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STUDIES ON THE ECOLOGY AND CONTROL OF THE MELON FLY *DACUS (STRUMETA) CUCURBITAE* COQUILLETT (DIPTERA: TEPHRITIDAE)

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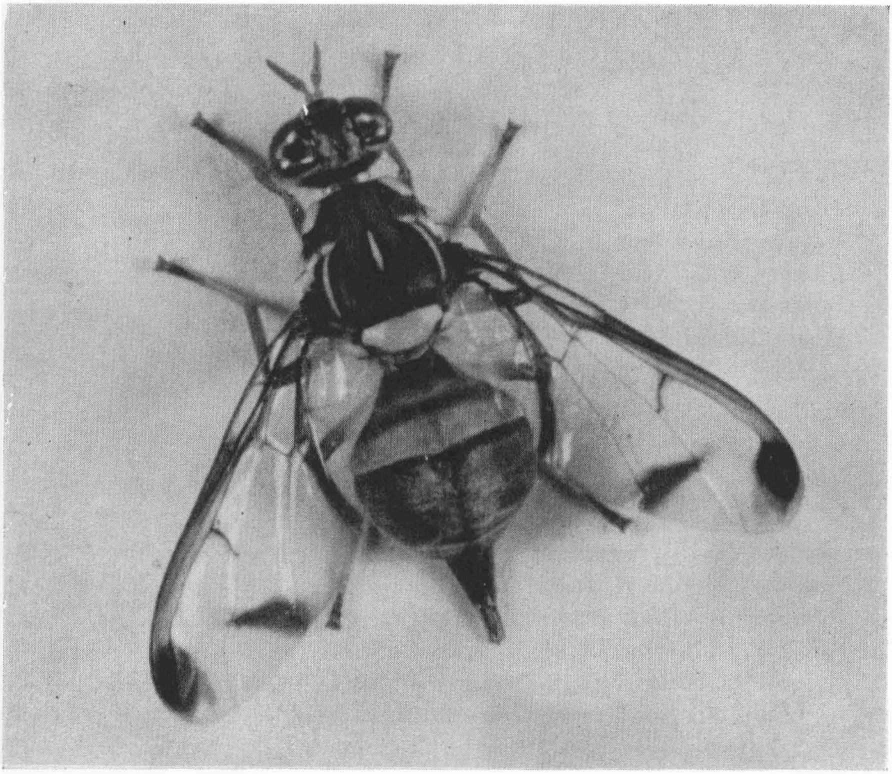

The melon fly [*Dacus (Strumeta) cucurbitae* Coq.].

STUDIES ON THE ECOLOGY AND CONTROL OF THE MELON FLY *DACUS (STRUMETA) CUCURBITAE* COQUILLETT (DIPTERA: TEPHRITIDAE)

T. Nishida and H. A. Bess

The control of the melon fly [*Dacus (Strumeta) cucurbitae* Coquillett], a tephritid fly discovered in Hawaii in about 1895 (Clark, 1898), has been a serious problem for many years. In the past, various methods, discussed in detail in a later section, have been used in attempts to control this pest. The control obtained by these methods was generally not satisfactory either from the standpoint of cost or effectiveness.

In 1948 a critical examination of the melon fly problem in Hawaii was made in an effort to develop effective methods of control. As the result of this examination of the problem, the writers were convinced that a comprehensive ecological study was needed before the control of the melon fly could be placed on a sound basis. Accordingly, such a study was made prior to undertaking further investigations on control. The results of this study have proved to be fundamental to our current approach to the melon fly problem. The primary purpose of this bulletin is to present some of the ecological information pertinent to current control practices and also the results of field studies on chemical control.

ECONOMIC IMPORTANCE

The melon fly is a pest of various crops throughout many of the tropical and subtropical regions of the world. It has been reported from southern China, Formosa, Okinawa, the Philippines, Malaya, Burma, India, Ceylon, Mauritius Island, Kenya Colony in East Africa, Guam, and Hawaii. In these countries the principal crops attacked are watermelons, cantaloupes, pumpkins, squashes, cucumbers, tomatoes, peppers, and beans. In addition to these crops, the melon fly attacks the passion fruit (*Passiflora edulis* f. *flavicarpa* Deg.) in Hawaii where this fruit is now being grown commercially.

Throughout the world where the melon fly is found, it is referred to by a number of common names. In the United States and the Philippines it is called the melon fly (Muesebeck, 1950; Ponce, 1937); in Formosa, "Kajtsu bai" (Koidsumi and Shibata, 1935) or the "Formosan melon fly" (Fukai, 1938); in India, the "melon fruitfly" (Renjhen, 1949); in Ceylon, the "Pumpkin fly" (Green, 1912) or the "cucurbit fruit-fly" (Fernando and Udurawana, 1941). Froggatt (1909*a*) in his discussion of this pest in various parts of the world referred to it as the "Bitter Gourd fly."

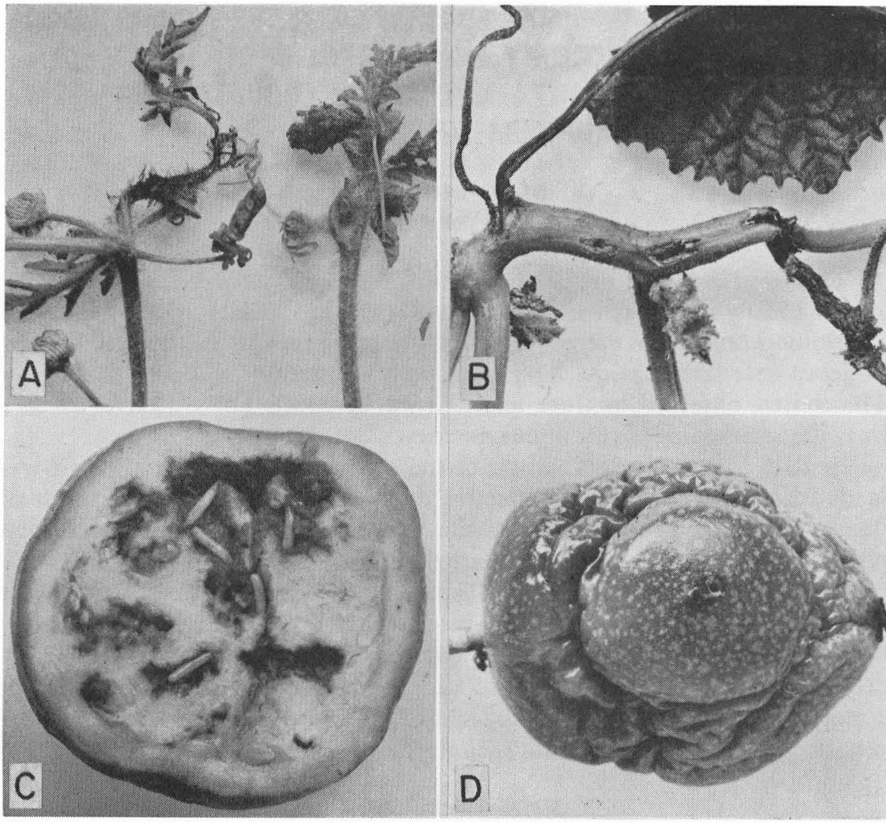

FIGURE 1. The damage caused by the melon fly to certain crops. *A*, terminal shoots of watermelon; *B*, terminal shoots of cantaloupe; *C*, young watermelon fruit in cross section showing larvae and damaged tissues; *D*, gall-like growth on passion fruit caused by the oviposition puncture of the melon fly in young fruit.

Nature of Damage

The damage to crops caused by the melon fly results from (1) oviposition in fruits and in soft tissues of vegetative parts of certain plants, particularly those in the family Cucurbitaceae, (2) feeding by the larvae, and (3) decomposition of plant tissue by invading secondary microorganisms. The combination of the feeding of the larvae and microbial action quickly destroys the tissues affected (fig. 1).

