in any given cropping situation, and they vary in severity from year to year; but, their average density or "equilibrium position" usually exceed their "economic threshold" levels (discussed below).

"Occasional" or "secondary" pests: Some workers class these as "part-time" pests for they attain economic levels only at certain times or places. These species are relatively minor.

"Potential" pests: These cause no significant damage under currently prevailing conditions. If not disturbed by external factors, such as the use of pesticides which destroy their natural enemies and unleash them from natural control, the introduction of new crop varieties which favor the pests' increase, or other environmental modifications that encourage their increase, these organisms will not become troublesome. In attempts to manage the key pest organisms, special care should be taken so as not to alter the agroecosystem in a way that favors the potential pests.

"Migrant" pests: As the name implies, these are non-residents of the agroecosystem but enter it periodically, sometimes causing economic damage. Examples are various species of grasshoppers, leaf beetles, and armyworms. To be effective, an IPM program for these pests sometimes must be applied over a large geographic area.

The population level that determines whether a pest species has attained real pest status is the economic threshold. This is the level of a pest population below which the cost to apply a control measure exceeds the losses caused by the pest (Stern, 1973).

The economic threshold, in other words, is the action threshold, the pest population level at which additional management practices must be introduced to prevent economic losses to the protected crop. In IPM, for each pest species, information is obtained on the population level that determines the species' economic threshold level. The economic threshold is not a constant value but varies from area to area, season to season, and with changes in market conditions. Economic threshold values are based upon assessment of the potential pest damage and the ecological, sociological, and economic costs created by the control measures. Economic thresholds are difficult to determine for they can depend upon many factors: crop density, crop variety, parasite, predator, and prey populations, stage of crop maturity, pesticide costs, soil type, etc. Economic threshold levels for the majority of our agricultural pests are not known. More basic research, information, and experience will be required before these values are available.

The development of a reliable monitoring or sampling method is essential to the understanding of the cropping system. A good unbiased sampling program is the prerequisite to full implementation of an IPM program and rational pest control. Samples and economic threshold levels work together. It is necessary to know the pest population density and the economic threshold levels to make meaningful IPM decisions. Sampling procedures vary with crop and the pest situation. Time requirements and economic factors make it necessary to develop practical sampling techniques for each pest and cropping situation involved. An understanding of the crop phenology and the related pest interactions is an essential aspect of monitoring development.

2. Continual presence of harmful species

One of the basic IPM philosophies is that IPM is a pest containment strategy, not an eradication strategy. For every pest species in an agroecosystem, there is a population level below which control cannot be justified. Although each pest species is potentially harmful and artificial control technologies may be required to maintain the pests at noninjurious levels, eradication is not recommended. The mere presence of a pest species does not necessarily justify the application of a control measure.

In fact, some low-level populations of pest species, weeds, for example, in the cropping system may be beneficial. The

weed *Euphorbia hirta* in Hawaiian sugarcane fields is a source of food for the tachinid fly, *Lixophaga sphenophori*, the larval parasite of the sugarcane weevil *Rhabdoscelus obscurus*.
Topham and Beardsley (1975) showed that parasitism of the weevil in sugarcane was closely associated with the distribution of the parasite and the food source. It has been well documented that the occurrence of noninjurious populations of some pest species is an advantage; the populations serve as important sources of food, reproductive hosts, or shelter for beneficial organisms--predators, parasites, and insect pathogens. Complete elimination of the pest organisms, therefore, may starve and/or force these beneficial species to leave the cropping ecosystem and, thereby, harmful side effects result.

3. Define the management unit

The agroecosystem is the management unit. Its limits are characterized by the local cropping system and the patterns of movement of the key pests. The management unit may be as large as an island, a valley on an island, a farm, an orchard, a tree, or some other ecological unit.

Any manipulation of the agroecosystem will affect the key pests as well as the beneficial organisms within the system. Changes that appear subtle to us may have a great effect upon the pest species. In some cases, the IPM strategy may aggravate some pest species while effectively controlling others. Any changes in cultural practices such as changes in pesticide use patterns, use of disease-free seed, changing from a monoculture (one crop) to a mixture of crops (polyculture), etc., may cause a drastic shift in the status of the pest species in the crop.

In Hawaii, the change in pesticide use patterns and the utilization of mulch paper in watermelon plantings completely changed the key pest status. The major growing area for watermelon is Kahuku on the north shore of Oahu. The key pests were a complex of dipterous serpentine leafminers, *Liriomyza sativae*, *L. trifolii*, and *L. huidobrensis*. The farmers were applying insecticides (naled, diazinon, and malathion) at least three times a week, some daily without effective control. They eventually gave up growing watermelons due to the severe injury by the leaf miners. Studies showed the widespread use of insecticides in the area directly killed the parasites that were limiting the leaf miner population. A demonstration field in the center of the area was established. Plants were examined weekly for leaf miners and parasites, and no insecticides were used for control of the leaf miners. Parasites moved into the field and within three weeks had controlled the leaf miners. Sticky traps were used to monitor leaf miners and parasite populations. The key pest status changed from the leaf miners to several species of aphids which were vectors for watermelon mosaic. If needed, one or two applications of dimethoate were applied per crop cycle for control of the aphids. The use of reflective mulch paper reduced the costs of weed control and slowed the invasion of aphids.

4. Utilizing the natural control agents

Integrated pest management strategies emphasize the reduction of pesticide applications and the maximization of natural control factors. Within each cropping system, there are natural control factors such as beneficial organisms (parasites, predators, and pathogens), periods of inclement weather (drought, cold, wind, and heat), shortage of food, space, and shelter, and the competition from other organisms (animals and plants in the area). These factors tend to limit the numerical increase of pest populations. Their effects may be insignificant in control of some pests but highly effective in the control of others. IPM strategies may alter the pest environment to enhance the combined action of these natural suppressive factors on a pest species.

Van den Bosch and Messenger (1973) stated that in an area with favorable climate and competitors absent or scarce, natural enemies of many insects and mites are universally present, often significantly so. The resident beneficial organisms in Hawaii are conserved and augmented by the deliberate introduction of parasites, predators, and pathogens into an area where they did not previously occur. These introductions follow the "classical" biological control concept. The reduction in the number of pesticide applications also encourages the development of parasite and predator populations.

Through the ages, people have observed their natural surroundings and developed many cultural, biological, and physical methods of pest control for their crops and stored food. The list of pest control methods is almost endless. The alternatives to chemical pesticides listed in Table 1 have the potential value of encouraging beneficial organisms in the cropping system. Some of the examples are utilized by IPM practitioners today.

Another important component of the IPM system is the judicious use of pesticide chemicals. The IPM philosophy does not eliminate the use of pesticides. All of you are cognizant of problems and undesirable side effects brought about by the heavy reliance on chemicals as the only pest control method. The use of some of the alternatives may also produce undesirable side effects (refer to Appendix 4, Limitations to Pest Control Methods). There is no panacea or alternative that will solve all pest problems.

Pests are continually changing, evolving more hardy and resistant strains, adapting to new environmental conditions, habitats, and control techniques. Therefore, we can assume that no single control measure will be permanently successful in limiting pest populations because of the pests' remarkable adaptive ability. Integrated pest management utilizing a variety of pest control technologies will give the longest lasting, effective, and economical crop protection.

5. Integration of components - systems approach

The traditional disciplines in the development of IPM programs were entomology, weed science, and plant pathology.

TABLE 1: Examples of Alternatives to Chemical Pesticides (Anon., 1965)

Insects, mites, and other invertebrates	Plant diseases	Weeds	Birds, mammals, and other vertebrate pests
Biological control	Disease resistance	Insects and other herbivores	Noise and physical repellents
Parasites	Reduction and losses by manipulations of plants and pathogens	Diseases	Chemosterilants
Predators	Control of plant pathogens by natural enemies	Environmental manipulation	Chemical repellents
Pathogens	Disease- and nematode-free seed and propogating material	Choice of variety	Trapping and shooting
Plant and animal resistance	Crop rotation and soil management	Seedbed preparation	Behavior
Environmental manipulations	Destruction of inoculum	Method of seeding or planting	Environmental manipulation
Plant spacing	Vector control	Seeding rates and row spacing	Exclusion
Species diversity	Nematode attractants and repellents	Fertilization	
Timing		Cultivation	
Crop rotation		Irrigation and water management	
Plant hormones		Erosion control	
Water management		Design of irrigation and drainage canals and ponds	
Fertilizer		Managed grazing	
Soil preparation		Sanitation	
Sanitation		Natural stimulants and inhibitors	
Induced sexual sterility		Plant competition	
Physical and mechanical control		Revegetation of weed- and brush-infested grazing lands	
Window screens		Breeding highly competitive forage species	
Light traps			
Fly swatters			
Protective packaging			
Sifting devices			
Barriers			
Flaming and burning			
Attraction and repellancy			
Attractants			
Repellents			
Genetic manipulation of pest populations			
Lethal genes			
Male-producing genes			

These specialists utilized their knowledge and expertise in solving pest problems along disciplinary lines. Disciplinary research will continue to be important, but the complexity of the agroecosystem requires the specialists to work together as an interdisciplinary team to understand the actions, interactions, and reactions of the pests' life systems in order to maximize the natural control factors that suppress pest populations. In Hawaii, the tomato spotted wilt virus is a serious problem in the production of lettuce. Three species of thrips, *Frankliniella occidentalis*, *F. schultzei*, and *Thrips tabaci*, are the key pest vectors of the virus. Weeds along the borders of the field act as hosts for the thrips and also as reservoirs for the virus. The team approach and close cooperation and collaboration between the weed scientists, entomologists, and plant pathologists are required to solve the complexities of the vector-weed-disease-lettuce cropping system.

The interdisciplinary team must cooperate and integrate their activities completely from the beginning of the research through the implementation and evaluation phases of the IPM program. Without close cooperation, the pieces of information obtained from the studies may not fit together into a single unified program. To avoid this pitfall, we must adopt a systems approach that utilizes the knowledge of the weed scientists, entomologists, plant pathologists, and other agricultural disciplines, combined with the expertise of system scientists who are knowledgeable in the ecological principles and application to the development of IPM programs. Today, everyone is interested in computers and associate their use with systems analysis. Computers have a place in IPM programs, but they are not essential. Many scientists believe the ultimate goal of a sophisticated pest management system is to develop a computer model that can be used to map out pathways for manipulating a crop (use of a disease-free seed, alter the irrigation schedule, etc.) to achieve effective pest management. Such a program depends upon the identification of key pests, valid sampling techniques, accurate assessments of economic thresholds and crop losses, meteorological data, etc. Models have been developed on the United States mainland in corn, cotton, deciduous fruits, and other crops. We have a long way to go for such a model in Hawaii.

6. Information delivery

The implementation of an integrated pest management program is primarily an educational process. As the extension agent on your island, you have the important role of educating the farmer, pesticide user, and other clientele in understanding the principles and objectives of the IPM program you are implementing.

Most extension personnel have been successful in implementing a demonstration on a farmer's field. Select one crop and one farmer to work with you. Prior to initiating the demonstration, be sure you have all the basic information on growing the crop and have followed through one or two crop cycles of your own to be sure the pest control actions you want to use are effective.

In the development of your IPM program system, you have evaluated the presently used pest control measures for your island; estimated the disease incidence and insect pest abundance; made a decision whether the level of pest damage has reached the economic threshold; and made a decision on what action should be taken at this time.

This information should be delivered to the farmer immediately following the examination of the crop. Most IPM practitioners devise a simple form containing the date, condition of the crop, pest status, etc., and the recommended action. The form is usually made in triplicate: one copy is given to the farmer or left in a mutually agreed upon spot; the second copy is for the field scout's (monitor's) use; and the third is filed in the extension office. Some field scouts leave a colored flag indicating to the farmer which treatment or pest control action is recommended.

You should follow up on any action recommended to ascertain and evaluate the effectiveness of the pest control method and the pest abundance. If you made a mistake in your decision, remember the conditions present and chalk it up to experience. If the occasion arises again with similar conditions, an appropriate change in action can be suggested. The decision process is trial and error, and success increases with experience. Do not be discouraged. With successive tries, the methods of monitoring the crop can be more finely tuned and more reliable decisions made.

Inform your clientele of what actions you are recommending; how you arrived at the decision and what results you expect. Better informed farmers will result in a better coordinated and effective IPM program. Remember, integrated pest management does not eliminate pesticides or eradicate a species. IPM recommends the use of pesticides only when as needed to keep the pest below unacceptable levels.

Successful integrated pest management depends upon teamwork and a dedication to cooperation in a "true systems approach." IPM is not a panacea for all pest problems. There are still some pests that chemical control is the only alternative. IPM is effective in reducing costs of crop production and offers excellent opportunities for long-term pest control at a minimum cost.

You are the leaders for integrated pest management in the South Pacific. We are ready to help you. Good luck.

ADDENDUM: SOME DEFINITIONS FOR INTEGRATED PEST MANAGEMENT

Agroecosystem: the ecological system existing in an agricultural area sufficiently large to permit long-term interactions among all the living organisms and with their nonliving environment.

Biological control: the use of natural enemies (parasites, predators, and pathogens) to control or regulate pests.

Control: as used here, it has the sense of causing pest population numbers and consequent damage to be reduced to tolerable levels.

Cultural control: is the use of farming or cultural practices associated with the crop production to make the environment less favorable for survival, growth, or reproduction of pest species.

Economic injury level or threshold: the pest population level or pest incidence at which additional management practices must be introduced to prevent economic losses to the protected crop. This level is not a constant value but varies from area to area, season to season, and with changes in economic aspects.

Integrated pest management (or IPM): integrated pest management is a multidisciplinary ecological approach to management of pest populations which utilizes a variety of control technologies or tactics compatibility, i.e., it is multitactical, in a single coordinated pest management system.

Multilateral control: this viewpoint stresses the role of alternate hosts of parasites and pests in neighboring agroecosystems.

Pesticide management: is the technology concerned with the safe, efficient, and economic use and handling of pesticides from the time of manufacture until final utilization and disposal.

Pest management: a general all-embracing term that applies to any form of .st population manipulation invoked by man in the interest of protecting his crops, animals, or health. The term has gradually come to replace the term pest control.

Supervised control: control of pests supervised by qualified pest managers and based on conclusions reached from periodic evaluations of pest density or incidence and natural enemies.

REFERENCES CITED

Anon. 1965. Restoring the quality of our environment. Rep. of the environmental pollution panel. President's Sci. Adv. Comm. The White House. U. S. Govt. Print. Office, Washington, D. C.

Bottrell, D. G. 1979. Integrated pest management. Council on Environmental Quality. U. S. Govt. Print. Office, Washington, D. C.

Bottrell, D. G. 1982. Principles of integrated pest management, concepts, techniques and application of integrated pest management in rice in West Africa, p. 183-195. In E. A. Akinsola, B. Ouayogode, and I. Akintayo (Eds.), Integrated pest management in rice in West Africa. Proceedings of a course held January 10-28, 1982, Fendall, Liberia. West Africa Rice Development Association, Consortium for International Crop Protection, and United States Agency for International Development. WARDA, Monrovia.

Bottrell, D. G. and R. F. Smith. 1982. Integrated pest management. Environ. Sci. Technol., Vol. 16(5):282A-288A.

Flint, M. L. and R. van den Bosch. 1981. Introduction to insect pest management. John Wiley and Sons. New York, New York.

Glass, E. H. 1975. Integrated pest management: rationale, potential, needs and implementation. Entom. Soc. America. Special Publ. 75-2.