The melon fly oviposits in the vegetative and the reproductive parts of the host plants. Although it does not oviposit in the stems of tomatoes, it oviposits readily in both young and mature tomato fruits. However, the larvae do not develop in young fruits, but the fruits are usually destroyed by the invasion of secondary microorganisms. At times the oviposition wounds in these young fruits heal; however, such fruits are unmarketable because of their deformed condition. In other plants, such as watermelons, cucumbers, squashes, and cantaloupes, the melon fly oviposits in newly emerged seedlings, terminal shoots, and fruits. Severe damage to seedlings and terminal shoots occurs when the adults are very numerous, but damage to the fruits occurs even under conditions of low fly populations. Damage to fruits is greatest in immature fruits; however, fully grown fruits may also be attacked particularly when there are cracks or wounds. At times the oviposition wounds in young cucurbit fruits heal, but the marketable quality of such fruits is reduced because of the deformed condition.

Damage in Hawaii

The extensive damage caused by the melon fly in the past to various crops in Hawaii has been well documented (Howard, 1900; Koebele, 1900; Perkins, 1902; Smith, 1902; Van Dine, 1904; Craw, 1905; Blackman, 1909; Van Dine, 1909; Froggatt, 1909*b*; Severin *et al.*, 1914; Back and Pemberton, 1914, 1918; Westgate, 1918; Illingworth, 1928; Pemberton, 1949). It is clear from these references that the damage to crops ran into millions of dollars annually.

In 1951–52, surveys were made at monthly intervals to determine the extent of damage that occurred throughout the year at Waimanalo and Waianae, Oahu. These surveys were made in fields where treatments of various kinds were being made for melon fly control. The data obtained, shown in figure 2, indicate that the infestation of cucumber and tomato fruits at Waimanalo ranged from 10 percent to 100 percent and 2 to 40 percent, respectively. At Waianae the infestation of cucumbers ranged from 5 to 60 percent and that of tomatoes, 2 to 70 percent. The highest incidence of infestation occurred during the fall months and the lowest during the summer when crop production was the highest.

The level of infestation during 1951–52 was lower than in the previous few years. During 1948 and 1949, both at Waianae and Waimanalo, the fly was so abundant that farmers experienced considerable losses. Young seedlings of melon plants were attacked and destroyed by the pest as soon as they emerged from the soil. Older plants, although not killed, suffered considerable injury and many of the tender young shoots and young fruits were destroyed.

Damage in Other Countries

The melon fly is reputed to be a pest of considerable importance in a number of other tropical areas besides Hawaii. On the island of Formosa, it has caused serious damage to various cucurbits as well as other crops such as beans and tomatoes (Muir, 1914; Kato, 1928; Koidsumi, 1931; Koreishi, 1937). In the Philippines, the melon fly is a major pest of cucurbits (Essig, 1913; Tuazon, 1917; Ponce, 1937). Tuazon estimated a loss of 30 to 40 percent of the cucurbits by the melon fly in the Philippines and stated that the combined attack of a bug, *Leptoglossus membranaceus* F., and the melon fly caused considerable damage. The bug fed on the

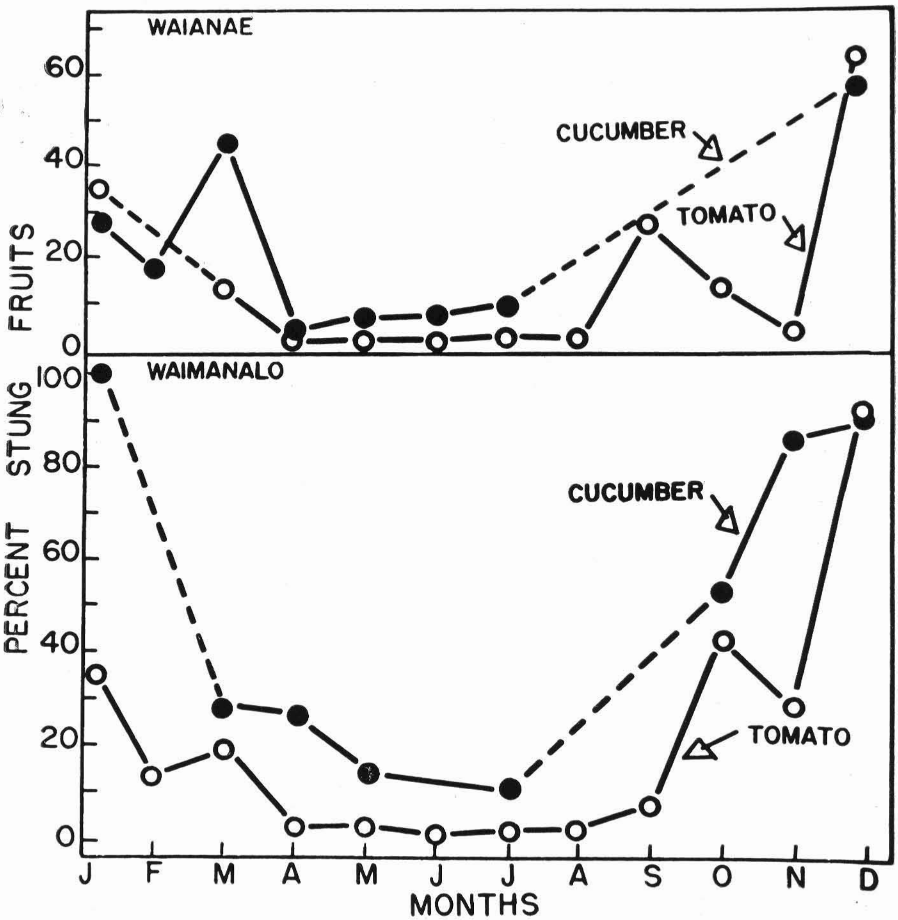

FIGURE 2. Monthly trends in the percentage of stung tomatoes and cucumbers during 1951 at Waianae and Waimanalo, Oahu.

fruits and the melon fly laid eggs in the feeding wounds. In Java it has been reported to be a pest of *Momordica, Citrullus,* and melons (Dammerman, 1914). In Malaya, this insect is a pest of cucurbits and tomatoes (Bunting and Milsum, 1930; Corbett, 1935). The only report on the occurrence of the melon fly in Australia is that of Hill (1915) who listed it as a pest of melons, pumpkins, and marrow squash in northern Australia. In India, the melon fly is reported to be a destructive pest to various crops, especially cucurbits (Maxwell-Lefroy, 1907; Ribeiro, 1934; Pruthi and Batra, 1938; Pruthi, 1941). Pruthi stated that damage to cucurbits was as high as 40 to 80 percent of the crop. Several workers (Green, 1912; Rutherford, 1914; Hutson, 1934, 1937) have also reported it to be a pest of cucurbits in Ceylon. De Charmoy (1915) reported it to be an economic pest on the island of Mauritius. Compere (1912) considered the melon fly to be a serious pest in Macao, China, but not to the extent that it was in the Hawaiian Islands.

Quarantine and Its Economic Effects

The economic importance of the melon fly cannot be evaluated entirely from the standpoint of the actual damage to the various crops affected. It must also be considered from the standpoint of quarantine which has far-reaching economic effects.

Quarantine laws aimed at preventing the entry and establishment of the melon fly in areas where it does not occur have been established and are being vigorously enforced. The United States Government has quarantine laws regulating the movement of certain commodities in order to prevent the entry of the melon fly into the continental areas of the United States. The Japanese Government also has laws which prevent the entry into Japan proper of certain commodities known to be attacked by the melon fly. The Egyptian Government is also concerned with the problem of keeping the melon fly out of its country.

Although exact data on the amount spent on quarantine control by the countries concerned are not available, it is evident that the melon fly has played an important role in the economy of the countries involved. To areas, such as the mainland United States, which attempt to prevent introduction, it means a considerable expenditure of money to maintain an efficient quarantine system. To other areas, as for example the Territory of Hawaii, it means a trade barrier which reduces the number of products to be exported. To some extent this trade barrier has been broken in recent years through commodity treatment, but it must be realized that the treatment may affect shipping quality and may also increase the cost of the products. The loss of quality and the increased cost place the products in question in an unfavorable competitive position in relation to similar products from other areas (Bird, 1952).

EVALUATION OF PREVIOUS METHODS OF CONTROL

Since the discovery of the melon fly in Hawaii a number of methods have been employed in attempts to reduce or prevent damage by this pest. These methods are: (1) mechanical control, (2) cultural control, (3) biological control, and (4) chemical control.

Mechanical Control

The mechanical methods of controlling the melon fly include the use of protective coverings on the fruit (fig. 3) and the destruction of adults by use of traps. The use of protective coverings is more effective and costly than the use of traps. In spite of its cost, protective coverings are still used to a certain extent largely by cantaloupe and watermelon growers.

The method of covering each fruit to protect it against melon fly attack, a method which has been in use for many years (Severin *et al.*, 1914; Back

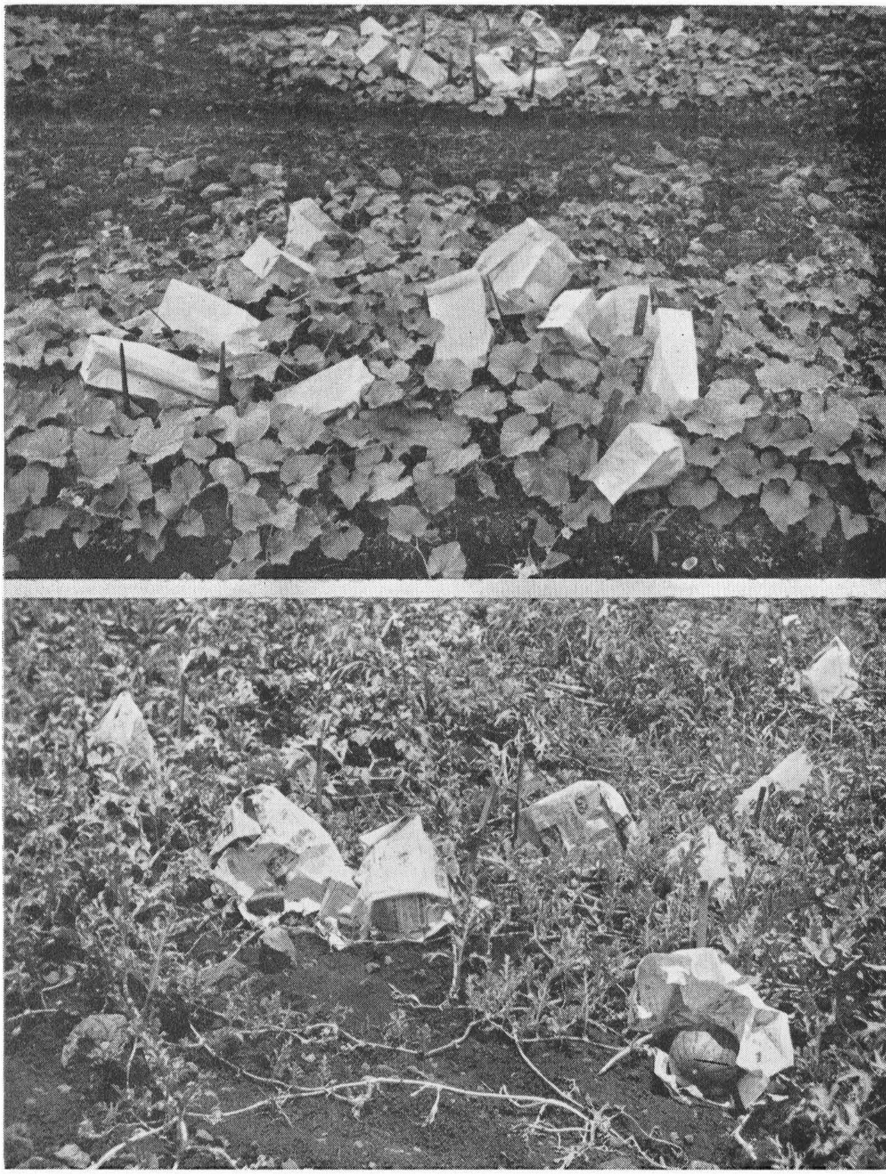

FIGURE 3. Fruits covered with paper bags and newspaper to protect them against melon fly attack. Top photograph, cantaloupe fruits covered with paper bags. Bottom photograph, watermelon fruits covered with newspaper. Fruit in lower right corner uncovered to show fruit.

and Pemberton, 1917; McPhail, 1943), is a tedious and expensive method. As soon as each fruit has set, it is carefully wrapped with newspaper, paper bags, burlap, cloth, metal gauze, straw, or even soil. Fruits which are cross-pollinated cannot be covered until pollination has taken place; otherwise there will be no fruit setting. When the melon flies are extremely abundant, they puncture the young fruits even before pollination has taken place. Therefore, when fruits are being covered, each fruit is examined and only those without oviposition punctures are covered. Fruits of crops such as the watermelon and cantaloupe are often covered twice; first, when the fruit has just set and second, about the time when the fruit has outgrown the first covering.

This method may give 95 percent or more protection of the covered fruits; however, it has serious limitations. It is not effective in preventing the fly from stinging the vines, flower buds, and fruits not yet pollinated. Furthermore, a considerable amount of hand labor is required, and hence, the cost of production is increased. Largely because of this increased cost of production, growers cannot expect to make a profit unless the price of their produce is relatively high. Consequently, this method is used only on those fruits such as watermelon and cantaloupe which bring high prices on the market.

In addition to the use of protective coverings, attempts have been made to control the melon fly mechanically by using various trapping devices to capture the adults. The early oriental farmers used rice bowls containing various attractive materials such as rice washings, cucumber or other fruit juices, sugar solution, and even wine. When the adults came to feed, they dropped into the liquid and drowned. Some of the farmers used home-made traps which were made by boring holes into the sides of gallon jugs or other similar containers. The adult flies entered these traps through the holes bored into the sides of the jugs and drowned in the liquid lure. Even though these traps set at various places within the field caught adults occasionally in moderate numbers, it is unlikely that the use of these devices gave effective control. McPhail (1943) carried out trapping experiments in which glass invaginated traps containing linseed oil lure were set out in a bitter melon (*Momordica charantia*) field. Although these traps captured considerable numbers of flies, continuous trapping did not reduce the trap catch. Furthermore, bitter melon fruits placed out in the trapping area all became infested. It was concluded by McPhail that traps were not effective in controlling the melon fly. Observations made during the present study as well as those made by others (Severin *et al.*, 1914; Back and Pemberton, 1918) also show that, in general, traps are not effective in controlling the melon fly.

Cultural Control

There are three principal cultural methods which may be used for melon fly control. These methods are: (1) field sanitation, (2) use of trap crops, and (3) use of resistant varieties.

Field sanitation is the most important cultural method of control. It is concerned primarily with field sanitation directed toward the destruction of all unmarketable and already infested fruits during the harvesting period, and the plowing and disking of the fields as soon as crops susceptible to melon fly attack are harvested. This procedure, which destroys much of the fruits in which the larvae develop, is extremely important because the adults which the farmer is trying to control are usually those which emerged from fruits of a previous crop left in the field by the farmer or his neighbor.

There is no doubt that one of the most important factors that cause a high melon fly population is continuous cultivation of crops and leaving unmarketable fruits in the fields. Under such conditions, the fly population may build up enormously within a relatively short time. Therefore, good field sanitation practices are important even where insecticides are used.