Huffaker, C. B. 1972. Ecological management of pest systems. In: J. A. Behnke (Ed.). Challenging biological problems--directions toward solutions. Oxford Univ. Publ., New York, New York. p. 313-342.

Metcalf, R. L. and W. H. Luckmann. 1975. Introduction to pest management. John Wiley and Sons, New York, New York.

Smith, R. F. 1959. The spread of the spotted alfalfa aphid, Therioaphis maculata (Buckton) in California. Hilgardia 28(1):647-691.

Smith, R. F. and R. van den Bosch. 1967. Integrated control p. 295-340. In: W. W. Kilgore and R. L. Doutt (Eds.). Pest Control--biological, physical, and selected chemical methods. Academic Press, New York, New York.

Smith, R. F. 1980. The integrated pest management approach. Proc. Seminar and Workshop on Pest and Pesticide Management in the Caribbean. Nov. 3-7, 1980. Vol. II. Invited papers p. 105-107. Caribbean Graphics, Bridgetown, Barbados.

Stern, V. M., R. F. Smith, R. van den Bosch, and K. S. Hagen. 1959. The integrated control concept. Hilgardia 29(2): 81-100.

Stern, V. M. 1973. Economic thresholds. Annual Review of Entomology 18:259-280.

Topham, M. and J. W. Beardsley. 1975. Influence of nectar source plants on the New Guinea sugarcane weevil parasite, Lixophaga spenophori (Vill.). Proceed. Haw'n. Entomol. Soc. Vol. 32(1):145-154.

van den Bosch, R. and P. S. Messenger. 1973. Biological Control. Intext. New York.

Watson, T. F., L. Moore and G. W. Ware. 1975. Practical insect pest management. A self-instruction manual. W. H. Freeman and Company. San Francisco, California.

Date: Oct. 18
Time: 1100

SAMPLING IN INTEGRATED PEST MANAGEMENT

Rainer Daxl

Sampling is done for research (life tables, development of IPM systems, inventory of agroecosystems), and for management (decision-making, rapid classification of situations, for example, sequential sampling).

Absolute estimates express numbers per unit which do not change (e.g., per acre or hectare). They permit comparison of foliage-feeding larvae with their ground hiding pupae, pests with their damage, pests with their natural enemies, etc.

Relative estimates measure populations in unknown units and allow comparisons only in space or time. Examples: catches per unit effort, when using sweep nets or traps. Relative estimates are adequate when good extensive sampling is carried out.

Population indices estimate the products or effect of animals, e.g., damage.

In IPM, we must sample pests, crop plants, beneficial organisms, rainfall, temperature, etc. We want to know the whole ecosystem, its important factors, and their interrelations, and to make analyses of important factors.

SOME NECESSARY STATISTICAL TOOLS

1. The mean (average) $\bar{x} = \Sigma x/n$, measures the location of population.

2. The variance $S^2 = \frac{\Sigma x^2 - (\Sigma x)^2/n}{n - 1}$ measures the dispersion; are the individuals close or distant to the mean?

3. Standard error of the mean $S(\bar{x}) = s/\sqrt{n}$, a measure of the distance of the estimated mean $\bar{x}$ to the true mean $\underline{m}$ of the population; measures the sampling error.

4. Relative variation of the mean (RV) = $S(\bar{x})/\bar{x}$, a measure of the reliability of the sampling result. RV permits a comparison in the reliability of different means from different samples (a RV of ≤ 10 percent or ≤ 0.1 is usually adequate).

5. Relative net precision of the mean (RNP) = $100/(RV)(C_s)$, measures the efficiency of a sample method by including cost (C_s = cost of sampling).

6. Confidence limits measure the reliability of sample results. They bracket the true mean and state that it lies within an interval of specified probability (usually 95 percent which brackets an interval of $\bar{x} \pm 1.96s/\sqrt{n}$ on the abscissa of the normal curve).

SPATIAL DISPERSION PATTERNS, STATISTICAL DISTRIBUTIONS

Correct sampling cannot be designed until the distribution pattern of the population is known.

Random Distribution

Every point on the area has an equal chance of being occupied by an individual. The probability (pn) that a sampling unit will contain n individuals follows the Poisson distribution:

$Pn = \lambda^n e^{\lambda}/n!$ (where $\lambda = \bar{x} = s^2$, n! = n factorial).

Spatial patterns can deviate from randomness in two directions:

1. More uniform, decreasing the probability of another individual being nearby to the one found ($s^2 < \bar{x}$)
2. More aggregated, clumped, increasing the probability of another individual being nearby. There are more zero counts and more high values than expected under random distribution, and so $S^2 > \bar{X}$. Clumped populations tend to be underestimated, for a large number of the individuals occur in a few clusters which are rarely included in sampling.

The Negative Binomial Distribution (NBD)

This gives most often the best fit to clumped populations. It is described by the mean $\bar{x}$ and an exponent k which is a measure of aggregation. Its basic formula is $(q-p)^{-k}$, and its expansion gives the probability Px that a sample will contain x = 0, 1, 2, 3.... n individuals as $Px = (k + x-1!)/x!(k-1)! * R^x/q^k$, where $R = p/q = \bar{x}/(k + \bar{x})$, $q = 1 + p$, $p = \bar{x}/k$.

Methods to compute k are given in Southwood (1978). When $k > 8$, the Poisson distribution serves as an adequate substitute for the complicated NBD.

The pattern of spatial distribution may not be constant from one time period, area, or life cycle to another. As population density increases, the distribution often changes from clumped to random.

TRANSFORMATIONS

Most common statistical tests are based on the normal distribution; so, data from a different distribution must be transformed to make them "normal."

Transform slightly clumped populations using square root of the data; transform clumped populations using logarithms [use log (x + 1)]. Transform percentages (if they are outside 20% - 80%) by arcsin $\sqrt{p}$ (p = proportion). Back transform by $(\sin \theta)^2$.

SAMPLE SIZE

The greater the sample size, the more reliable is the information, but also the higher the costs are. So, we must determine the smallest sample number which gives the desired reliability of the estimates.

Let us define the reliability by $RV = S_{\bar{x}}/\bar{x}$. Let us decide on a reliability of C which may be 10 percent of the mean. Then, we can substitute RV by $C = S_{\bar{x}}/\bar{x}$. Remembering that $S_{\bar{x}} = s\sqrt{n}$, we can write $C = \frac{s\sqrt{n}}{\bar{x}}$ and solve for $n = (s/\bar{x}\ C)^2$. This is the general case, for a <u>normal</u> distribution.

Under a NBD, $s^2 = \bar{x} + \bar{x}^2/k$, and substituting this in the general formula gives the sample size for NBD, $n = \frac{1/\bar{x} + 1/k}{C^2}$.

Under a Poisson distribution, $s^2 = \bar{x}$, and the sample size is $n = 1/\bar{x}\,C^2$. Under a positive binomial distribution, $n = q/pC^2$, where p = probability of occurrence, q = 1 - p.

SAMPLING PATTERNS

Random Sampling

In random sampling, every sampling unit has an equal chance of being selected. It avoids bias. But, it often is unacceptable in the field because it requires much walking time.

Stratified Sampling

Stratified sampling is more adequate for IPM work because it reduces the variance. You can stratify the surface area or the habitat.

Sequential Sampling

Sequential sampling is for decision making; it can greatly reduce the amount of time required for sampling. Samples are taken in sequence with decisions made after each sample, based on the cumulative information obtained. You must know the spatial distribution of the population, the economic threshold, and the level of risk involved in making a wrong decision. Sequential sampling plans must be generated for the various growth stages, pests, and economic thresholds during a crop cycle.

Planning and Design of Sampling

1. Do preliminary sampling to determine $\bar{X}$ and S^2
2. Use more than one sampling method to get confidence in results
3. Use sampling forms
4. Give sampling guides (percentage defoliation, size of larvae, etc.)
5. Check the sampling method against a reliable absolute technique.

SAMPLING TOOLS AND TECHNIQUES

Absolute methods include visual counts, clam trap, drop bucket, fumigation cage, ground cloth, and mark-recapture, for example. Here a number of marked animals *n* is released; after mixing with the total population *N*, a sample is taken which has *a* marked and *A* unmarked animals. The relationship is $a : A = n : N$, and we estimate $N = An/a$.

Relative methods include the sweep net (rapid and unreliable) and the many traps available: light, sticky, pitfall, pheromone, suction, and pan traps.

When sampling parasitoids, bias can arise due to:

1. Interruption of the host's exposure to the parasitoids
2. Spatial variation of parasitism
3. Variation of parasitism with host age
4. Competition with other natural enemies.

All of these factors tend to underestimate parasitism. When sampling pathogens, avoid cross-contamination of insects in containers. Sample pathogens periodically throughout the crop season. Weeds can be sampled: number/acre or meter^2, by percent coverage of the ground, and by weight (combines density and size, permits estimation of competition by comparing weed and crop weight). Soil inhabiting insects and nematodes are sampled by taking soil, sieving, separating animals in Berlese funnels, or washing through sieve sets and finally floating the material in concentrated sugar or other solutions.

REFERENCE CITED

Southwood, T. R. E. 1978. Ecological methods with particular reference to the study of insect populations. Chapman and Hall, London.

Date: Oct. 18
Time: 1330

IPM IMPLEMENTATION: CASE HISTORY EXAMPLES AND GUIDELINES FOR DEVELOPMENT

A CASE HISTORY STUDY FROM NICARAGUA

Rainer Daxl

In Nicaraguan agriculture, two universes can be distinguished:

1. Large holdings of 350 hectares average, growing cash (export) crops like cotton, sugarcane, with capital and energy intensive methods
2. Small scale farmers of 2.5 hectares average, growing corn, beans, and vegetables for subsistence and local markets using traditional low input methods.

DEVELOPMENT OF IPM SYSTEMS

In the crops under study [cotton and food grains like corn (maize), beans, and sorghum], the agroecosystem was evaluated first of all. In each major growing area, untreated fields and fields treated according to local practice were set up on farmers' land, serving for research and demonstration. Observations were made at least twice weekly, but often daily, on growth and development of the crop plants, population dynamics of pests and beneficial insects, climatic factors, and farmers' practice. In food grains, a special survey was conducted to evaluate farmers' cropping systems, pest control methods, and the economic situation. Special field trials investigated economic thresholds, damage potential of pests, influence of fertilization and soil moisture on maize plant tolerance, benefits of pesticide use, selective usage of pesticides, and other factors.

The field research program demonstrated:

1. The importance of knowing the stages of plant growth and development in relation to pest abundance and activity. The crops showed susceptible periods (peak fruit formation and maturation) and tolerant periods (before and after the former). Corn usually did not need protection against defoliating Spodoptera frugiperda before the second half of the whorl stage or after tasseling. Beans could tolerate more than 60 percent of defoliation before bloom, but only 30 percent during pod formation. In cotton, the peak fruiting period was 70-105 days after planting, and 20 percent defoliation was acceptable during this period. Before and after this period, 50 percent defoliation was tolerated.
2. Predators and parasites were abundant during the early part of the cotton season, virtually absent during the critical period of fruit formation and maturation, and most abundant in the following dry season. Hence, it was recommended to refrain from insecticide usage in early season so as to conserve the natural biological

control agents and to make full use of the crop's high pest tolerance. In food grains, beneficial arthropods are abundant during the whole cropping season in Nicaragua.

3. Key insect pests in cotton are the boll weevil (*Anthonomus grandis*) and the bollworm (*Heliothis*) and in corn the armyworm (*Spodoptera*). In beans, there is no general key pest, but severe damage can be inflicted by slugs one year, armyworms and loopers another, and bean leaf beetles still another.
4. In corn, a selective and cheap way to use insecticides against *Spodoptera* is to drop small quantities of granulated phoxim or chlorpyriphos mixed with sawdust by hand into the infested whorls. Treatment is carried out only after the economic threshold of 20 percent damaged whorls is reached.
5. In corn, pesticide use alone gave 24 percent yield increase, and fertilizer alone only 6 percent, compared with an untreated check. But, using the two agrochemicals in combination gave 60 percent more yield. So, the farmer who decides to use fertilizer should also protect his crop, or if he wishes to use pesticides, he should also apply fertilizer so as to get the full potential of his investment. Under conditions of drought, plant protection had no beneficial effect,

i.e., did not save or raise yields.

6. Mixed croppings of corn associated with beans suffered significantly less from insect pest attack.

It was found that often simply by understanding the agroecosystem and the interplay of its relevant factors, effective pest management programs could be designed. For example, knowing that the presence of eggs and small larvae of noctuid insects (*Spodoptera* and *Heliothis*, for example) tend to be high around new moon, and knowing that the critical cotton fruit formation period is between 70-105 days after planting, the new moon phases were determined in advance, and planting was timed so as to escape significant egg lays during the critical fruiting periods.

TECHNOLOGY TRANSFER (EXTENSION)

Through personnel of the Ministry of Agriculture and the Development Bank, demonstration plots were established to show growers and technicians:

1. Field sampling procedures
2. Numbers of insects and degree of damage which cotton plants can tolerate
3. The importance of natural mortality factors in pest control
4. Selective pest control with pesticides
5. The need for following plant growth and development throughout the season.

Weekly meetings with cotton growers and technicians were held. Farmers discussed their pests and other problems, and the technicians provided them with educational information. Numerous meetings and training courses were held for food grain growers and technicians.

Action was initiated which led to the formation of a national Coordination Committee for Integrated Control. This Committee coordinates and guides research activities, reviews research results, formulates and publishes control and crop management recommendations, and functions as clearing house and liaison for all integrated control activities. Members of the Committee are the key government institutions involved in crop protection, private enterprise technicians, the National University, and international advisers.

The Committee prepared a "Guide to the Integrated Control of Cotton Pests in Nicaragua" in 1971 and has revised it almost yearly since then.

Guidelines for IPM in food grains were prepared by the Ministry of Agriculture in cooperation with FAO and later GTZ.

In 1982, the Committee reduced drastically (by 75 percent) the number of pesticide brands used in cotton production, selecting the most appropriate products based on their effectiveness, ecosystem impact, role in integrated control, safety, and price.

Since 1982, a Pilot Boll Weevil Suppression Program has been underway in 17,600 hectares cotton. The program suppresses weevil populations in the off-season by a series of trap crops fortified with pheromone traps. This program saved nine insecticide applications in 1981 on a test farm.

EDUCATION PROGRAM

A four-semester postgraduate course titled "Applied Ecology: Integrated Control" was initiated in 1971. During 1974 through 1978, four, one-month intensive courses were held with the participation of international scientists and consultants and nearly 100 students in total. In 1981, the National University promoted these courses into a postgraduate five-semester Master of Science degree.

At the technical level (pregraduate), four, two-semester courses were held during 1973-1982 at two of the University campuses; 160 students graduated.

GUIDELINES FOR DEVELOPMENT BASED ON EXISTING CHEMICAL CONTROL TECHNIQUES

James A. Litsinger

For many crops in the Pacific, the only developed pest control technology is the use of pesticides. National chemical control recommendations typically list a number of pesticides with their respective dosages for each pest known to attack a particular crop.

The task of translating these general recommendations into actual practice has been left to the extension service officers. The result has been that pesticides are often used preventively on calendar schedules with little or no economic analysis to support decision on optimal application frequency and timing.

A methodology has been developed which follows an objective step-wise procedure which can be applied to any crop to determine the optimal number of pesticide applications and their timing in a given location.

The methodology can be carried out in each crop by one or two people with little scientific background and requires minimal budgetary support because the farmers and the farm community take an active role in the applied research program.