In the spring of 1949 a sanitation program was carried out on the Hawaii Agricultural Experiment Station farm at Poamoho, Oahu, to study the effectiveness of the method. On this farm, well isolated with the nearest truck crop areas at least two miles away, tomatoes and cucurbits had been grown more or less continuously for many months and melon fly was a serious problem. Studies were first begun in early April in a 3-acre tomato field just beginning to set fruit. This field was being invaded by melon flies from a nearby area of volunteer tomatoes in which appreciable numbers of flies were breeding. Prompt action was taken to spray the surrounding vegetation with DDT and to eliminate the volunteer tomatoes. In addition, throughout the period of study (April to September), an attempt was made weekly to pick and dispose of all stung mature green and ripe fruits in which flies might develop, by placing them in 50-gallon drums containing water. It was not necessary to destroy stung immature fruits for the larvae cannot develop in these fruits.

The effect of these sanitation practices became evident within a short time. Melon flies soon became extremely scarce and failed to increase in numbers as long as the sanitation practices were continued. Crops, practically undamaged by flies, were harvested even though no insecticides were used. Approximately 10 additional acres of tomatoes in three plantings were grown during the same season in adjacent fields where sanitation was practiced with similar good results. However, because of labor shortage, sanitation practices were discontinued in September and the melon fly infestation increased rapidly, and immediately prior to plowing the field about 75 percent of the tomatoes were infested (Nishida and Bess, 1950).

Field sanitation practices are easily carried out effectively on isolated farms such as the one mentioned above. However, in areas where farms are close together it is difficult to get every grower to cooperate and carry out sanitation practices on his own farm. Melon flies are capable of moving considerable distances, and hence, the beneficial effects of sanitation practices carried out by one farmer may be nullified to a great extent by the carelessness of his neighbor.

The use of trap crops is another cultural method of control. Severin *et al.* (1914) reported that they planted a trap crop of cantaloupe around a cucumber field, thinking that the melon flies would be attracted to the cantaloupe, thus preventing damage to the cucumbers. This method was a complete failure for both the cantaloupe and the cucumber were severely damaged.

Although no attempts have been made to control the melon fly by use of resistant varieties, it seems appropriate here to cite the literature on the susceptibility of different varieties to melon fly attack. Marlowe (1937) reported that the Break of Day tomato variety was less susceptible to melon fly attack than the Pritchard. Under field conditions the infestation of the Break of Day tomato was 19.3 percent and the Pritchard, 59.3 percent. Holdaway (1940) observed that certain varieties of green beans were less susceptible to attack than others. Among the three varieties, Lualualei, McCaslan, and Kentucky Wonder, the Lualualei variety was reported to be the most susceptible and the Kentucky Wonder, least susceptible to melon fly attack.

Biological Control

Extensive search by officials of the territorial and federal governments has been made in various parts of the world to locate natural enemies of the melon fly that might be introduced into Hawaii. The most effective natural enemy discovered to date is *Opius fletcheri* Silv., a braconid parasite, which attacks the melon fly during the larval stage. It was found in India and introduced into Hawaii in 1916 (Fullaway, 1916).

Studies on the effectiveness of this parasite as a controlling agent of the melon fly have been made by Willard (1920), Newell *et al.* (1952), and Nishida (1955). These studies showed that *Opius fletcheri* often destroys considerable numbers of melon fly larvae infesting the wild *Momordica balsamina* fruit. However, it destroys few larvae in cultivated crops. The value of *O. fletcheri,* therefore, is limited primarily to the reduction of the melon fly population in the wild areas.

Chemical Control

The chemicals used for melon fly control have been used as (1) repellents, (2) toxicants in baits, and (3) sprays and dusts.

The only report concerning the use of repellents appears to be that of Marlowe (1940) who tested various repellents in small plot field experiments. Among the repellents tested, the Bordeaux plus nicotine sulfate treatment gave the highest percentage of uninfested cucumber fruits. However, the Bordeaux plus nicotine sulfate may not have had a repellent effect on the fly. The reduced infestation in plots given this treatment might have been due to aphid control for it is known that melon flies are attracted to the honeydew. Marlowe stated that aphids were not present on plots treated with Bordeaux plus nicotine sulfate, but were abundant in all plots, including the check, where the melon fly infestation was high.

The use of poison baits has been reported by various workers. Marsh (1910) sprayed cucumber and cantaloupe plants with bait sprays containing molasses, Paris green, or lead arsenate and water. Similar experiments were carried out by Severin *et al.* (1914) and by Back and Pemberton (1917) using bait sprays containing brown sugar, arsenate of lead, or sodium arsenite and water. In all experiments the authors stated that although the bait sprays caused a reduction in the number of flies no practical control was obtained. Holdaway (1945) reported that a bait spray containing tartar emetic failed to give consistent control and thus could not be recommended for the control of the melon fly. However, Steiner (1954, 1955) reported that effective control of the melon fly can be obtained by use of a bait spray containing yeast hydrolysate and either malathion or parathion. Further experiments on the control of the melon fly attacking various truck crops are being conducted at the present time in cooperation with the United States Department of Agriculture, Agricultural Research Service. The results of these experiments will be published jointly in another publication.

The use of insecticides in the form of sprays and dusts for the control of the melon fly has been reported by various workers. The insecticides were applied either to the crop to be protected, to the plants with which the adults are closely associated, or to both. Holdaway *et al.* (1947) reported that effective control was obtained in a tomato field in which a 3 to 5 percent DDT dust was applied to the tomato plants. They also reported that effective control was obtained with cucumbers when 5 pounds of 50 percent wettable DDT per 100 gallons was applied to corn planted around a cucumber field.

ECOLOGICAL ASPECTS PERTINENT TO CONTROL PRACTICES

In the fall of 1948, when the present studies were begun, field observations showed that in spite of heavy applications of insecticides to the crops to be protected, losses of tomatoes, cucumbers, and watermelons due to melon fly attack were exceedingly high. Many growers were applying to the crop heavy dosages of DDT, TEPP, and other recently developed insecticides several times a week and still were unable to get successful control. In the light of these failures the authors decided to reinvestigate certain aspects of the field biology and ecology of the fly to obtain information which might lead to an effective method of control. The information obtained led to the development of control procedures based on these ecological findings. Some of the more pertinent of these findings are presented in this section.

Summary of Life History

Detailed accounts of the life cycle and biology of the melon fly in Hawaii have been published by Back and Pemberton (1914, 1917, 1918) and by Severin *et al.* (1914). For the purpose of orientation, a brief account on life history is presented in this section stressing those aspects pertinent to the discussion which follows later.

The eggs are laid either in the tissues of the fruits or the vegetative parts of the host, principally, tomatoes, cucumbers, watermelons, squashes, gourds, and pumpkins, which the larvae utilize as food. From 40 to 48 hours are required for incubation. The larvae complete their development in 6 to 8 days. The full-grown larvae then leave the host tissue, enter the soil to a depth up to 4 inches and pupate. Seven to 14 days later the adults emerge from the puparia in the soil and the adults burrow their way out to the soil surface some 3 weeks after the larvae are hatched. Upon reaching the surface these young adults move to sheltered spots, such as under fallen leaves, lumps of soil, rocks, or pieces of wood. After remaining motionless in these sheltered sites for 2 to 3 hours they then fly to certain kinds of favored plants with which they are associated during the greater part of their adult life (figs. 4 and 5). When ready to lay eggs, the gravid females move on to various crops and begin egg laying. Eggs continue to mature in the ovaries and egg laying extends over a period of several months.

Plants with Which Adults are Associated

Surveys were made in the Waianae and Waimanalo areas to determine the plants with which the adults are associated. In making the survey, various plants were swept with an insect net at monthly intervals and the number of times at which adults were taken on the different plants was used as a measure of association of the flies with the different plants. Table 1, which presents the data obtained, lists only plants on which adults were found. More plants on which no adults were captured are not listed.