All research is carried out in farmers' fields utilizing existing technology. Sound chemical control recommendations normally can be developed in 3-4 years depending on the reliability of the existing technology under farmers' conditions.

The methodology involves the following steps:

1. Crop selection
2. Site selection
3. Team formation
4. Description
5. Design
6. Testing
7. Evaluation
8. Extension and follow up.

Steps 5-7 are repeated each year, based on the evaluation of previous years' results, i.e., technology is redesigned, tested, and evaluated annually until a practice is determined.

CROP SELECTION

Select a crop that you believe farmers are now over-treating with pesticides. Quicker results will be obtained from short-term crops such as vegetables than from a crop such as banana. Watermelon in Tongatapu, Tonga, is used as an example here.

SITE SELECTION

Initially, the applied research should focus on one village which is representative of watermelon production for Tongatapu. By focusing on one village near the experiment station, valuable time will not be consumed traveling to and from the research sites. Other aspects of site selection include your familiarity with the farmers and extension workers in the village, as well as the expected level of cooperation that is likely to be offered by the farmers themselves.

TEAM FORMATION

An IPM operational team is composed of research and extension officers and farmers. The degree of involvement of research and extension officers depends on their availability and interest in such a project. A research officer or an extension officer should take the lead in the project with the other providing support. Input from both sides will be necessary for the success of the project. The research officer will provide technical support on the technology and sampling methods, and the extension officer will carry the program to more villages once the chemical control technology has been determined from field trials.

Before finally selecting a village, a meeting should be held in the village with all the watermelon farmers. In that meeting, the pest problems and control methods should be discussed. The farmers then should be asked if they would be willing to cooperate in the field testing. Arrangements for field trials should be agreed upon ahead of time in terms of what is expected on the part of the farmers and what compensation will be given for any loss in yield from the treatments. It is important that a common set of arrangements be followed for all farmers. Do not make separate arrangements with different farmers.

At the end of the meeting, the farmers should formally invite the IPM team to work with them on the project.

DESCRIPTION

Information gathering is a vital part of IPM work as it reduces guesswork and facilitates in narrowing the selection process to determine what technology to test. The research team should informally interview five farmers before developing a questionnaire which should be used to survey 20-30 farmers in the area. The questionnaire serves to provide background information on current farmer practices and levels of technology employed. The following information should be gathered from the farmers' experience:

1. Variety
2. Area planted
3. Spacing of rows
4. Seeds per meter or row, per hill, etc.
5. Tillage/crop establishment method
6. Crop rotation/cropping system
7. Fertilizer use
8. Pesticide use (herbicide, insecticide, fungicide, etc.) for each application
   a. brand name
   b. kind of sprayer/capacity
   c. number of sprayer loads per application (calculate spray volume)
   d. number of tablespoons, etc., of pesticide per sprayerload (calculate dosage based on reported area)
   e. availability and source of water for spraying
   f. application time and frequency
9. Nonchemical control methods
10. Weed control methods
11. Farmers' recall of pest outbreaks in the past

12. Source of money to purchase pesticides (interest rates)
13. Landowner/leasehold
14. Expected yield
15. Expected price
16. Enumeration of pest problems (insects, diseases, weeds, etc.) by growth stage (do not help the farmer, let him volunteer information):
    a. seed/seedling stage
    b. vine running stage
    c. fruiting stage.

    After the farmer has listed the pests, have him rank them in terms of importance: 10 = most important, 1 = least important. Average the farmers' responses and give a zero for a pest not mentioned. An average mark of 10 means all farmers have the pest and mark it as the most important pest. Two pests can be given the same mark.

From the above information, you can calculate the relative value of pesticide in the production costs as well as the profit from watermelon production. You also have knowledge of the farmers' perception of pest problems and their level of technical ability to control the pests. You can determine the average pest control practice that farmers in the area use.

DESIGN

Review the national recommendations for watermelon and calculate the cost of each application of pesticide. Select the least expensive pesticide among those listed for each part. Consult with the researcher to determine a range of values for establishing economic thresholds for each pest. These may be no more than educated guesses. Establish sampling methods for each pest (sample unit and numbering of samples).

TESTING

All trials will be done on farmers' fields. Select four farmer cooperators around the village who are representative of watermelon growers on Tongatapu but have large fields. The farmers will prepare the land, plant, and manage the crop for all operations except for pesticide application. You will provide the farmer seeds, fertilizer, and pesticide. The farmers should keep the yield records.

At the end of the trial, the average yield of all treatments (refer below) will be determined, and if this is lower than his current practices (Treatment 6), then the farmer should be compensated for the difference. You should not be held responsible for any crop losses due to events beyond the scope of the treatments (hurricane damage, stray cattle, etc.). Do not rent the land from the farmer.

The trial will be a randomized complete block design with the four farmers being the replications. Randomize all nine treatments in each field; plot size should be about 75 $meters^2$. When spraying the plots, have two helpers hold a plastic sheet barrier to reduce spray drift between plots.

The first five treatments are designed to measure the yield loss from insects in each growth stage of the crop. This information is helpful in evaluating economic threshold values. None of these five treatments is a potential recommended practice.

THE TREATMENTS

Treatment 1 - Complete insect control

a. seedling protection (carbofuran with the seed)

b. vine running stage (weekly applications of a broad spectrum insecticide at a high dosage)

c. fruiting stage (weekly applications of a broad spectrum insecticide at a high dosage)

Treatment 2 - Omit 1a. but apply 1b., 1c.

Treatment 3 - Omit 1b. but apply 1a., 1c.

Treatment 4 - Omit 1c. but apply 1a., 1b.

Treatment 5 - Untreated

Treatment 6 - Farmers' practice

Treatment 7 - Spray when economic threshold level 1 is exceeded (see Table 1)

Treatment 8 - Spray when economic threshold level 2 is exceeded (see Table 1)

A standard high level of fungicide protection should be applied to Treatments 1-8. A ninth treatment might test a reduced

TABLE 1: Economic Thresholds and Chemical Control

Recommendations for Watermelons

Pest	Economic Threshold: Level 1	Economic Threshold: Level 2	Chemical (dosage in kilograms of active ingredient per hectare)
Seedling Stage			
Pumpkin beetle	2 feeding marks/hill	6 feeding marks/hill	Chemical A (0.75)
	(10-hill sample)		
Vine Running Stage			
Melonworm	25% infested leaves	75% infested leaves	Chemical B (0.75)
	(10 vine sample)		
Aphid	25% infested leaves	75% infested leaves	Chemical C (0.75)
	(10 vine sample)		
Fruiting Stage			
Melonworm	10% infested leaves	30% infested leaves	Chemical B (0.75)
Aphid	15% infested leaves	45% infested leaves	Chemical C (0.75)

fungicide spray schedule based on information from the farmers' survey. Insect control on Treatment 9 would be that in Treatment 6.

Treatments 7 and 8 compare two levels of economic threshold. Set the values sufficiently far apart so that meaningful comparisons can be made over a wide range of values. These values will be modified each year based on your results. Treatment 7 is the provisional insect control practice. Because of plant growth compensation, different economic threshold values may be established for early plant growth stage.

In Tonga, we expect the insect pests to be pumpkin beetle in the seedling stage and melonworm and aphids in the vine running and fruiting stages. Fungal disease will be primarily powdery mildew.

The following data should be collected from each plot (treatment):

1. Incidence of pumpkin beetle in the seedling stage (number of feeding marks per hill in a sample of 10 hills)
2. Incidence of melonworm in both the vine running and fruiting stages (number of worms per leaf in a sample of the six youngest mature leaves from 10 vines)
3. Incidence of aphids in both the vine running and fruiting stages based on the number of infested leaves in a sample of the six youngest mature leaves from a

sample of 10 vines)

4. Incidence of fungal disease in both vine running and fruiting stages (number of infested leaves in the 6 oldest leaves from 10 vines); sample melonworm, aphid, and fungal diseases at the end of each of both growth stages
5. Yield.

FOR TREATMENTS 7 AND 8 ONLY

Visit the plots weekly, walk through them, making casual counts. If you suspect the economic threshold value has been exceeded for any pest, take a formal sample and record those levels in only those affected fields. If you apply a pesticide to a plot in response to an exceeded economic threshold, sample and record pest incidence in that treated plot and the untreated check during the following two weeks as well to verify if the insect population declined. This is important to have as it will show whether the recommended chemical/dosage is working. If it is not working, then change it, immediately, by increasing dosage or switching to a new chemical.

EVALUATION

Analyze the data statistically to determine the differences in yields and pest populations among treatments. Use analysis of variance (F test) and an appropriate statistical method such as Duncan's multiple range test to compare treatments at the 5 percent probability limits (P = 0.05). Calculate the coefficient of variability (CV) for each variable to see how reliable your sampling technique has been. If the CV exceeds 20 percent, then increase your sample size.

Calculate yield loss in each growth stage. Total yield loss equals yield in Treatment 1 less yield in Treatment 5. Is there a significant yield loss? If so, in which growth stage(s) did it occur? Yield loss in the seedling stage equals yield in Treatment 1 less yield in Treatment 2, etc., for the other growth stages.

Determine the key pest(s) responsible for the yield loss in each growth stage. Compare insect incidence to yield loss. Did the complete control (Treatment 1) suppress insect populations? If not, make appropriate changes in Treatment 1 for the next crop. If needed, keep changing the insecticide chemicals, dosage, and/or timing to enable you to achieve a high level of control, below that level of insect incidence where yield loss occurs (economic injury level). Compare the yield in Treatment 6 with yields of Treatments 7 and 8. Did the economic threshold values work? Look at the yield results and insect incidence in each field separately. Compare the yields in Treatments 6 and 9 (if Treatment 9 is included). Did the reduced fungicide application frequency of Treatment 9 result in a lower yield? But, as economic returns are more important than yields are, you must compute the net returns (profit) and benefit/cost ratios (rate of return) for Treatments 5-9.

Net returns or profits from pesticide use equal the yield multiplied by the crop price less pesticide cost. Pesticide cost equals the value of chemical applied plus interest on borrowed money plus labor and sprayer use costs. Consult an economist for local value of labor, equipment, and interest to charge. Labor for each pesticide application is in the order of 16 man hours per hectare.

Benefit/cost ratio measures the rate of return for monetary investment. For Treatment 6, the benefit/cost ratio is the net returns from Treatment 6 less the net runs from Treatment 5, divided by the cost of pesticide. As a rule of thumb, the benefit/cost ratio should exceed 2.0. In other words, farmers in general will not accept a new technology if it produces less than a 2:1 return on investment.

Experience has shown that by following the above methodology, many changes will need to be made on economic threshold values, sampling methods, and pesticide regimes after the first year, but that in succeeding years the changes will be fewer as you focus on the optimal recommendation.

If the reduced fungicide practice in Treatment 9 gave good control, then in the second year use that level of fungicide to protect watermelons grown under Treatments 7-8, but maintain the high level of fungicide protection on Treatments 1-5. You may want to test an even further reduced fungicide regime in a modified Treatment 9 in the second or succeeding years by reducing the number of applications or dosage. Once you have settled upon the final recommendation, you are ready to explain your results to the farmers in the site and in other villages.

Consider carrying out a demonstration which compares the new recommendation (Treatment 7) with the current farmers' practice (Treatment 6). All farmers in the village where the treatments are being evaluated should be given weekly classes to instruct them on the newly-found results. The farmers' classes should be held during a full crop cycle from planting to harvest where they can be shown the development of pest problems as they naturally occur. Discuss the topics to be taught in the classes with the farmers beforehand. Topics can cover all aspects of watermelon production.

Farmers, however, cannot be expected to learn to use fully the economic thresholds in one year. A number of years of experience will be required.

Each week, meet with farmer leaders and have them explain what pests they observed the previous week and whether or not the pests have exceeded economic threshold levels. However, it should be agreed that the farmers will not spray until after the weekly follow-up meeting in which you go to the field to verify their reports.

It is only through repeated trial and error that farmers will begin to gain enough confidence in their ability to diagnose a pest problem, quantify it, and determine the appropriate control actions to take. This aspect of IPM should not be overlooked; only through regular follow-up meetings over the succeeding years will farmers achieve the required capability of decision making. It is important for the success of the follow-up meetings that the extension officer be punctual in showing up for the meetings.

After a number of years, the follow-up meetings can be held less frequently than at weekly intervals. Practice a gradual withdrawal to a point when you visit the village only once during each key crop growth stage. New pest problems may arise in the future, and you must be there when these occur.

Date: Oct. 18
Time: 1505

PRACTICAL FIELD EXERCISE IN ASSESSING THE PEST PROBLEMS AND NEEDS FOR IPM IMPLEMENTATION IN CABBAGE, CAPSICUM, PEANUT, AND PAPER MULBERRY

Coordinated by James A. Litsinger

The objective of this field exercise was to determine how well the trainees had grasped the IPM concept and its application. This exercise and the exercise of October 19, in fact, served as the course's "final examination."

The trainees were assigned to one of the following crop groups: cabbage, capsicum (bell pepper), peanut, and paper mulberry (the tree crop used as a source for bark used in making the traditional "tapa"). All the crops were growing on the Vaini Experimental Farm and infested with various pests. The trainees were instructed to go into the crop fields assigned to them, to assess the pest problems, and to develop short- and long-term recommendations for IPM development and implementation. They were asked to present their assessments and recommendations to the trainers on October 19.

Date: Oct. 19
Time: 0915

REPORTS OF WORKING GROUPS ON THE PRACTICAL FIELD EXERCISE IN ASSESSING THE PEST PROBLEMS AND NEEDS FOR IPM IMPLEMENTATION IN CABBAGE, CAPSICUM, PEANUT, AND PAPER MULBERRY

Coordinated by Niels von Keyserlingk

Reporters for the four working groups presented their findings on the cabbage, capsicum, peanut, and paper mulberry crops which they had examined on the previous afternoon. They gave detailed accounts of the growing sites, the crop culture, and the growth stages before going on to talk about the pest problems they had observed.

Although the exact identification of the pests had not been possible in all cases, the participants had recognized the disease, insect, mite, and weed problems present and made assessments of the damage they were causing. The reports went on to suggest appropriate action and control methods to deal with or monitor further the problems observed.

In the opinion of all the resource people present, the participants had prepared really excellent reports on the status of the crops examined making full use of the information acquired during the first two weeks of the course.

Summaries of the reports follow.

CABBAGE (SUMMARY OF REPORT)

The cabbage (an English or "head" variety) chosen for the observations was in two different stages of growth: one planting was fully headed and mature, and the other planting was in the seedling (5-6 leaf) stage. Adults and eggs of the diamondback moth, bacterial black rot, and nutgrass were observed in the mature planting. However, the working group concluded that the pests were not at levels that threatened the yields and control would not be profitable at this late stage of maturity. They recommended that the mature planting be harvested immediately as a measure to avoid spread of the bacterial black rot organism to the next young plantings of cabbage.

Leaf miners were causing significant damage (25-30 percent leaf area damaged) to the seedling cabbage (other pests of the seedling cabbage were diamondback moth larvae, large cabbage moth larvae, bacterial black rot, and weeds--nutgrass but these were not causing serious damage). Several insecticides will control the leaf miners, but the working group did not know what pest level constituted an economic threshold during the seedling stage. They outlined a field trial for obtaining data required to establish the economic threshold.

The primary integrated pest management components recommended by the working group were as follows:

1. Use of disease-free seeds so as to avoid the bacterial black rot organism

2. Hand weeding for control of nutgrass and other weed species
3. Use of insect pest and disease resistant varieties, if possible
4. Crop rotation--rotating cabbage with crops that are not hosts of the cabbage insect pests and diseases
5. Practice mixed cropping
6. Remove from the field and destroy old cabbage leaves and other cabbage parts before planting a new crop.

CAPSICUM (FULL REPORT OF WORKING GROUP)

The following report on capsicum is presented here in its original form (with minor editing as required to make the format conform with the Proceedings' format) to illustrate the type of reporting carried out by the trainees.

Observations

1. Size of plot:
   a. 33 feet x 95 feet
   b. 12 rows with 95 plants per row or 1,140 plants: 3 feet between rows, 1 foot within rows.
2. Field conditions:
   a. The capsicum plot was bordered on one side by a planting of string beans (heavily infested with aphids) and on the other side by a plot of silver beets. At one end it was bordered by a road and at the other end

it was bordered by weeds

b. Within the plot there were only a few weeds, and there were signs of recent weeding.

3. Plant characteristics:

   a. The plants were already in the fruiting stage. On a label placed at one end of the plot we found out that initial planting or transplanting was made on May 3, 1982

   b. Some plants had lost a number of leaves, particularly from the lower branches

   c. Fruit development ranged from the flowering stage to ripened fruit

   d. Some fruits were rotting on the plants, and there were also a number of them on the ground.

4. Climatic conditions:

   a. During the past week, there had been very little rain

   b. The ground was dry, and in some areas there were cracks

   c. On the day of observation, it was sunny and the wind was blowing about 1-3 miles per hour. The time of observation was between 3:30 and 4:15 p.m.

5. Organisms found on the plants:

   a. Few aphids on the leaves

   b. Few lady beetle larvae and adults were on the leaves

   c. Two syrphid flies (predators) were seen hovering around

d. Few twigs were found on the fruit

e. Fly eggs were noticed on damaged rotting fruit

f. One plant was uprooted and examined for nematodes but there were no signs

g. Some of the leaves had bacterial leaf spot

h. Substantial number of the fruits were rotting (causal organisms: fungi and birds).

6. a. Some fruit had signs of bird damage. There was evidence of bird pecking. A number of birds were observed in the nearby plots of tomatoes and on shrubs and trees some 50-100 feet away

   b. From a brief conversation with one of the experimental station staff, we found out that the capsicum plants had been sprayed with a fungicide and an insecticide. The insecticide was infrequently sprayed, while the fungicide was regularly sprayed.

7. Discussion of findings:

   We found out that the capsicum planting was nearly six months old. Fungicide had been used presumably to control the fruit rot. We did not have any information on yield but from the best we could determine, at the time of observation, there was an average of five and one-half fruits per plant on approximately 6,636 fruits in the plot. Let us say that five fruits amounted to one pound at time of harvest. We can say that this plot is capable of producing approximately 1,267 pounds of fruit. However, we found out by sampling that about 28 percent of the fruits were damaged, thus reducing the yield to 912 pounds. The most significant damage was caused by fungus (fruit rot) and by birds. Some of the bird damage predisposed the fruit to secondary infection. We also noticed fly eggs on some of the wounded fruits. Maggots produced from these eggs will cause further deterioration of the fruit.

We felt that the populations of other pest organisms found in the plot were insignificant as there were only a few seen on the relatively numerous plants examined. The aphids present were probably migrant species from the nearby heavily infested bean plants. The few ladybird beetles and syrphid flies were probably also migrant natural enemies of the aphids. However, the mites and the aphids should be monitored as they may be secondary or potential pests.

Climatic factors should also be taken into consideration. The dry condition of the soil may have reduced production of the fruit, weakened the plants, and lowered its resistance to fungal infection.

8. Conclusion:

We determined the key pest to be a pathogenic fungus, causing fruit rot, and the birds were a secondary pest. The combined damage of these two pests can reduce yields by as much as 28 percent.

9. Recommendation:

   The plants were nearly 6 months old. We felt that they had reached a point of diminishing returns in terms of fruit production. We recommend, therefore, that a last harvest be made and then the plants be disposed of properly.

Lessons Learned from This Exercise

1. Importance of field observation
   a. Observing all organisms in the environment, not just within the crop system, but also the surrounding vegetation
   b. Observing, especially the condition of this crop in question, to determine what may be causing the problem.
2. Information gathering
   a. Get information on the life cycle of the crop, age at time of observation, life span, productive period, etc.
   b. Get climatic data
   c. Get history of the plant, i.e., what has been done with regards fertilizer, pesticides, irrigation, etc.
3. Decision making
   a. Put together all the information obtained and to sum up the knowledge of plant protection, IPM, decide on the course of action to take.

Capsicum Working Group

J. A. Tenorio - Northern Marianas
(Reporter)

S. Uili - Tokelau Islands

Simione Leo - Vava'u, Tonga

Piliu Tavaka - Tongatapu, Tonga

F. Falaniko - American Samoa

Semisi Toa - Western Samoa

PEANUT (SUMMARY OF REPORT)

The peanut working group identified the following pest problems:

1. Weeds (some 16 species, mostly annuals)
2. Leaf rust
3. Leafhoppers, grasshoppers, leaf miners, and an unidentified species of caterpillar.

They observed that a low germination rate in the field (or possible bird damage) had resulted in a poor stand of peanut; drought perhaps was also a contributing factor. They reported that the poor stand, and not the pest problem, was the major yield constraint. They suggested that use of high quality seeds, proper selection of variety, weed management, fertilizer application, and supplemental irrigation during dry periods, would be essential to ensure good yields.

The leaf rust organism seemed to be the major pest problem; about 20-25 percent of the lower plant leaves were infected. They recommended the use of a fungicide to prevent the problem from worsening but were skeptical if any control measure would be justified considering the low yield potential. The unidentified caterpillar appeared to be causing some damage. They suggested hand picking as a control for this problem. The other pests--leafhoppers, grasshoppers, and leaf miners--were causing little, if any, problem.

PAPER MULBERRY

The paper mulberry, a perennial crop cultured for harvest of bark used for making tapa, was in a generally poor growing state.

Heavy infestations of a red spider mite (nearly 100 percent of the leaves infested) and red scale (about 75 percent of the leaves infested) appeared to be causing some damage. However, other factors probably contributed to the problem:

1. Shade from the interplanted coconut was probably excessive
2. Damage from the March 1982 hurricane was evident
3. Poor soil fertility may have slowed the growth
4. High winds (no windbreak around the plantation) may have also slowed the growth
5. The trees were too thick--the spacing was too close, and the plants needed thinning and pruning. The present crop was a ratoon crop.

The working group speculated that the first crop had heavily taxed the soil nutrients and this factor had weakened the ratoon crop and made it much more susceptible to spider mite and scale insect attack. Disease was not a problem, and weeds had been effectively removed from the mulberry planting. Some rose beetles were found on the trees but were not considered to be serious.

The working group outlined an integrated program for managing the mulberry pests, as follows:

1. Use of resistant varieties for mite control (however, it is doubtful if these are available)
2. Use of cultural methods, such as crop rotation
3. Biological control against the mites and scales
4. Proper spacing and use of good planting material
5. The development of a harvest grading system to give guidelines on the economic profitability of insecticide use for mite and scale control.

Date: Oct. 19
Time: 1045

WORKING GROUP SESSIONS ON REQUIREMENTS FOR INTEGRATED PEST MANAGEMENT IN BANANA, TOMATO, COCONUT, AND TARO

The trainees again split into four working groups. On this occasion, they considered the implementation of IPM programs in the four crops--banana, tomato, coconut, and taro--that they had previously identified to have the greatest regional significance (refer to evening workshop session of October 7, page 120). The trainees' reports were presented on October 20.

Date: Oct. 19
Time: 1330

REPORTS OF WORKING GROUP SESSIONS ON REQUIREMENTS FOR INTEGRATED PEST MANAGEMENT IN BANANA, TOMATO, COCONUT, AND TARO

Moderated by Ivor D. Firman

The groups reported the results of their discussions for each crop, concentrating on the following headings:

- What are the real pests?
- What limits them in nature?
- What are the other potential control methods?
- When does control become profitable?
- What are the economic, social, and environmental consequences of control?
- What is the best combination of control methods?

After these findings were presented, there was a full discussion among all the participants with resource people (lecturers and others) providing additional comments and information if required.

Summaries of the reports are included here.

BANANA

When bananas, especially plantain types, are grown for home consumption, pests are not usually controlled. When Cavendish bananas are grown for export, it was noted that a complete package of control methods for such pests as black leaf streak (Mycosphaerella fijiensis), bunchy top virus, burrowing nematode (Radopholus similis), scab moth (Lamprosema octasema), and weevil borer (Cosmopolites sordidus) is essential. These problems can be, and are being, controlled but only with very considerable expenditure on pesticides and their application. Because of this, some, but not all, participants expressed doubt as to whether this crop was suited to local growing circumstances while all participants expressed concern about the use of carbofuran and ethoprophos soil treatments.

TOMATO

On tomatoes, there are a large number of pests in the region including fruitworms, leaf-eating ladybirds, leafminers, vegetable bugs, mites, bacterial and fungus diseases, and, of course, weeds. Attention to planting season, proper selection of cultivars, correct identification of pests, use of biocontrol agents, and appropriate pesticides all have their place but the programs needed are extremely site specific.

COCONUT

In coconut, the rhinoceros beetle (Oryctes rhinoceros) and the hispine (Brontispa longissima) came in for particular mention. For rhinoceros beetle control by the Baculovirus, the fungus Metarhizium anisopliae and judicial use of sanitation already constitutes an integrated management system whereas Brontispa control, despite the introduction of parasites, still presents problems.

Knowledge is available for the estimation of rat damage and/ or a rat baiting program, although this is seldom well understood in the region. Several other pests, including fungal leaf spot in the nursery, mealybugs, and scale insects, spiralling whitefly, and weeds, were also mentioned in the report.

TARO

In taro, some of the key pests were identified as armyworm (*Spodoptera litura*), taro planthopper (*Tarophagus proserpina*), corm and root rots (especially root rot caused by *Pythium* spp.), and weeds.

In the home garden, chickens give a degree of control of the insect pests while livestock can be used to assist weed control. The use of disease resistant varieties, good water management, and, in Cook Islands and French Polynesia, the addition of sand to the planting holes, helps to control *Pythium* root rot. An integrated control for armyworm in Western Samoa utilizes *Apanteles* parasites and carefully timed insecticide sprays.

Date: Oct. 20
Time: 0910

THE FUTURE OF INTEGRATED PEST MANAGEMENT IN THE ISLAND COUNTRIES OF THE SOUTH PACIFIC-- OPEN DISCUSSION

Wallace C. Mitchell, Chairman

All trainees entered into the discussion. They agreed on the basic philosophy of IPM and the need to seek alternatives to pest control rather than total reliance on pesticide chemicals. Pesticide chemicals should only be used when and as needed. Several participants were concerned about receiving additional sources of IPM information, resources needed to carry on an IPM program, continued interchange of ideas among the trainees, and the availability of further in-depth training in IPM and related disciplines.

Some trainees were concerned whether the support of their colleagues and supervisors for the development of IPM programs would be forthcoming upon their return home. All were enthusiastic and willing to try to prevent the widespread use of pesticide chemicals at home, through the development of an integrated pest management program.

Date: Oct. 20
Time: 1140

TRAINEES' RECOMMENDATIONS: FUTURE NEEDS IN IPM TRAINING, RESEARCH, AND COORDINATION IN THE ISLAND COUNTRIES OF THE SOUTH PACIFIC

Presented by Edwin C. Pickop

The following recommendations were developed by the trainees themselves and presented by their elected spokesman, Edwin C. Pickop.

RESEARCH

1. The existence of a research station does not mean work is being done on integrated pest management
2. Research staff and administration should be encouraged strongly to undertake IPM work/studies, etc.
3. The available information on economic thresholds for pests in the South Pacific region should be made available. Specialists should help with in-country IPM development.

TRAINING

1. Guidelines on how to implement an integrated pest management program (with practical examples) is needed
2. There is a need to train the IPM counterpart (in-country-local) so when the "expert" leaves, the local staff has its

own expertise

3. There is a need for more regional-sub-regional, etc., IPM training programs in research and extension. (The consensus of opinion was annual meetings).

INFORMATION COORDINATION

1. All integrated pest management information should be transmitted to the South Pacific Commission (or other regional body) for dissemination to member/associate countries:
   a. biological control information
   b. resistant varieties, etc.
   c. chemicals.
2. Information on available experts within the Pacific region that can assist in specific IPM areas
3. All information should be translated into the country's language. The translations could be done "in country."

APPENDICES

APPENDIX 1

PANS Vol. 21 No. 1, March 1975 19

Rat Damage to Coconuts in Fiji. Part II Efficiency and Economics of Damage Reduction Methods

J. M. Williams†

Koronivia Research Station,

Department of Agriculture, Fiji.

Summary. The effectiveness and economics of two commonly recommended methods of reducing rat damage to coconuts were examined.

Three replicated trials were used to investigate the effectiveness of a 30 cm wide aluminium band placed around the palm trunk 3.5–4.5 m from the ground. On palms only 9–10 m high these bands did not effectively reduce rat damage as senile fronds frequently bridged the bands, providing rats with access to the palm crowns. Bands did prevent damage on tall palms (over 15 m) since no bridging by fronds occurred.

A poison trial indicated that rat damage could be almost eliminated in a mature plantation for up to three months following one application of 3 kg/ha warfarin bait. This confirmed work carried out in Jamaica and the Gilbert and Ellice Islands.

The cost of control by the two methods was assessed in relation to four copra values and it was concluded, in view of the relatively low levels of rat damage that prevailed, that neither form of control would be worthwhile until the value of copra exceeds F$150 per tonne and in the case of banding would only apply in the limited number of situations where bands are really efficient. **PANS 21: 19–26, 1975.**

Introduction

Possible methods of reducing rat damage in Fiji have been considered since 1925 when Turbet (1925) suggested a widespread rat destruction programme using poisons, trapping and galvanised palm trunk collars. In 1932, Taylor also recommended the use of poisons, such as red squill, and discussed the possibility of employing various biological methods, including viruses. Taylor rejected the use of metal bands on the grounds that in his experience of them, in Tahiti, they required too much effort to prevent coconut fronds or other trees from bridging the bands.

Lassalle-Sere (1955) summarised the results of banding trials carried out in Tahiti in 1951. In sixteen plots of 50 palms each, four were banded with the remainder acting as controls. Twelve months data clearly showed that banding reduced damage in areas of tall mature palms surrounded by little undergrowth. Lassalle-Sere assumed that the reduction in damage produced a corresponding increase in yield but this data was later shown by Williams (1971) not to support this assumption. Between 1955 and the mid 1960's a large scale banding programme was carried out in Tahiti, financed by a levy on copra (Millaud, 1966). However, banding was discontinued in the late 1960's as it had not been shown that it resulted in an economic increase in copra yield (Millaud, personal communication, 1972).

Yelf (1966) advocated banding in Fiji using aluminium alloy, 30 cm wide. However he established neither the prevailing level of rat damage nor its effect on yields, which was probably why only limited areas of palms were banded in the following two to three years.

In Jamaica and the Gilbert and Ellice Islands (R. W. Smith, 1967; and F. J. Smith, 1969) it has been demonstrated that warfarin baits incorporating paraffin wax reduces rat damage in coconut plantations. Smith (1967) treated one area of 225 palms in Jamaica, where the damage was severe, and seven weeks after the first treatment found that damage was reduced from an equivalent of 32 to only two nuts per palm per year. However, no data were provided to suggest that any economic increase in yield resulted and banding was rejected on

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account of the expense and the difficulty of keeping plantations free of hanging fronds (Fig. 1), creepers or other interplanted tree crops.