From table 1 it is evident that there is considerable variation in the degree of association between adult melon flies and certain plants. Among crop plants the melon flies were most frequently associated with corn in both Waianae and Waimanalo areas. Among wild plants, castor bean (*Ricinus communis* L.), spiny amaranth (*Amaranthus spinosus* L.), rattlepod (*Crotolaria incana* L. and *C. mucronata* Desv.), and the wild Euphorbia (*Euphorbia geniculata* Ortega) were the plants with which the adults were frequently associated (figs. 4 and 5).

The factors which influence the degree of association between adult flies and plants are not fully understood. In certain cases the presence of food in the form of honeydew from homopterous insects appears to attract the flies in large numbers. In others, the presence of other foods such as pollen and glandular exudate influences the attractiveness. In general, plants in a succulent state of growth are favored over those in a less succulent condition. Perhaps the microenvironmental conditions, particularly humidity, among succulent plants have an effect; however, such plants also are more likely to have honeydew producing insects associated with them and they also produce a more copious flow of glandular exudations than less succulent plants.

TABLE 1. Adults of the melon fly attracted to various plants at Waianae and Waimanalo, Oahu (1951)

Common name	Scientific name	Waianae		Waimanalo		Waianae and Waimanalo	
		Number of times captured	Percentage of total	Number of times captured	Percentage of total	Number of times captured	Percentage of total
CROP PLANTS:							
Corn	*Zea mays* L.	77	42.5	25	12.6	102	26.8
Papaya	*Carica papaya* L.	----	----	4	2.0	4	1.1
Broccoli	*Brassica oleracea* L. var. *botrytis* L.	1	0.6	2	1.0	3	0.8
String bean	*Phaseolus vulgaris* L.	1	0.6	1	0.5	2	0.5
Lima bean	*Phaseolus limensis* Macf.	1	0.6	----	----	1	0.3
Bell pepper	*Capsicum frutescens* L. var. *grossum* (L.) Bailey	1	0.6	----	----	1	0.3
WILD PLANTS:							
Castor bean	*Ricinus communis* L.	47	26.0	35	17.6	82	21.6
Spiny amaranth	*Amaranthus spinosus* L.	11	6.1	41	20.6	52	13.7
Fuzzy rattle pod	*Crotolaria incana* L.	17	9.4	27	13.6	44	11.6
Wild euphorbia	*Euphorbia geniculata* Ortega	9	5.0	27	13.6	36	9.5
Popolo	*Solanum nodiflorum* Jacq.	1	0.6	20	10.0	21	5.5
Cocklebur	*Xanthium saccharatum* Wall.	10	5.5	2	1.0	12	3.2
Sorghum	*Sorghum vulgare* Pers.	----	----	11	5.5	11	2.9
Pigeon pea	*Cajanus cajan* (L.) Millsp.	1	0.6	3	1.5	4	1.1
Jimson weed	*Datura stramonium* L.	2	1.1	----	----	2	0.5
Ilima	*Sida fallax* Walpers.	1	0.6	----	----	1	0.3
Guava	*Psidium guajava* J.	----	----	1	0.5	1	0.3
Hairy morning glory	*Merremia aegyptia* (L.) Urban.	1	0.6	----	----	1	0.3
TOTALS		181	100.2	199	100.0	380	100.3

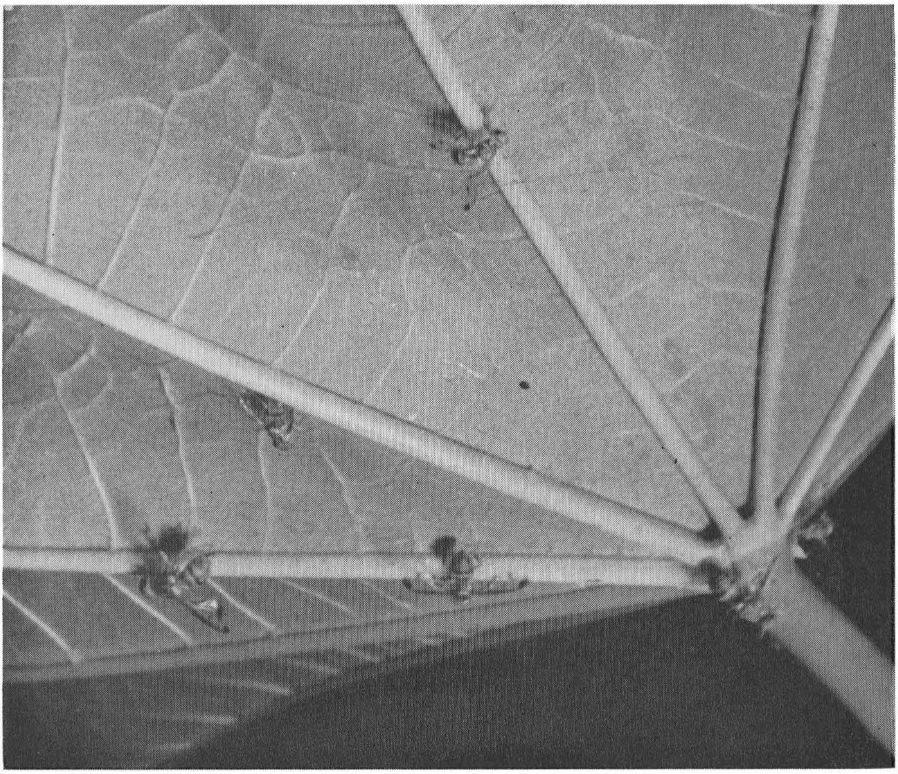

FIGURE 4. Melon fly adults on the lower surface of a castor bean leaf (*Ricinus communis* L.).

Adult Fly Movements

This discussion on adult fly movements is restricted to those of newly emerged adults and gravid adults. Newly emerged adults may be recognized in field populations by the presence of spherical, pale yellow, fat globules in the body cavity. These globules are present in individuals up to approximately 3 days old. Gravid individuals may be recognized by the presence of fully developed eggs which are elongated and glossy white. The examination of the fat globules and mature eggs was made under a dissecting microscope in the laboratory.

Movement of newly emerged adults out of crop areas

The first field data on the movement of young flies were obtained during the fall of 1948 in a tomato field on the experimental farm at Poamoho, Oahu, in which the fruits were heavily infested and many flies were emerging. This field was visited weekly and adult flies were collected by means of an insect net from various sites within as well as outside of the field. It was found that out of 210 adults captured in the peripheral areas on *Crotolaria* spp. and young mango trees (*Mangifera indica* L.) 36.1 percent were young individuals. The absence of young individuals within the field