In the Gilbert and Ellice Islands Smith (1969) attached warfarin baits to palm trunks six feet from the ground and in one large scale trial (1450 palms in nine plots) reduced damage from the equivalent of 25 to one nut per palm per year, four weeks after poison application. In other trials in the Gilbert and Ellice Islands zinc phosphide baits were used in addition to warfarin but Smith, like other workers, produced no data to suggest any resultant increase in yield. Banding was found to be inefficient under atoll conditions, primarily because of corrosion caused by salt spray. Dense irregular stands of palms also meant that many bands were bridged by hanging fronds or other vegetation (Smith, 1969).

The first paper in this series (Williams, 1974a) describes the results of a widespread damage assessment programme in Fiji. This paper examines the effectiveness and economics of two commonly recommended methods for reducing rat damage to coconuts.

Methods and results

A. *Banding*

(i) Materials and methods

The use of mechanical barriers to prevent the scaling of palm trunks by rats is probably the simplest method of reducing damage and is particularly attractive since most rats in Fiji coconut plantations are not dependent on coconuts as a major source of food. Banding is a form of habitat manipulation that should not disperse a rat population by forcing it to turn markedly to other sources of food.

Yelf (1966) made considerable efforts to locate a low cost durable banding material and 0.15 mm thick aluminium alloy with a projected life of 20 years was chosen. Black sheet plastic, 0.25 mm thick, was also tested but was not considered suitable for widespread use as it becomes brittle with age and was thus easily damaged by wind or falling fronds. After cage trials with *Rattus rattus,* the larger of the two species attacking coconuts in Fiji, the other being *R.exulans,* Yelf established that an aluminium band 25 cm wide prevented rats from climbing palm trunks. However, to allow for non-vertical trunks he recommended 30 cm bands fixed by aluminium nails 4.5–5.0 m from the ground. This height was arbitrary but it placed the band above the thicker lower trunk (saving material) and avoided risk of damage by cattle or bridging by creepers. As considerable stocks of the 30 cm wide banding material used by Yelf were on hand in 1970 this material was used for all trials.

Three trials were established in 1970 to assess the efficiency of banding under general plantation conditions. Two were located on stands of younger palms (nine to ten metres high) as it was apparent at an early stage of the damage assessment programme that shorter palms incurred most damage (Williams, 1974a).

Trials on shorter palms were carried out on the island of Taveuni with one sited on Tuvamaca plantation and another on a property at Wainiyaku. At the former, palms were nine to ten metres high while at the latter they were 3.5–4.5 m. In addition a trial on tall palms (over 15 m) was established on Vunilagi Estate, Vanua Levu, on an area banded by the estate in 1968. At the Taveuni sites a uniform stand of 1000–1200 palms was divided into two and approximately half the area banded. Bands, depending on palm height, were placed 3.0–4.5 m from the ground. Six 20 palm plots were established within the adjacent banded and unbanded areas, all plots within each area being separated by at least one row of palms while there were six to eight rows between the plots in the two areas. Damage and production was recorded at Tuvamaca and Vunilagi but only damage was recorded at Wainiyaku.

All recording was done at monthly intervals. Tuvamaca and Wainiyaku plots were banded in January 1970, but recording was not begun until December 1970. The 11-month delay allowed production from the banded palms to recover at least partially from the effects of previous rat damage, for the time lapse from flowering to maturity is approximately 12 months.

(ii) Results.

At Tuvamaca in 1971 (Table 1) there was significantly less damage on the banded plots ($F = 7.4$; $p < 0.025$). Nevertheless the higher level of damage on the unbanded plots, which had probably been current for several years, did not result in significantly less production in either 1971 ($F = 1.9$) or 1972 ($F = 3.2$). This

TABLE 1A. SUMMARY OF BANDING TRIAL AT TUVAMACA ESTATE TAVEUNI

1970–71 (12.6 months)

Plot number	Number of nuts, rat damaged		Number of nuts harvested		Wet copra weight (kg)	
	Banded	Unbanded	Banded	Unbanded	Banded	Unbanded
1	82	105	666	771	212	250
2	119	123	760	530	247	233
3	85	130	919	924	290	303
4	83	108	1045	703	292	246
5	104	143	894	725	285	241
6	107	112	997	611	319	196
Mean per plot	96.7	120.2	880.0	710.0	274.0	245.0
s.e.	6.3	6.0	58.6	54.1	15.6	14.4
Mean difference in damage between banded and unbanded plots.	23.5					
Banding efficiency* (percentage)	19.5					

TABLE 1B

1972 (9.4 months)

Plot number	Number of nuts rat damaged		Number of nuts harvested		Wet copra weight (kg)	
	Banded	Unbanded	Banded	Unbanded	Banded	Unbanded
1	41	66	506	690	179	234
2	151	65	635	486	208	162
3	76	85	693	580	225	202
4	84	42	817	550	250	204
5	111	91	827	625	277	224
6	114	86	737	503	253	165
Mean per plot	96.2	72.5	703.0	572.0	232.0	199.0
Mean difference in damage between banded and unbanded plots	-23.7					
Banding efficiency* (percentage)	0					

*See text for explanation of this term.

TABLE 2A. BANDING EFFICIENCY TRIALS WAINIYAKU ESTATE, TAVEUNI

1971 (11.7 months)			1972 (9.3 months)		
Plot number	Number of nuts rat damaged		Plot number	Number of nuts rat damaged	
	Banded	Unbanded		Banded	Unbanded
1	37	127	1	46	146
2	85	50	2	13	106
3	30	106	3	20	98
4	34	114	4	25	85
5	42	168	5	36	176
6	48	173	6	65	150
Mean damage per plot	46.0 ± 8.2	123.0 ± 18.4		34.2 ± 7.8	126.8 ± 14.5
Mean difference in damaged between banded and unbanded plots	77.0			92.6	
Banding efficiency (percentage)*	63.0			73.0	

TABLE 2B. VUNILAGI ESTATE, VANUA LEVU

1972 (5.0 months)				
Plot number	Number of nuts rat damaged		Number of nuts harvested	
	Banded	Unbanded	Banded	Unbanded
1	0	3	212	242
2	0	1	311	271
3	0	1	263	236
4	0	8	253	220
5	0	0	262	218
6	0	0	291	249
Mean damaged per plot	0	22	265 ± 13.8	239 ± 8.0
Mean difference in damage between banded and unbanded plots	2.2			
Banding efficiency* (percentage)	100			

*See text for explanation of this term.

TABLE 3. CONTROL COSTS IN COCONUTS AT A SERIES OF VALUES PER TONNE†

Loss/ palm year*	$70/Tonne gross $24/Tonne net			$100/Tonne gross $54/Tonne net			$150/Tonne gross $104/Tonne net			$200/Tonne gross $154/Tonne net		
	Net value of loss/ ha	Control feasibility		Net value of loss/ ha	Control feasibility		Net value of loss/ ha	Control feasibility		Net value of loss/ ha	Control feasibility	
		Poison	Bands		Poison	Bands		Poison	Bands		Poison	Bands
2	$1.50	X	X	$3.30	X	X	$6.40	X	X	$9.50		
4	$2.95	X	X	$6.50	X	X	$12.80	X	X	$18.85		
6	$4.45	X	X	$9.80	X		$19.20			$28.40		
8	$5.90	X	X	$13.10			$25.60			$37.90		
10	$7.40	X		$16.30			$32.00			$47.40		

†(Losses and costs per hectare per year)

*Real loss after allowing for 50% compensation (see text)

NB

1) Cost of poisoning plus 8% per year for one year = $8.22/ha/y where:–
poison = 50 cents/kg (nine kg/ha/y)
labour = 42 cents/h and 7.5/ha/y

2) Cost of banding plus 8% per year for 15 years = $5.26/ha/y where bands costed at 30 cents each with a life of 15 y and 90% effective.

3) Palm density = 160/ha

4) Production calculated at 5,200 nuts/t and a yield of approximately 1t/ha/y (8 cwt/ac)

5) Production costs assessed at $46.0/t

6) X indicates that control would not be economical

was not an entirely unexpected result in view of the known responses to rat induced nutfall, which enables palms to compensate for at least 50% of rat damage (Williams, 1974b).

Despite such factors, limited replication could have obscured a difference in yield between plots, therefore the standing crop (i.e. coconuts on the palm over four months old) was counted in March 1972. This method of yield assessment also showed that there was no significant difference between the yield of banded and unbanded plots ($t = 1.8$; $p > 0.05$, $N = 240$).

Banding significantly reduced damage at Wainiyaku in both years (Table 2A) and completely eliminated damage at Vunilagi (Table 2B) although the damage was clearly very low in the whole area.

Banding efficiency (i.e. the reduction in damage produced by the presence of the band) can be illustrated by expressing the difference in damage between banded and unbanded plots as a percentage. For example, where bands prevent all damage the percentage efficiency would be 100. In the current trials efficiency ranged from zero to 100 percent with maximum efficiency being reached only on tall palms (Tables 1 and 2).

Bands clearly did not appreciably reduce damage on shorter palms and possible reasons for this were investigated. Senile fronds hanging parallel to the trunk, just before detachment, on palms with a trunk height of less than 12 m usually bridge the band (Fig. 1). Five monthly surveys of the Taveuni trials in 1972 showed that an average of three bands per plot and adjacent guard rows were bridged per month. Such fronds provide easy access to palm crowns which if contiguous enable numerous trees to be reached. The low efficiency of bands at Tuvamaca is possibly a reflection of palm density, which at 210/ha was considerably denser than the 110/ha at Wainiyaku. An almost complete canopy at Tuvamca probably permitted more extensive crown movements by rats, once they had crossed a band, while the incomplete canopy at Wainiyaku reduced such movement, confining rats to the palm actually climbed. *R.rattus* and *R.exulans* were trapped on both properties and as the level of damage on the unbanded plots was similar it suggests that the rat population levels did not differ greatly between the two areas. However, once palms are tall enough for bands to be placed below the reach of senile fronds, i.e. when trunk height exceeds 10.5–12.0 m, the method is very effective as long as bands remain in good condition.

The durability of aluminium bands that had been in place on 235 palms for seven years was investigated on Wainiyaku estate in July 1971. Ten bands were missing (4.2%), possibly because of faulty installation, but more probably as a result of corrosion around the area of band overlap which, because it tends to be on the reverse slope of the trunk, is exposed to rain water draining from the palm crown.

Fig. 1 Aluminium band bridged by a hanging frond

Samples of corroded material were tested by the manufacturers (Astral Crane) in Australia. Traces of phosphates were found which could have been derived from animal excreta (birds, lizards etc.), decaying plant material (trunk lichens and ferns), soil, fertilisers or herbicides. These phosphates combined with moisture trapped under the band were considered by the manufacturers to be the main cause of corrosion, the impact of corrosion on band life being closely related to the thickness of the aluminium alloy. In a high rainfall area, such as Wainiyaku, most bands showed signs of corrosion after seven years of exposure. While it is difficult to estimate accurately the effective life span of a 0.025 mm thick alloy it could be expected that band loss due to corrosion would be unacceptably high after 20–25 years.

B. *Poisoning.*

Legislation governing the use of poisons in Fiji prevents the widespread use by unskilled personnel of acute poisons such as zinc phosphide. Trials, using various bait bases were therefore limited to the anticoagulant warfarin, during rat control studies on cocoa (Williams, 1973). Trials concentrated on the lowest priced commercial preparation (warfarin impregnated wheat, set in wax) as it is difficult for the average farmer to mix baits of grated coconut or similar material that prove consistently attractive to rats. In addition very few centres in Fiji have supplies of paraffin wax for producing a waterproof bait.

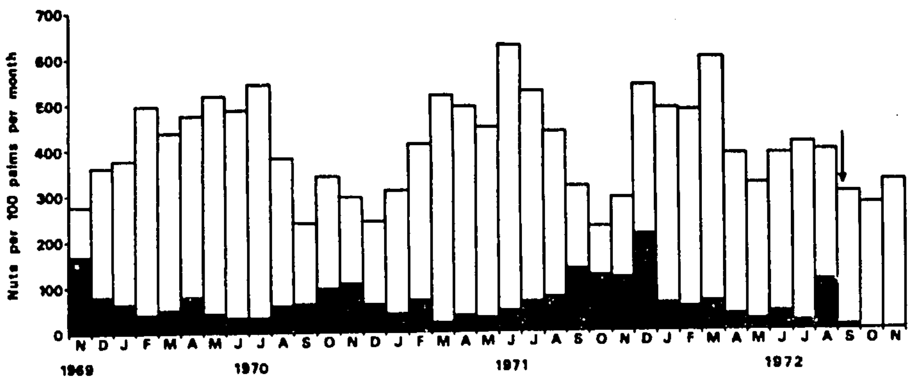

Fig. 2 Effect of rat poisoning on the level of damage. The arrow indicates poison laid, total height of histogram represents harvestable nuts, black represents both fresh and old damaged nuts.

Since bait acceptance trials in cocoa showed that the commercial paraffin/wheat preparation produced good results under most field conditions (Williams, 1973) it was used in a coconut trial primarily aimed at confirming the results of work carried out in Jamaica and the Gilbert and Ellice Islands. The trial site selected had been part of a long term damage survey and thus had a history of rat damage (Williams 1974a). When the survey was completed in August 1972, 30 palms (in the 100 palm plot) with a history of regular rat damage were selected and 115 g baits tied to the trunks 2.75 m from the ground. Palms favoured by rats were used as bait points in an attempt to ensure maximum rat/bait contact and thus increase the effectiveness of poison applications. Since very few of the baits had been attacked during the five days after laying they were all transferred to the palm crowns as the trunks may have been an exposed feeding position. In the following 10 days 2.5 kg of bait were eaten and no damage recorded until 12 weeks later. This marked reduction was attributed to the poison, for in the years 1969 to 1972 damage on the plot rose noticeably in the last three to four months of each year. Poisoning thus clearly reversed this trend in 1972 (Fig. 2).

This trial indicated that damage can virtually be eliminated for up to three months in a plot of one hectare. A possible limitation is the apparent need to place baits in the palm crowns, although it should be noted that in the Gilbert and Ellice Islands Smith (1969) obtained good results with baits placed on trunks, possibly because of the absence of predators such as the Barn Owl (*Tyto alba*).

Provided there is no danger to domestic livestock and interference by crabs is limited, ground-placed baits should give good results even if bait consumption is increased by *R.exulans*, a species that causes less damage to coconuts than *R.rattus* since it does not forage in the crowns of tall palms as frequently as the latter.

Since trials in cocoa (Williams, 1973) suggested that approximately 30 bait points per hectare provided good control, a similar spacing would probably be satisfactory in coconuts. Thus three applications per year, at a rate of 3 kg/ha per application would on the basis of cocoa trials give satisfactory control.

Smith (1967) recommended three to four 6 kg applications of an anticoagulant block per hectare per year for Jamaica plantations, but no allowances were made for waste or the drop in consumption that occurs when an area is poisoned over a number of years (Williams, 1973). Smith (1969) similarly considered necessary an application rate of 6 kg/ha of an anticoagulant block but considered repeated applications could be governed by subsequent damage levels.

Control costs in coconuts

The 1969 to 1972 survey of rat damage in Fiji revealed levels ranging from zero to 9.2 nuts per palm per year, with mean damage per palm per year at all sites being 5.4 in 1970, 3.9 in 1971 and 2.5 in 1972 (Williams, 1974a). However a trial to investigate the effects of known levels of simulated rat damage, on palm productivity established that there was an increase in female flower production, and no apparent decrease in the number of harvestable coconuts produced even before the flower increase could influence yield; responses to the loss of developing coconuts that were conservatively estimated to compensate for 50% of the nuts attacked (Williams, 1974b). Thus the damage levels quoted above have to be reduced by approximately one half in order to represent an actual production loss.

Table 3 presents the practicability of rat control methods in coconut plantations in Fiji. Since corrosion may cause high loss over a longer period the installed life of aluminium bands has been set arbitrarily at 15 years. The installed cost of bands was derived from estate accounts in 1971 (Morris Hedstrom Ltd.). The capital costs of bands plus interest have therefore been spread over 15 years which, while producing a lower cost than poisoning, has serious disadvantages. For example it has been shown (Williams, 1974a) that loss varies considerably from year to year while the gross value of copra can range from Fiji $75/t (mid 1972) to Fiji $250/t (September 1973). These two factors make costing on a 15 year basis very difficult but do not seriously affect a 'short term' (two to three years) control method such as poisoning.

Conclusions

It is evident from the above damage survey figures (after allowance has been made for palm compensation) that nut loss, even in areas of highest damage did not exceed four to five nuts per palm per year. At these relatively low levels neither form of control would be worthwhile until the value of copra exceeds Fiji $150/t and in the case of banding would only apply in very limited situations. That is, palms would have to have vertical trunks 10.5–12.0 m high (not achieved until at least the 25th year), be evenly spaced and have no vegetation that could cause bridging of bands. Poisoning does not have such severe limitations, but a decision to control using this method has to allow for changes in the level of damage, copra yield and value over at least a two year period.

The final decision on whether or not to reduce rat damage must be governed by the size of the affected area and the overall efficiency of the plantation unit in addition to the level of damage, copra yield and value. Clearly where a percentage of the nuts are lost in secondary bush on the plantation floor, as occurs on some Fiji plantations, control is of little value.

Reduction of rat damage in Fiji coconut plantations would, in view of the number of variables, be of marginal value at current levels of damage. Only if the average level rose significantly and the value of copra remained at over Fiji $200/t would widespread control be economically sound.

References

LASSALLE-SERE, L. (1955) Rat control for Tahiti planters. *Bulletin of the South Pacific Commission* 1: 5–6.

MILLAUD, R. (1966). The protection of crops against rat damage in the South Pacific Territories. *Bulletin of the South Pacific Commission* 2: 15–18.

SMITH, F. J. (1969). *Rodent research in the Gilbert and Ellice Islands.* Special Publication. Gilbert and Ellice Islands Condominium. Department of Agriculture.

SMITH, R. W. (1967). A new method of rat control in coconuts. *Tropical Agriculture*, Trinidad 44: 315–324.

TAYLOR, T. H. C. (1932). The possibilities of controlling rats on coconut estates in Fiji. *Fiji Agricultural Journal* 5: 22–25.

TURBET, C. R. (1925). Rats and coconuts. *Agricultural Circular of the Fiji Department of Agriculture*, No. 5. pp. 98.

WILLIAMS, J. M. (1971). Assessing the effect of rat damage on coconut yields. *Fiji Agricultural Journal* 33: 55–6.

WILLIAMS, J. M. (1973a). Rat damage assessment and control in cocoa. *Fiji Agricultural Journal* 35: 15–25.

WILLIAMS, J. M. (1974a). The Effect of Artificial Rat Damage on Coconut Yields in Fiji. *PANS* 20: 275–282.

WILLIAMS, J. M. (1974b). 'Rat damage to coconuts in Fiji. Part 1. Assessment of damage'. *PANS* 20: 379–391.

YELF, J. D. (1964). *'Rat damage'.* Fiji Department of Agriculture. Unpublished report.

YELF, J. D. (1966). Rat control by banding coconut palms. *Bulletin of the South Pacific Commission* 2: 22–24.

APPENDIX 2

The need for plant quarantine

By I.D. FIRMAN, SPC Plant Protection Officer

Taro leaf blight, a serious disease not yet present in all countries of the region.

In this, the first of two articles, SPC's Plant Protection Officer spells out the reasons for plant quarantine and gives examples of diseases and pests which threaten the SPC region. A second article will explain some details of quarantine procedure and describe how international cooperation is involved.

Plant quarantine; a national responsibility.

Every government has the responsibility not only to protect the health of its people but also the health of the plants on which people depend for food, clothing, shelter and export commodities. This is why countries have plant quarantine services.

The objective of plant quarantine is a positive one; to keep the country free of the plant diseases, pests and weeds which it does not have and to prevent the wider spread of those which it has already. Too often the public see it as only a negative activity because it is necessarily associated with restrictions and prohibitions.

There are many popular misconceptions about plant quarantine in the region. These articles will explain what it is about, why it is necessary and how regional and international organisations, including the South Pacific Commission (SPC), are involved with it.

Origin of the word quarantine

The word 'quarantine' was applied to a period of isolation (originally 40 days; from the Italian *quarantina*) to allow for detection and exclusion of human diseases. It was the period, for example, during which a ship suspected of carrying people with a serious disease such as bubonic plague or cholera, would be kept isolated after its arrival in port. In the sense of plant quarantine, this meaning has been extended to cover all those activities related to preventing the introduction and spread of new diseases and pests. The aspect which is nearest to that of the original meaning is 'post-entry' plant quarantine in which newly introduced species or varieties of plants from another country are grown in isolation until agricultural specialists are certain they are free of pests and diseases and can be released.

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The region is relatively free of plant diseases and pests

Throughout the world, losses to agriculture from diseases, pests and weed competition total about 35 per cent of potential production and further losses occur during storage and distribution. Everybody can see the need to reduce these losses if we are to continue to feed the world's growing population. This aspect of plant protection which involves controlling diseases and pests in the field and after harvest is widely accepted, especially if it can be achieved without excessive use of pesticides.

Plant quarantine is more controversial; not only does it inconvenience people on occasions but some believe that it is not justified on economic grounds. They would argue that since pests and diseases are spreading all the time, the sooner they are spread everywhere the better it will be because all the restrictions can be ended.

It has been estimated that more than 50 per cent of the major plant pests and diseases in the United States of America were introduced there from other countries.

Australia reports that the number of plant diseases recorded overseas but not in Australia total 2000 for pasture and forage crops, 800 for vegetables, 1600 for fruits, vines and nuts and 1400 for ornamentals. There are only about 500 known insect pests of plants in Australia; by contrast, just one crop, rice, has

Coffee berry disease an important problem for coffee growers in Africa, but so far confined to that continent

more than 1000 recorded insect pests throughout the world Australia, New Zealand and the Pacific island countries in the SPC region are, in fact, relatively free of serious diseases and pests of plant. The existence of plant quarantine legislation and associated services can be justified if we believe that this situation is worthwhile maintaining for as long as possible.

Some historical examples.

Most people believe that some useful lessons can be learnt from history and history provides many examples of the catastrophic results from the spread of plant diseases and pests.

Potatoes (and taro)

Late blight disease of potatoes (caused by the fungus *Phytophthora infestans*) reached epidemic proportions in Europe and especially Ireland in 1845. The resulting famine in Ireland where potatoes were a staple food caused the death of more than a million people and the subsequent emigration of more than a million others. The potato was originally taken to Europe from South America. If the late blight disease organism had been left behind and only healthy potatoes introduced to Europe the sad events in Ireland would not have occurred.

L ally, we might equate the potato with taro. In Papua New Guinea, Solomon Islands and parts of the Trust Territory of the Pacific Islands taro leaf blight (also caused by a species of *Phytophthora*) has been a major factor in the decline of taro cultivation and is very serious where the rainfall is high. It must certainly be worthwhile to keep it out of those countries such as Fiji and Western Samoa where it does not occur.

Coffee

Coffee rust, a fungus disease which, like its host plant, originated in Africa, destroyed the coffee industries of Ceylon, South India and the Netherlands East Indies (now Indonesia) in the 1870's. It was because of this that the centre of world coffee production eventually moved to Central and South America, especially Brazil. Fiji was an early victim and we read in accounts of planting enterprises there that the disease was introduced in 1879 (probably on seed imported from Ceylon) and that the developing coffee industry never recovered from the set back.

The disease continued to spread around the world finally even reaching Brazil in 1970 from where it is now spreading to other South and Central American countries. It has cost billions of dollars to control this disease throughout the world and it will continue to do so. It has had dramatic social as well as economic effects wherever it has occurred. In Brazil alone, for example, the livelihood of six million people depends on the crop. Although of course it did eventually arrive in Brazil, for every year which it was kept out millions of dollars were saved because the disease caused no loss of production and control costs were not incurred

Papua New Guinea recognised the importance of this type of saving when the disease was discovered there in 1965. Not less than $A70,000 was spent in eradicating the disease. But loss from coffee rust, if it had been allowed to spread to the main coffee areas, was estimated as a minimum of $6,500,000 for the combined 1965-66 acreages. The cost of spraying to control the disease would have been $1,556,250. Of course the losses and control costs would have continued so by now a very considerable sum has been saved by this plant quarantine operation. Without the eradication, the coffee industry may have collapsed

African cassava mosaic: a serious disease not present in the SPC region (Photo John Guthrie, Kenya Agricultural Research Institute)

altogether entailing serious economic and social consequences.

Elms (and coconut)

A very virulent form of Dutch Elm disease was recently introduced into England on logs of wood. It has killed practically all the millions of elm trees in the south of England where they were the dominant feature of the landscape and so has changed the appearance of the countryside completely.

We can scarcely dare imagine what effect a disease which affected coconuts in a similar way could have on the appearance, economy and life of a small Pacific island country. Yet not too far away from us Cadang Cadang disease of coconuts has spread from island to island in the Philippines. It appeared on the main island of Luzon in 1928 and by 1963 some 20 million trees had been killed or had stopped producing nuts.

And many more

Books about plant pathology, entomology, virology, nematology and weeds are full of similar horror stories. American chestnut trees were all destroyed by a blight which entered the USA on nursery stock from the Orient and the loss was conservatively estimated at one hundred thousand million dollars; the cotton boll weevil moved into the USA from Mexico and now costs the USA at least $375 million a year.

We can quote the spread of the water weed *Salvinia auriculata* choking lakes and dams through Africa and India, the spread of the bacterium causing fireblight of apples and pears in Europe, the spread of the pear decline virus in the USA, the spread of the golden nematode of potato around the world and many many more examples of diseases, pests and weeds doing untold damage.

Some regional examples.

Among the earliest conferences convened by SPC was one in 1951 at which specialists in plant and animal quarantine from the member governments were to work out a practical method of assembling information on pests diseases and weeds likely to

The oriental fruit fly is but one of several similar pest species absent from or with limited distribution in the SPC region. (Photo University of Hawaii)

spread into or within the region. Eventually SPC prepared an illustrated book (*Exotic Plant Pests and Diseases*, by B.A. O'Connor) on the subject which is still in print. It deals with the major crops one by one, describing many of their important pests and diseases which are not yet present in any, or some, of the countries in the Region. A few examples will show that the Pacific islands will have much to fear from pests and diseases.

Bananas

Panama disease of bananas caused more than 100,000 acres of banana-growing land to be abandoned in Central and South America; the disease does not occur in the Pacific Islands. Those islands which have bunchy top virus and scab moth are well aware of the damage they cause and the difficulty and expense of controlling them. Some countries, such as the Cook Islands, still do not have these problems.

Cocoa

Cocoa prices have recently reached record high levels and many countries in the region are interested in expanding their acreage of the crop. In Ghana, more than 100 million cocoa trees have had to be cut down since 1945 in attempts to stop the spread of cocoa swollen shoot virus. The virus does not occur in the Pacific and is only one of several important disease-causing organisms which we do not yet have here

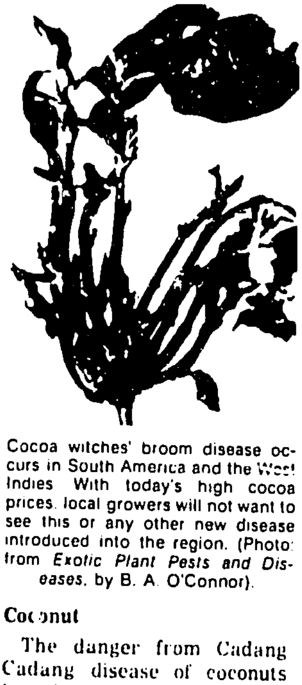
Cassava

Cassava in the Pacific region is usually very easy to grow because it does not suffer from any serious diseases or pests. But cassava in other parts of the world is attacked by more than 30 bacterial, fungal, viral and mycoplasma agents of disease. The mosaic virus present in Africa and a bacterial blight in South and Central America cause particularly serious losses.

Citrus

Since 1958, approximately 100,000 citrus trees have been lost to Greening disease in South Africa. Recently, the disease has caused catastrophic losses in India and is present in several other countries in south-east Asia. It has not yet reached the SPC region but is present in the Philippines.

Canker, a bacterial disease of citrus, was found in Fiji in 1951 and put an end to any possible fresh fruit exports from that country. There are still many Pacific islands which do not have the disease. Within the SPC region there are a number of species of fruit fly which can be serious pests of citrus and other fruits. They are distributed in such a way that each country could import a new species from another country.



Cocoa witches' broom disease occurs in South America and the West Indies. With today's high cocoa prices, local growers will not want to see this or any other new disease introduced into the region. (Photo: from *Exotic Plant Pests and Diseases*, by B. A. O'Connor).

Coconut

The danger from Cadang Cadang disease of coconuts has already been noted. There are many similar, potentially serious, diseases not present in the region and also various insects and other organisms which would be undesirable. Even the well-known rhinoceros beetle is not yet present in all islands.

Coffee

Coffee growers of the region should be grateful for the absence of Coffee Berry Disease, American Leaf Disease, *Antestia* bugs, *Leucoptera* leaf miners and many other diseases and pests which would lower production and be expensive to control.

Peanut

Most countries of the region are free of Groundnut (Peanut) rust and Groundnut Rosette virus; just two of the important diseases of that crop.

Rice

None of the serious bacterial or virus diseases of rice are present in the region and there are very many insect pests which we do not have. Their introduction could badly affect production especially, for example, Fiji where self-sufficiency in rice is a major objective of agricultural development.

There really are hundreds of diseases and pests which we do not have in the region and which are potentially damaging to our staple food crops, cash crops, forest trees and ornamentals.

Migration, trade and travel

Some people find it surprising that all the diseases, pests and weeds were not spread through the islands during the early migrations of South Pacific peoples. There are good reasons why this did not happen. Many of the crop plants now grown were not present in the region in those times; they, and some of their diseases and pests, only arrived when planters and the developing agricultural departments introduced and tried out many new crops. Sometimes the diseases and pests accompanied the original introductions and sometimes they were introduced accidentally later.

Probably, the early travellers were also good cultivators and would certainly have been likely to select only the healthiest plants to take with them. Nor can we blame the early migrations for spreading all the troublesome weeds around the Pacific. Although some weeds came from the west with the early migrants many others came from the Americans with the Spanish and other early explorers. *Lantana*, *Clidemia* (Koster's Curse) and *Mikania* (Mile-a-minute) are all American plants which have been serious weeds in the Pacific.