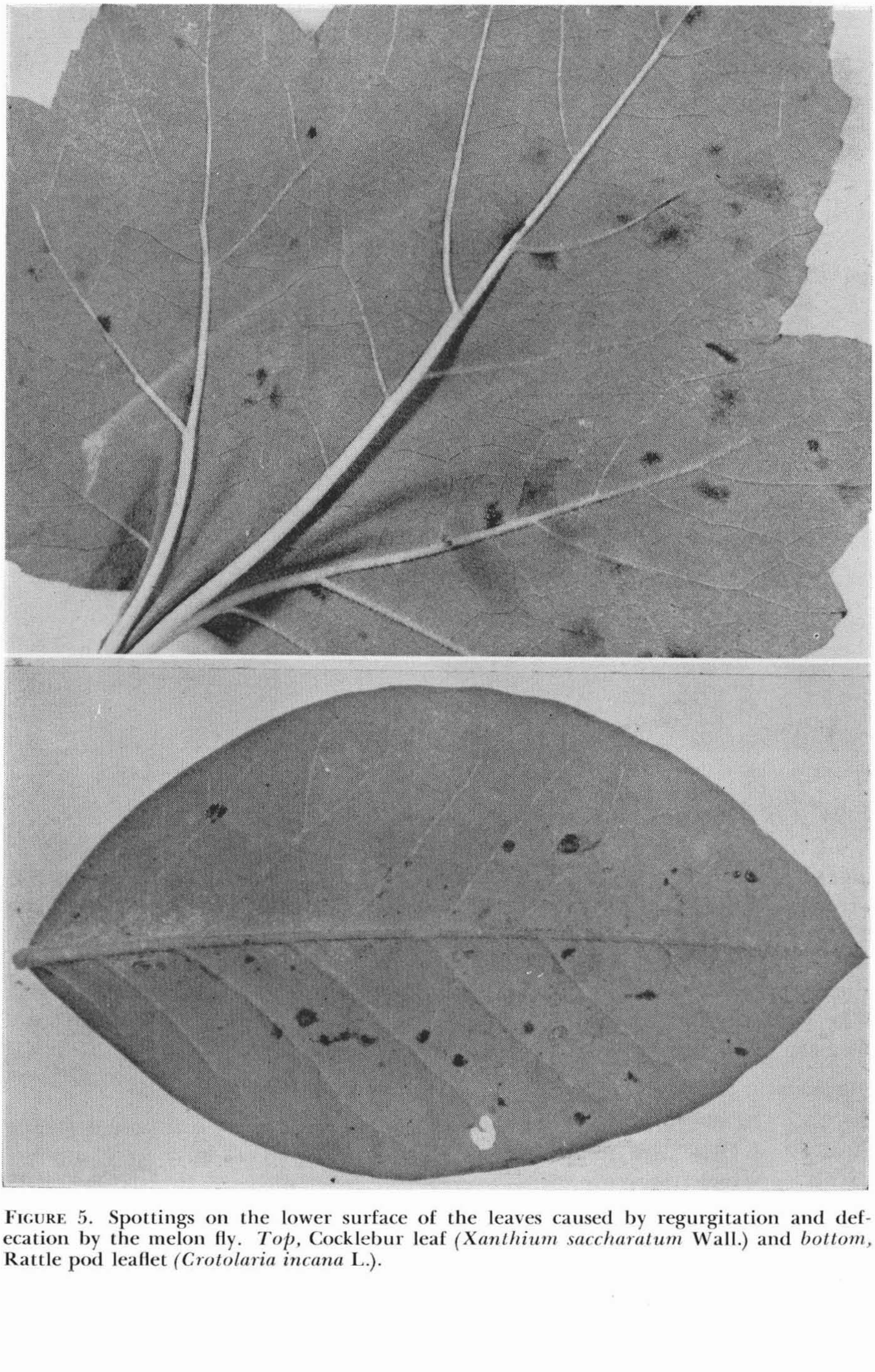

FIGURE 5. Spottings on the lower surface of the leaves caused by regurgitation and defecation by the melon fly. *Top*, Cocklebur leaf *(Xanthium saccharatum* Wall.) and *bottom*, Rattle pod leaflet *(Crotolaria incana* L.).

seemed paradoxical in view of the fact that young adults were emerging from puparia within the field.

A similar study was subsequently made in a tomato field at Waimanalo where the proportion of young adults within and outside of the field was again determined periodically for a period of approximately two months. The percentages of young adults on tomato plants, weeds within the tomato field, and weeds outside of the tomato field are shown in table 2. At the beginning of this study when there were only a few small weeds in the field most of the young flies moved to the weeds outside of the field. Later, however, after a large portion of the crop had been harvested and weeds had been allowed to grow, many young flies were present on the weeds inside of the field. Only a small percentage of the young adults was present on the tomato plants at any given time.

Further studies on the movement of young adult flies out of a field were made in cooperation with Dr. Walter Ebeling (Ebeling *et al.*, 1953) by means of marked flies. A total of 2,000 laboratory cultured day-old adults were inactivated by subjecting them to carbon dioxide and marked by placing a small drop of paint on the dorsum by means of a hypodermic needle. The marked flies were released in the center of a ½-acre rectangular tomato field on the University of Hawaii Mid-Pacific Experimental Farm. At the same time invaginated glass traps baited with yeast, sugar, vinegar, and water were placed within the field and also in the surrounding area. Out of a total of 2,000 released 131 flies were recovered and 97 percent of them were captured in the traps placed outside the field. The capture of such a high percentage of marked individuals outside of the field indicates that the young adults released had moved out of the field.

TABLE 2. The percentage of young adults in the samples collected within and outside of a tomato field

Date of collection	Tomato plants		Weeds within field		Weeds outside of field	
	Number	Percent	Number	Percent	Number	Percent
November 14, 1951	23	0.0	3	0.0	44	50.0
21	28	20.0	20	50.0	82	78.0
30	19	5.2	22	4.5	72	33.3
December 5	25	0.0	42	23.8	123	41.4
14	19	21.0	76	72.3	149	29.5
21	----	----	101	78.2	193	45.5
28	----	----	----	----	74	50.0
January 4, 1952	----	----	----	----	22	27.2
11	----	----	----	----	23	17.3

That newly emerged adults move out of the crop areas soon after emergence has been actually observed in the field. During the morning hours when emergence takes place, young adults were seen flying feebly from host plant to host plant toward the periphery of the field where weeds of various kinds were present. They tended to move into the wind rather than with the wind under low to moderately windy conditions. These movements out of the crop areas occur if the fields are free of suitable weeds, but when the fields are overgrown with weeds young flies remain on them.

Movement of gravid flies into crop areas

In tomato fields or other fields, where the plants are not yet producing fruits, melon flies are rarely present. However, about the time fruiting begins they may be seen flying from plant to plant and often many may be seen ovipositing. Such observations led to a speculation that only the gravid females were moving into the crop areas. Detailed studies were then made to determine whether there was a differential movement of the sexes.

During 1949, many tomato, cucumber, and melon fields were visited periodically and samples of the adults present collected to determine the sexual composition of the population. The results of these studies showed conclusively that the flies present among crop plants were predominantly females. For example, of 258 flies collected periodically between May 31 and June 20, 1949, in a tomato field at Waianae, Oahu, 96.5 percent were females.

Studies were then undertaken to determine gravidity, as evidenced by the presence of fully developed eggs, of the females present on these crops. A 3-acre tomato field on the University of Hawaii Experimental Farm at Poamoho, Oahu, was visited periodically and all adults seen were captured with an insect net and later dissected under a microscope to determine whether or not they were gravid. The data obtained from this study (table 3) indicate that the females in this field where there was no fly emergence were nearly all gravid individuals. Data obtained in other tomato fields, as well as on other crops, also showed the predominance of gravid females on crop plants. The presence of these gravid females suggested that these adults were coming in from the wild areas.

An investigation was then undertaken to learn more about the movement of adults into the fields. At Waianae a series of transect lines ranging from 50 to 100 feet in length were established at various places within as well as outside of the field. The number of adults present within 5 feet on each side of these transect lines were counted at various hours of the day without disturbing the adults. Because the previous study showed the predominance of gravid flies in the field where there was no fly emergence, it was assumed that the adults counted in the field represented largely gravid individuals. However, those counted outside of the field no doubt represented gravid and non-gravid females and males. The result shown in figure 6 indicates that gravid females were not present on crop plants during the very early morning hours. However, they were found to move

TABLE 3. Number of males and gravid and non-gravid females collected in a 3-acre tomato field at Poamoho, Oahu, in which no flies were emerging

Date of collection	Number of females		Number of males
	gravid	non-gravid	
February 14, 1949	1	0	0
21	1	0	0
28	1	0	0
March 4	5	0	0
11	0	2	0
18	3	0	0
20	6	0	0
21	3	0	0
25	7	0	0
29	3	0	0
TOTAL	30	2	0

into the field from nearby wild vegetation later in the morning. Females in varying numbers were observed in the field during the greater part of the day, but the highest numbers were present around 5 p.m. After that the number of flies in the field diminished and few or no flies remained in the field at night. To check this, several tomato plants were swept with an insect net just before dawn and not a single adult was captured. Sweepings made in other fields indicated that when favorable weeds were present some adults instead of leaving the fields remained on these weeds.