Fast transport and large volumes of cargo have now much increased the risks of introducing undesirable organisms, but at least we are fully aware of these risks and have quarantine services to cope with them. We also realise that organisms that may be harmless in their country of origin may get out of hand and cause damage if introduced to a new and vulnerable environment such as a Pacific island

It is, of course, necessary for people to travel, for international trade to take place and for countries to introduce new species and varieties of plants to improve their production. Plant quarantine does not seek to interfere with these activities but does try to find ways of minimising the risk of diseases, pests and weeds being introduced by them. The way this is done will be described in a second article. □

SPC SECRETARY-GENERAL COMPLETES TERM OF OFFICE

Dr. E. Macu Salato, who has been Secretary-General of the South Pacific Commission for the past three and a half years, left New Caledonia on 29 June at the completion of his term of office.

Since Dr. Salato was appointed, SPC has seen a number of important changes. As a result of recommendations made by a Review Committee which met in 1976, the SPC work programme now concentrates on activities of practical value to Pacific Islanders, with particular emphasis on marine resources, rural, youth and community development, training, consultancy services and cultural exchanges. The Commission's internal structure has been rationalised. Solomon Islands and Tuvalu have become Participating Governments of SPC, and the voting procedure in the Committee of Representatives of Participating Governments has been modified to give Island and metropolitan Governments an equal voice in the Committee.

Dr. Salato was appointed Secretary-General in 1975 by the Fifteenth South Pacific Conference. After retiring from the Fiji Medical Department, where he was Director of Curative Medical Services, he served as Acting Fiji High Commissioner in London and Ambassador to the European Economic Community in Brussels before taking up his appointment with SPC.

Dr. Salato's successor as Secretary-General is the Honourable M. Young Vivian of Niue. □

NEW CENTRE FOR FRENCH STUDIES IN NOUMEA

Courses in French language and civilization will begin in Noumea, New Caledonia, at a Centre to be opened in January 1980 for students from Fiji, New Zealand and Australia. If universities or tertiary institutions in other countries in the region subsequently offer French as a subject, then they too will be able to use the Centre.

The initial objective of the Centre will be to co-ordinate and organize courses for university French departments, university departments of education, teachers' colleges, institutes of modern languages and Alliances Françaises in the three countries. The basic control of each course will lie with the groups using the Centre, not the Centre itself, so that courses offered will depend on the needs of individual departments.

The *Centre de rencontres internationales du Pacifique Sud* resulted from a conference in Noumea organized by a group keen to promote the teaching of French in the Pacific. The conference was organized by AUPELF (Association des Universités partiellement ou entièrement de langue francaise), an international, non-governmental organization concerned with facilitating cultural and informational exchanges both within the French-speaking world and between it and non-French-speaking countries and bodies.

The Centre hopes to arrange scientific exchanges in collaboration with ORSTOM (Office des recherches scientifiques et techniques outremer) and educational and cultural exchanges in collaboration with other organizations, including the South Pacific Commission.

The Centre will accommodate about 30 students at a cost not likely to exceed $40 per person per week. It is already booked for some 23 weeks in 1980. □

APPENDIX 3

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National and international action in plant quarantine

By I.D. FIRMAN, SPC Plant Protection Officer

In his first article (South Pacific Bulletin 2nd Quarter, 1979) *SPC's Plant Protection Officer spelled out the reasons for plant quarantine and gave examples of diseases and pests which threaten the Region. He now explains some details of quarantine procedure and describes how international cooperation is involved.*

In the first article about plant quarantine, it was established that there were still many diseases, pests and weeds that should be kept out of the SPC region or prevented from spreading further within it. Plant quarantine was easily justified by considering the losses which such unwelcome organisms could cause.

On the other hand, it was recognised that it was necessary for people to travel, for international trade to take place and for countries to introduce new species and varieties of plants to improve their agricultural production. Plant quarantine must allow for this but at the same time minimise the risk of new diseases, pests and weeds being introduced.

The purpose of quarantine law

The main purpose of the law should be to prevent the introduction of plant pests not already present, to control those that are already present by eradicating them or restricting their spread, to provide facilities and services for import and export of plants and to extend cooperation in the prevention of movement of plant pests in international trade. The word 'pest' is usually defined widely to include any organism likely to be harmful to plants: fungi, insects, weeds, etc., are all included in the definition.

A country which pays no attention to plant quarantine not only exposes itself to danger but also its neighbours. Furthermore, people will be reluctant to trade with a country which has no plant protection services, cannot issue reliable phytosanitary certificates and has no information or interest in the pest-and-disease status of its crops and produce.

It must be made clear that plant quarantine law and the associated regulations are the sole prerogative of individual countries. The South Pacific Commission, although often asked for advice, has no special responsibility for, or authority to impose, any form of plant quarantine. Whether or not they are members of international or regional organisations, most countries have their own plant quarantine law and regulations.

Components of plant quarantine activity

There are several different components of plant quarantine activity. Occasionally, a country may declare a **complete embargo** on some types of plants or plant parts or agricultural commodities. A country in the SPC region should, for example, place a complete embargo on coconut-propagating material from any place where Cadang Cadang disease exists.

More usually, plant quarantine services will allow the **controlled introduction of plant and plant products.** If the introduction involves an element of risk they may recommend a treatment such as fumigation, cold storage or insecticide application, etc., which would eliminate the risk. Insects can be killed by methyl bromide

The Papua New Guinea delegation at the 11th (1978) meeting of the Plant Protection Committee for the South-East Asia and Pacific Region.

fumigation and a sufficient period of cold storage eliminates some species of fruit fly, for example; provided the treatment does not also damage the particular plants or produce involved, these are useful ways of overcoming quarantine hazards.

Importing countries will often require **inspection and certification at the point of origin.** The plant quarantine services of the exporting country will be asked to provide a phytosanitary certificate of the type approved by the International Plant Protection Convention. This will certify that the material has been inspected for freedom from pests and is considered to conform with the current phytosanitary regulations of the importing country and will give the details of any special treatments applied.

Despite these precautions countries will also wish to carry out **inspection at the point of entry.** It may be necessary to confiscate plants or produce which have been imported illegally, or to hold for further treatment or for destruction any legally imported produce found to be infested with pests or diseases of quarantine importance. Such actions must, of course, be based on sound biological grounds and derive from authority under the law.

Occasionally, despite all precautions, a new disease, pest or weed will become established in a country. In such cases **eradication** of the new organism may be attempted. Papua New Guinea, for example, successfully eradicated coffee rust when it was found there in 1965.

The introduction of new crop plants and new varieties of already established plants into the countries of the Pacific can play an important part in agricultural development. **Post-entry and intermediate plant quarantine** procedures seek to reduce the risk of introducing pests and diseases with such plants.

First of all, such plant material should only be imported when it is certain that it is really needed, after considerable investigation into the best source of material, after finding out about the pests and diseases present in the country where it is coming from and after arranging for certification of freedom from any important diseases and the application of any necessary treatments. In some cases it may be considered too risky to bring plants directly to the country of final destination without first putting them into intermediate quarantine in some other country during transit from the country of origin.

The country of intermediate quarantine will be one where the introduction involves no risk (for example, the country does not grow the crop in question and is never likely to do so) and/or where special facilities and expertise for testing, are available. Australia, New Zealand and the United Kingdom have all afforded such facilities to countries in the SPC region from time to time.

When plants arrive at their final destination they may be kept in post-entry quarantine. The main requirements of both intermediate and post-entry quarantine are trained specialist staff, a plant house (a glass or screen house) and some associated field plots where plants can be grown in safe isolation and under close supervision.

Plant quarantine deserves public support

It is obvious that well-trained and dedicated staff are needed to carry out the duties involved with all these components of plant quarantine whether they be "back-room boys" concerned with specialist advice on plant pathology, entomology, nematology, etc., or are in the "front line" as inspectors at airports and docks. It cannot be too strongly emphasized that the role of the quarantine inspector is just as important as that of the customs officer.

Quarantine officers deserve the backing of the public in the important duties they perform and the law must apply as much to VIPs as to the humblest traveller. If goods escape customs duty the country loses some revenue, but if a serious plant disease or pest breaches the quarantine barrier the effect could be disastrous to the economy of the country.

International cooperation

Naturally there is a great deal of scope for international cooperation in plant quarantine. Eighty countries are parties to the International Plant Protection Convention. The following are its main features.

National plant protection organisations. The Convention requires each contracting country to establish an organisation to carry out surveys and inspection of growing plants and plant products, to disinfect or disinfest plant materials moving in international trade, to issue phytosanitary certificates, to strengthen advisory services and research in plant protection, and to report on the outbreak and spread of plant pests.

Model phytosanitary certificate. In order to promote the standardisation of the information and certifying statements required by each country concerning imported plants and plant products, the Convention calls for the use of a model phytosanitary certificate. Importing countries have undertaken not to require a certificate inconsistent with this model.

Plant quarantine. The Convention specifies a number of measures which the countries may take to regulate the entry of plant material and so prevent the introduction of diseases and pests. No such measures should be taken unless made necessary by phytosanitary considerations; they should not be used as an excuse for trade restrictions.

World reporting service. Countries are required to cooperate with the Food and Agriculture Organisation of the United Nations (FAO) in establishing a world reporting service on plant pests. This service collects and disseminates information on the incidence, spread and control of important plant pests.

Jone Vetowa from Fiji (left) and Tavau Teii from Tuvalu inspecting cargo during an SPC plant quarantine workshop

Regional organisations. Countries cooperate in establishing regional plant protection organisations to promote and coordinate the plant protection activities in different geographic areas. There are organisations in Africa, the Caribbean, North, Central and South America as well as the Plant Protection Committee for the South-East Asia and Pacific Region which covers our own area.

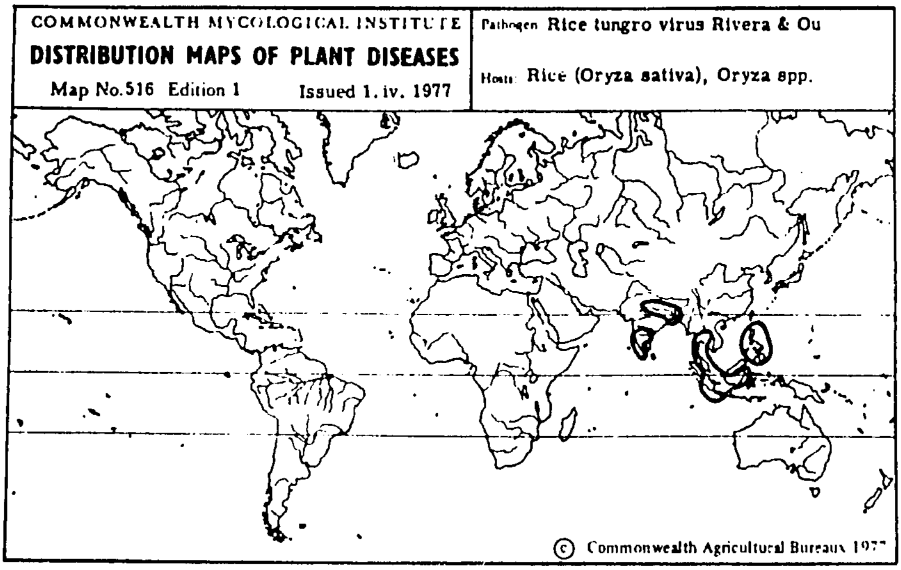
In the SPC area, only Papua New Guinea and Solomon Islands are parties to the International Plant Protection Convention, although Australia has contracted on behalf of Norfolk Island and New Zealand in respect of the Cook Islands and Niue.

Regional cooperation

Three countries of the SPC Region, Fiji, Papua New Guinea and Western Samoa, are members of the Plant Protection Committee for the South-East Asia and Pacific Region and are signatories to the Plant Protection Agreement for the South-East Asia and Pacific Region. One of the important functions of the Committee is the maintenance of an information service through a Quarterly Newsletter, Technical Documents, Information Letters and Information Circulars. The Committee also makes recommendations and advises governments and FAO on all aspects of plant protection.

Of particular interest to the SPC countries are the lists of pest, disease and weed distributions published by the Committee and their recommendations on measures regulating the importation and movement of plants. Generally, member governments base their regulations on the recommendations of the Committee and SPC also takes note of them when called upon to advise other governments in the region.

For seven countries of the region (Cook Islands, Fiji, Kiribati, Niue, Tonga, Tuvalu and Western Samoa) an FAO 'Agricultural Pests and Diseases Survey' has recently been completed. The project which was coordinated by the South Pacific Bureau for Economic Cooperation had the main objective of assessing the plant-pest-and-disease



The distribution of one of the several rice virus diseases not yet present in the SPC region.

status of the islands with a view to standardising plant quarantine practices and removing any unnecessary trade restrictions. It is envisaged that lists of the fungi, bacteria, viruses, nematodes and invertebrate pests found on the various crops in the countries will eventually be published, together with plant quarantine procedural and treatment manuals and specific quarantine recommendations.

SPC and plant protection

Of course, there is already quite a lot of information available about the distribution of plant pests and diseases throughout the world. In addition to the FAO reporting service, there are many published lists and also the very valuable "Distribution Maps of Plant Diseases" and "Distribution Maps of Pests" published by the Commonwealth Mycological Institute and Commonwealth Institute of Entomology respectively.

Among the earliest conferences convened by the South Pacific Commission was one in 1951 at which specialists in plant and animal quarantine from the member governments were to work out a practical method of assembling information on pests, diseases and weeds likely to spread into or within the region. Eventually SPC prepared an illustrated book (*Exotic Plant Pests and Diseases*, by B.A. O'Connor) on the subject which is still in print. It deals with the major crops one by one, describing many of their important pests and diseases which are not yet present in any, or some, of the countries in the region. More recently, SPC published an *Annotated Bibliography of Sources of Information on Plant Disease Distribution in the Area of the South Pacific Commission* as well as a *List of Documents Useful to Plant Quarantine Services*.

SPC prefers to look upon plant quarantine as a part of an overall plant protection program and its activities in this field have already been described in the *South Pacific Bulletin* (1976, Vol. 26(1): 29-34). Specifically on plant quarantine, however, and in addition to the publications already mentioned, SPC holds training courses in plant quarantine methods, is preparing quarantine posters for display at ports of entry in the countries of the region and is attempting to interest countries in a regional uniform for plant quarantine officers.

Training courses and workshops are particularly valuable because they bring together quarantine officers from the region and help to establish mutual trust and cooperation among them.

National, regional and international organisations are all working together to keep the Pacific as free as possible from the diseases, pests and weeds which can cause so much damage to our agricultural crops, forest trees and other plants of economic or amenity importance. □

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APPENDIX 4

LIMITATIONS TO PEST CONTROL METHODS

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INTRODUCTION

The techniques for controlling pests draw from a wide range and history of applied science and technology. Ancient civilizations developed many biological, cultural, and physical methods for the protection of crops, animals, and selves. Many of these practices subsequently proved scientifically valid, through originally derived from crude empirical methods (Ordish, 1976).