In summary, it was found that the flies collected on crop plants early in the growth of a crop were nearly all females and a very high percentage of them gravid. Furthermore, except when there were favorable weeds in these crop areas, these gravid females left the crop areas in the evening before dark and moved into favorable vegetation nearby when present. During the day, particularly in the late afternoon hours, they entered the crop areas again. It appears evident that the gravid females move from wild areas on to crop plants to lay eggs rather than to feed or for shelter, for males and non-gravid females were seldom encountered in fields where there was no fly emergence.

Distribution of Adults Outside of Crop Areas

After the above studies had revealed something about the movement of young adults, a further study was made to determine the distributional

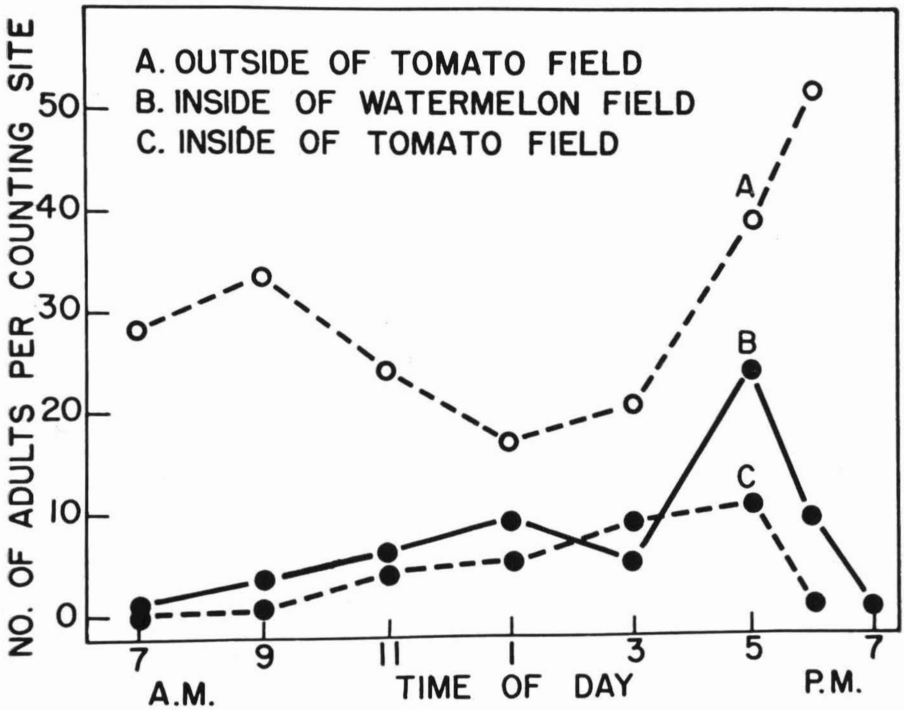

FIGURE 6. Graph showing diurnal changes in abundance of melon fly adults in melon and tomato fields.

patterns of the adults in the vegetation surrounding crop areas and also to determine the relative abundance of adults at different distances from the crop areas.

The distributional patterns were determined by making sweepings and observations along transect lines radiating outward in all directions from cultivated tomato and cucumber fields. Each field and the surrounding vegetation were sketched to scale, and the areas in which adults were found mapped. Some of the representative distribution patterns, diagrammatically sketched, are presented in figure 7. This figure shows that there was considerable variation in the distributional patterns. In certain fields, as for example in A and B, the adults were present only in a few localized areas near the edges of the fields. In others, however, as in fields C and D, the adults were widespread over considerable areas.

In addition to the distributional patterns, the relative abundance of adults at various distances from the edges of fields into the wild vegetation was also determined. The procedure, similar to the one mentioned above, consisted of making sweepings for a period of 3 minutes at various points on transect lines radiating outward from the fields into the surrounding wild areas. The results expressed as percent of total flies captured at vari-

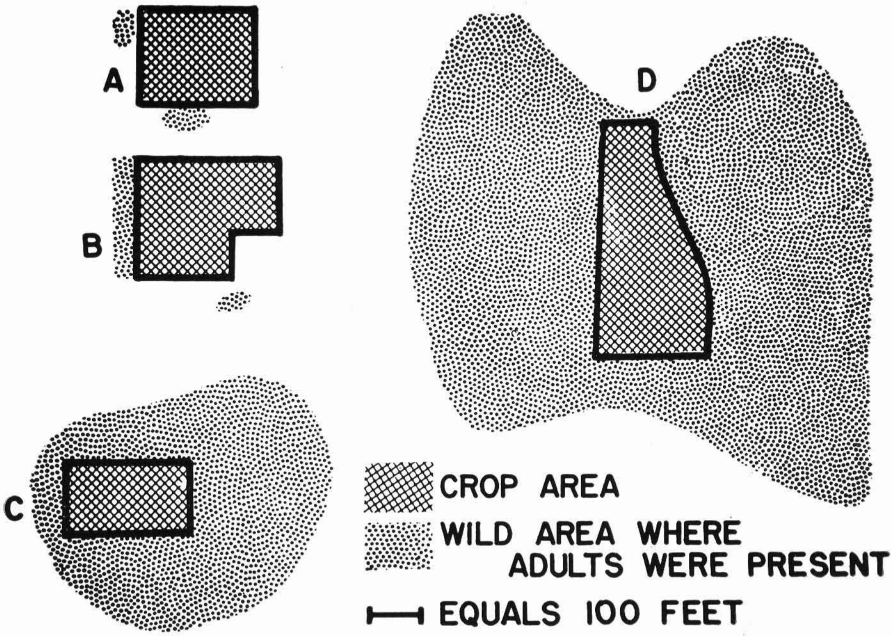

FIGURE 7. Variation in distribution patterns of adult melon flies in the vicinity of crop areas.

ous distances are shown in figure 8. From these data it is evident that although there was a tendency for the adults to be more abundant near the periphery of a field, this trend was not consistent. In some instances, the adults were just as numerous or more so at considerable distances away from the field as they were near the edges. Furthermore, there was also considerable variation in abundance among the north, west, south, and east sides of the field. Such variations are not at all surprising if the adult fly-plant relationship already discussed is considered. As shown earlier, there is a close association of adults with certain plants and the distributional patterns observed were correlated with the distribution of plants favored by the adults. Consequently, when favorable plants occurred as isolated stands near the edges of the field, nearly all adults observed were found on these plants. When favorable plants were scattered over wide areas, the adults were usually found scattered over wide areas.