As noted in another paper presented at this training course (Chemical Control: Use in IPM Programs by Dale G. Bottrell), the earliest reference to the use of chemicals to control pests dates to about 2500 B.C. when the Sumerians used sulfur compounds to control insects and mites. Biological methods also have a long history. Several centuries before Christ, the Chinese developed significant pest control techniques, learning to control insect pest densities by exploiting "natural enemies" and by adjusting crop planting times. By A.D. 300 the Chinese were establishing colonies of predatory (insect-feeding) ants in citrus orchards to control caterpillars and large boring beetles (Flint and van den Bosch, 1981). The first methods of weed control involved human, livestock, and mechanical energy. From 6000 to 5000 B.C. weeds were controlled by human hands. Crude wooden implements, including hoes, used from 3000 to 2000 B.C. were supplemented by hand sickles and the first wooden plow about 1000 B.C. A wooden spiked-tooth harrow had been invented by 500 B.C., and improved wooden plows became available during A.D. 1600-1800. The first all-steel plows, drawn by horses or mules, were introduced in 1837 (Timmons, 1970).

Today, the list of pest control procedures is almost endless. In addition to the large variety of chemical insecticides, fungicides, herbicides, and other pesticides, there are many alternative methods (refer to Table 1). Some of the most effective alternatives, such as pest-resistant crop varieties, crop rotation, and biological control, have been known and used for many years. Promising alternatives to chemical pesticides, including insect attractant chemicals, weed disease agents, and chemical growth regulators, are being developed, and some are being used in pest control programs. Yet for many of the most serious pests, there are no suitable alternatives, and for the foreseeable future, chemical pesticides will remain basic tools in pest control.

The evolution of genetic resistance in significant pest groups and the chemically-provoked ecological disruptions, discussed in another paper at this training course (Chemical Control: Use in IPM Programs, by Dale G. Bottrell), have dramatized that chemical pesticides can have unexpected and undesirable consequences. However, continued use of an alternative method can have similar con-

TABLE 1: Examples of Alternatives to Chemical Pesticides (Anon., 1965)

Insects, mites, and other invertebrates	Plant diseases	Weeds	Birds, mammals, and other vertebrate pests
Biological control	Disease resistance	Insects and other herbivores	Noise and physical repellents
Parasites	Reduction and losses by manipulations of plants and pathogens	Diseases	Chemosterilants
Predators	Control of plant pathogens by natural enemies	Environmental manipulation	Chemical repellents
Pathogens	Disease- and nematode-free seed and propogating material	Choice of variety	Trapping and shooting
Plant and animal resistance	Crop rotation and soil management	Seedbed preparation	Behavior
Environmental manipulations	Destruction of inoculum	Method of seeding or planting	Environmental manipulation
Plant spacing	Vector control	Seeding rates and row spacing	Exclusion
Species diversity	Nematode attractants and repellents	Fertilization	
Timing		Cultivation	
Crop rotation		Irrigation and water management	
Plant hormones		Erosion control	
Water management		Design of irrigation and drainage canals and ponds	
Fertilizers		Managed grazing	
Soil preparation		Sanitation	
Sanitation		Natural stimulants and inhibitors	
Induced sexual sterility		Plant competition	
Physical and mechanical control		Revegetation of weed- and brush-infested grazing lands	
Window screens		Breeding highly competitive forage species	
Light traps			
Fly swatters			
Protective packaging			
Sifting devices			
Barriers			
Flaming and burning			
Attraction and repellancy			
Attractants			
Repellents			
Genetic manipulation of pest populations			
Lethal genes			
Male-producing genes			

sequences. Pest organisms are remarkably adaptive; the intense selection pressures imposed by human manipulation of their environments accelerate the evolution of new strains that adapt to and override control methods. Apart from these technical limitations, use of the alternatives may be challenged because of other factors--their social and economic consequences, for example.

This paper discusses some of the limitations to pest control methods, with emphasis on problems in the developing countries.

THE SETTING IN THE DEVELOPING COUNTRIES

Traditional agriculture, characterized by small farms, polyculture (growing of two or more crops simultaneously on the same field in the same year), local, unimproved varieties, little or no artificial fertilizers, pesticides, or other artificial inputs, and minimum tillage, is still practiced by a large portion of farmers in the developing countries. Yields are very low, and there are no organized methods of pest control; pests simply are tolerated or controlled intermittently by natural forces and rare pesticidal treatments. The farmers have access to limited capital and technology, many of them are illiterate, and they have virtually no knowledge of the benefits or limitations of pest control practices.

However, high yielding varieties, irrigation, mechanization, fertilizers, and other modern innovations are being introduced into the traditional agricultural areas. The crop yields have increased, often significantly, and this has provided incentives to adopt other crop improvement techniques that maximize yields (Glass and Thurston, 1978).

LIMITATIONS TO PESTICIDES

Parallel with these modern innovations, pesticides, particularly insecticides and herbicides, are being used more and more in the developing countries. Pesticides have already been employed extensively in a large number of these countries and have created serious problems in some instances.

In the Gezira of Sudan, for example, heavy use of insecticides on cotton has led to secondary pest outbreaks, causing near bankruptcy of the cotton industy--Sudan's chief export industry and its primary source of foreign currency (FAO/UNEP, 1980). Heavy use of insecticides on cotton in Central America is a special health concern. Insecticides have poisoned humans directly and caused significant contamination of foodstuffs (Davies et al., 1978). Applications of DDT to control pests on cotton in Central America and India have so modified the mosquito habitat that insecticide-resistant malarial mosquitoes have evolved and greatly increased their abundance, thus adding yet another dimension to the human health problems in these areas (Chapin and Wasserstrom, 1981).

Pesticides are important to the developing world in the control of various pests affecting agriculture and public health for which there are no effective alternatives. However, the infrastructures and economic resources in a large number of developing countries are not adequate to ensure efficient and safe use of these chemical materials. Often, there is no extension service to teach pesticide safety, no poison control center, and few medical personnel to treat cases of pesticide poisoning. A significant portion of the developing countries have no effective means of enforcing proper labeling of the pesticides. Even when there is a label on a pesticide package, it has no value for the many farmers of the developing countries who cannot read. On quite a different level, some developing countries may lack the foreign currency necessary to maintain an adequate supply of effective pesticides and application equipment which they must import from the United States or Europe. As a result, farmers, especially those far from the urban centers, cannot readily access the pesticides and equipment, even when they can afford them.

Because of these reasons, chemical pesticides are presently impractical and inappropriate for many farmers in the developing countries.

LIMITATIONS TO THE ALTERNATIVE METHODS

Many of the alternative methods are also impractical and inappropriate for use in the developing countries. The countries' lack of economic resources and poor service structures are common obstacles hindering the use of some potentially effective alternatives. For example, the development of varieties of hybrid maize that resist disease or insect attack may be of limited value to farmers in some developing countries, even if the farmers find the pest-resistant varieties to be more agronomically acceptable than the varieties which they use. For hybrid maize production, new seeds must be produced each year by the deliberate crossing of carefully maintained purebred lines. Many developing countries lack the facilities for producing this seed or for distributing it, and the subsistence farmers may not be able to afford the recurring cost of the seed (Jennings, 1976).

The attitude of risk is another factor that may limit the use of potentially effective alternatives. Understanding risk requires an understanding of human behavior and value judgment. The farmers' perception and value judgment of a pest or a pest control technique may differ considerably from the pest control specialists' perception and value judgment of the same pest or technique. For example, farmers in some developing countries often feed their livestock weeds during periods when forage is scarce. Therefore, they may let the weeds invade and grow in their fields, even though they know that the weeds will reduce the crop yields (Hildebrand, 1981). Hence, these farmers will likely resist adopting an otherwise desirable agronomic practice such as crop rotation that the pest control specialists may recommend for control of the weed "pests." Fears, religious and cultural background, level of education, and past experience with pests also influence the farmers' perceptions and may be major factors hindering progress in the promotion of sound pest control systems.

Peoples' acceptability of the taste of a food product, the farmers' ability to store the crop harvest, and urban consumer demands may also be factors. An insect-pest-resistant crop variety, for example, may be more cost effective than insecticides, may significantly increase food production, and may reduce the risks of crop failure. However, the farmers may refuse to plant the pest-resistant variety if they do not like the taste of the food product, they cannot properly store the crop harvest, or they have difficulty selling the surplus harvest to urban consumers.

The socioeconomic organization may also influence the farmers' acceptance of an alternative method. Faced with an identical set of policy-determined conditions, subsistence farmers and large-enterprise farmers may behave quite differently. The enterprise farmers tend to be profit maximizers, using purchased inputs up to the point where their margin value just equals their margin cost. Although there are exceptions, the subsistence farmers tend to place less emphasis on profit maximization and more emphasis on risk minimization (USDA, 1981). Therefore, a subsistence farmer may view an insecticide application as good insurance against a yield loss and may resist use of a more effective but less costly method if not convinced of the alternative's superiority. On the other hand, the large-enterprise farmer may be more prone to accept the alternative method.

The institutional arrangements in a developing country may profoundly influence the pest control practices and limit the farmers' use of various methods. In some countries that have ostensibly achieved independence from a foreign power, neocolonialism may be very apparent and the puppet government may be completely controlled by the foreign government. In those countries that have achieved greater autonomy, the old colonial power may still exert considerable influence through aid, technical assistance, and other programs. Complicating the situation, a given developing country may receive aid and technical assistance from a variety of donors, and the donors all may have different policies concerning the use of pesticides and alternative methods. The pest management programs are further influenced by the country's national policies and programs, and regional organizations may also exert influence.

All of these institutional arrangements may influence the pest management activities in the farmers' fields. In some developing countries, regional organizations and international donors not even based in the countries are in charge of developing the national policies and programs in pest management. In some instances, the national crop protection services completely control the pest management operations; the farmers may not even participate in these operations. Fully- or partially-subsidized pest control programs run by the governments are found in many developing countries. Unless these national governments, regional organizations, and international donors are sympathetic towards the use of alternative methods of pest control, these methods have limited potential.

From a technical point, the alternatives may offer little, if any, advantage over chemical pesticides if used continuously and unilaterally. The practice of plowing and cultivating, for example, may completely eliminate a perennial weed from a field, but an annual weed may invade the field and pose even more of a problem than did the perennial weed that was eliminated. The use of insect- and disease-resistant crop varieties may eventually give rise to new strains of insects and disease organisms capable of overcoming such resistance. There are no panaceas in pest control.

Introduction of natural enemies (parasites, predators, disease agents) into new areas can be quite hazardous unless done with great care by experts using special precautions under strict quarantine security. The mongoose, a carnivore of the family Viverridae, became a terrible pest on some islands where introduced to control rats. In Puerto Rico the predator found other prey such as lizards and birds more attractive than the problem rats and fed on them only occasionally (Pimentel, 1955).

Fire, a time-honored method of vegetation control still used widely by farmers practicing "slash-and-burn" agriculture, is one of the most effective methods for preparing new cropping sites.

However, use of the method may result in considerable soil disturbance, erosion, water pollution, destruction of wildlife habitats, and atmospheric pollution. Over the long term, it may be more environmentally damaging than certain chemical herbicides.

As noted in the paper, Cultural Control in Modern Practice, presented by Dale G. Bottrell at this training course, cultural control is one of the oldest and most effective methods of pest suppression. Yet, it also has some very serious limitations, as discussed in that paper.

MAXIMIZING THE EFFECTIVENESS OF THE CONTROL METHODS

The best way to maximize the effectiveness of pest control methods and to minimize their unwanted side effects is to use them in comprehensive integrated pest management (IPM) schemes. (Refer to the paper presented at this course by W. C. Mitchell, Definition, Objectives, and Features of Integrated Pest Management, for a discussion of the IPM concept.) A basic premise of IPM is that no single control method will be effective over the long term. Therefore, IPM emphasizes a broad interdisciplinary approach that spreads the burden of crop protection over a combination of pest control methods. By doing so, the probability of crop failure is reduced. Even if one of the methods fails, one or more of the others may still provide protection. Hence, IPM is less risky than crop protection programs based on single methods such as pesticides or pest-resistant crop varieties.

Also, by drawing heavily from natural biological and environmental controls, improved varieties with pest-resistant characteristics, and traditional methods of control, and using pesticides selectively, IPM should reduce costs of control in those crops now treated heavily with pesticides. In fact IPM has already achieved this objective on some crops in various areas of the developing world (Brader, 1979; IOBC, 1981).

For the developing countries, integrated pest management represents an important trend toward a more rational approach to pest control. However, developing IPM systems for those countries will involve much more than simply importing IPM "packages" from the developed countries. The nature of the pest problems in the developing countries tends to be location specific, and the best solutions for them will depend upon the types of pests involved, environmental conditions, availability of labor, economic welfare, educational level, and attitudes of the farmer, and a variety of social and political factors (Smith and Adkisson, 1979). Every situation must therefore be evaluated individually under actual farming conditions, and the pest management system must be synchronized with and integrated into the farmers' socioeconomic base.

Each IPM program therefore will have to be tailored for the particular group of intended beneficiaries. The whole effort, from the time the initial research is performed through the implementation of the IPM program, must evolve as a true partnership between farmers, researchers, and extension workers. Research personnel should make every effort to utilize the farmers' fields for their experimental work; extension personnel should organize demonstrations of the emerging new practices in these same fields and extend the demonstrations to other areas where the conditions are similar. This farmer-field approach to research and extension is the best way to accelerate the adoption of emerging technology. It is also the best way to ensure the selection, integration, and implementation of economically, ecologically, and sociologically sound systems of pest control.

REFERENCES CITED

Anon. 1965. Restoring the quality of our environment. Rep. of the environmental pollution panel. President's Sci. Advisory Comm. The White House. U.S. Government Print. Office, Washington, D.C. 317 p.

Brader, L. 1979. Integrated pest control in the developing world. Annu. Rev. Entomol. 24:225-254.

Chapin, G., and R. Wasserstrom. 1981. Agricultural production and malaria resurgence in Central America and India. Nature. 293:181-185.

Davies, J. E., R. F. Smith, and V. H. Freed. 1978. Agromedical approach to pesticide management. Annu. Rev. Entomol. 23: 353-366.

FAO/UNEP. 1980. Comments on the pest control crisis in Sudanese cotton production. Excerpted from the report of the Ninth Session of FAO/UNEP Panel of Experts on Integrated Pest Control: Food and Agricultural Organization of the United Nations.

Flint, M. L., and R. van den Bosch. 1981. Introduction to integrated pest management. Plenum, New York. 240 p.

Glass, E. H., and H. D. Thurston. 1978. Traditional and modern crop protection in perspective. BioScience, 28:109-115.

Hildebrand, P. E. 1981. Generating technology for traditional farmers--the Guatemalan experience, p. 31-38. Proc. IX Int. Congr. Plant Protection. Vol. 1. Plant Protection: Fundamental Aspects. Entomol. Soc. Amer., College Park.

IOBC. 1981. IOBC Special Issue, Int. Organ. Biol. Control Noxious Animals and Plants. Centre Overseas Res., London. 75 p.

Jennings, P. R. 1976. The amplification of agricultural production. Sci. Amer., 235:180-194.

Ordish, G. 1976. The constant pest. Peter Davies, London. 240 p.

Pimentel, D. 1955. Biology of the Indian mongoose in Puerto Rico. J. Mammalogy., 36:62-68.

Smith, R. F., and P. L. Adkisson. 1979. Expanding horizons of integrated pest control in crop production, p. 29-30. IX Int. Congr. Plant Protection, Proceedings: Open Session and Plenary Session Symposium. Entomol. Soc. Amer., College Park.

Timmons. F. L. 1970. A history of weed control in the United States and Canada. Weed Sci. 18:294-307.

USDA. 1981. Food Problems and Prospects in Sub-Saharan Africa--The Decade of the 1980s. U.S. Dep. Agr., Econ. Res. Ser., Foreign Agr. Res. Rep. No. 166.

INDEX TO COMMON AND SCIENTIFIC NAMES *

* Names of crops do not appear in the Index.

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