Relative Abundance of Adults Within and Near Crop Areas

Although often even casual observations indicated that melon flies were more numerous outside of the field than inside, a number of attempts were made to obtain estimates of the abundance of adult flies in the crop areas and in the immediate surroundings. In several cases, however, the studies did not go to completion because the farmer on whose farm the

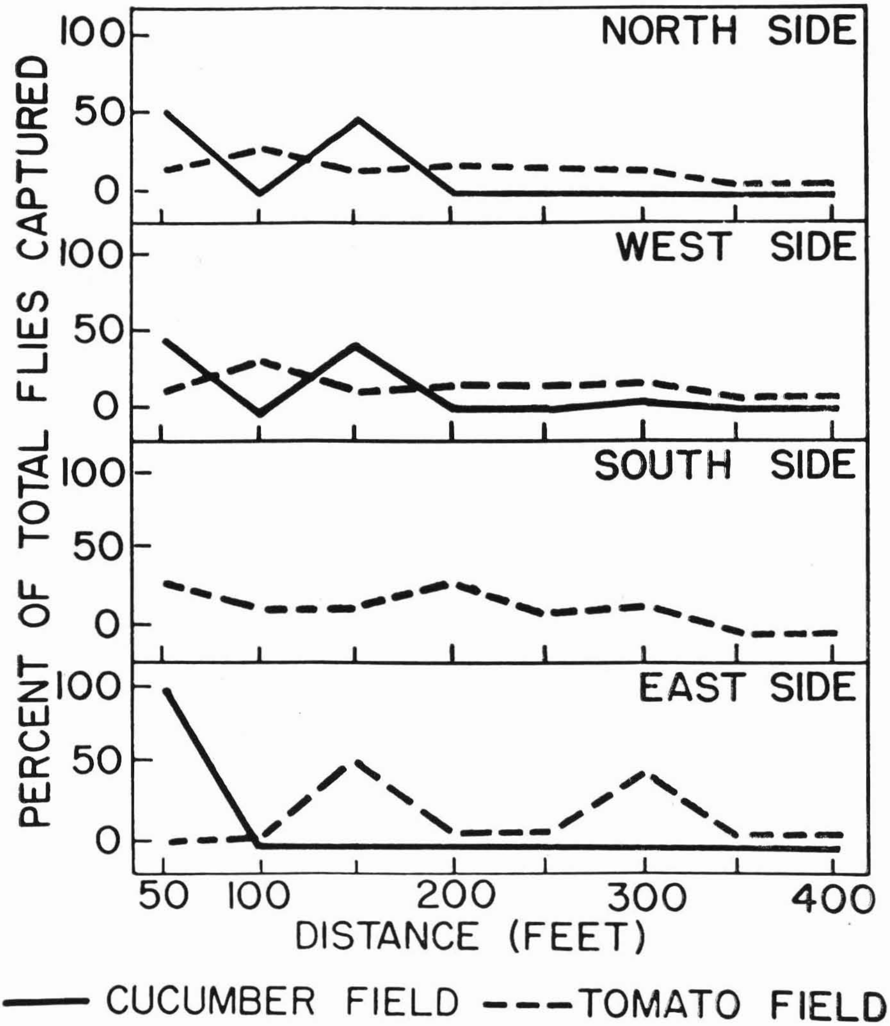

FIGURE 8. Relative abundance of adult melon flies at various distances from crop areas.

studies were made decided to plow the field before all the data desired were obtained. The most complete information was obtained from a 3-acre tomato field at Waimanalo. Three sampling sites were established among both tomato plants and weeds within the field and three among miscellaneous weeds along the periphery of the field. At each sampling site sweepings were made by means of an insect net for a period of 10 minutes per site periodically for approximately two months. At the time the study was initiated the tomato fruits were still immature and there were few weeds be-

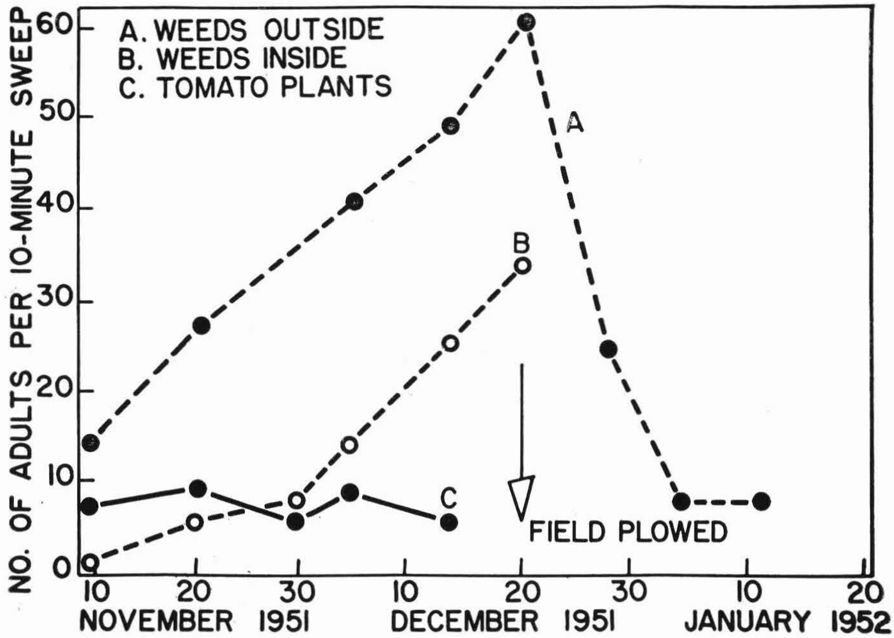

FIGURE 9. Comparative data showing the abundance of adults on weeds outside of the tomato field, weeds inside of the field, and on the tomato plants.

tween the rows and roadways. However, as time elapsed the weeds gradually increased to such an extent that by the end of the sampling period the tomato plants were nearly completely covered by weeds. The data obtained (fig. 9) show that throughout the sampling period the adults were consistently more numerous outside than inside of the field. The number of adults collected on the tomato plants was about the same throughout the sampling period, but the number on the weeds both inside and outside of the field increased until the time when the field was plowed by the farmer. Soon after plowing the population rapidly declined. These observations show that as long as a field has decaying fruits and suitable succulent weeds melon flies will remain in such fields and when such fields are disked or plowed the melon flies will move into other areas.

Ovipositional Behavior Patterns

In this section observations on the ovipositional behavior of the melon fly are reported with particular reference to the following aspects: (1) distributional pattern of stung fruits, (2) variation in the extent of oviposition in cultivated fruits, and (3) diurnal ovipositional behavior.

Distributional patterns of stung fruits

Surveys were conducted in a large number of tomato, watermelon, and cucumber fields to determine if there were definite patterns in the distribution of stung fruits. In the preliminary survey a series of transect lines parallel to the longest axis of the field and cutting through the entire length of the field were used. The extent of stung fruits along these lines was then determined. These preliminary investigations showed that the percentage of stung fruits was highest along transects located along the edges of the field and lowest along those cutting through the central portions of the field.

Following this preliminary work, more detailed studies were conducted using a modified technique. In this technique the field concerned was divided into plots of equal size and fruits on each plant within each plot were examined and the number of stung fruits recorded. By this procedure a better picture of the distributional patterns of stung fruits was obtained. The results of these studies showed that there was a distinct pattern in the distribution of stung fruits. The number of stung fruits was in general higher near the periphery than in the interior of the field.

The occurrence of a larger number of stung fruits along the edges of the field than in the interior is to be expected in view of the movement of gravid females in and out of the fields and the higher population outside of the fields which have been discussed. The frequent occurrence of greater numbers of stung fruits along the edges of the field suggests that the majority of the gravid females begin to lay eggs shortly after entering the field from the surrounding wild areas. However, the presence of stung fruits even in the central parts of the fields indicates that at least some individuals do move deeply into the fields.

The variation in the number of stung fruits among plots located along the periphery is evident from the data shown in figure 10. This variation may be attributed to the uneven distribution of the flies which in turn is influenced by the presence of favorable plants along the periphery of the field. Observations made in other fields indicate that in general fruits located near plants harboring flies tend to be more severely damaged than those located in sites where such plants were not present. For example, it was frequently observed that the fruits located near corn and castor bean plants were stung to a greater extent than those located near grasses or other plants unattractive to the flies.

Variation in the extent of oviposition in cultivated fruits

The extent to which the melon fly oviposits in various host crops has been observed to vary considerably. This variation is due to a number of factors among which are melon fly abundance, host plant susceptibility, fruit maturity, and abundance of fruits.

The observations made during this investigation indicate that there is a correlation between the abundance of the melon fly and the number of different kinds of host plants attacked. In years when this pest was abundant a very wide number of host plants were attacked and plants which are very rarely attacked under lower population levels have been recorded as host plants of the melon fly. These records have at times raised questions as to whether or not a recorded plant is a host of this pest.

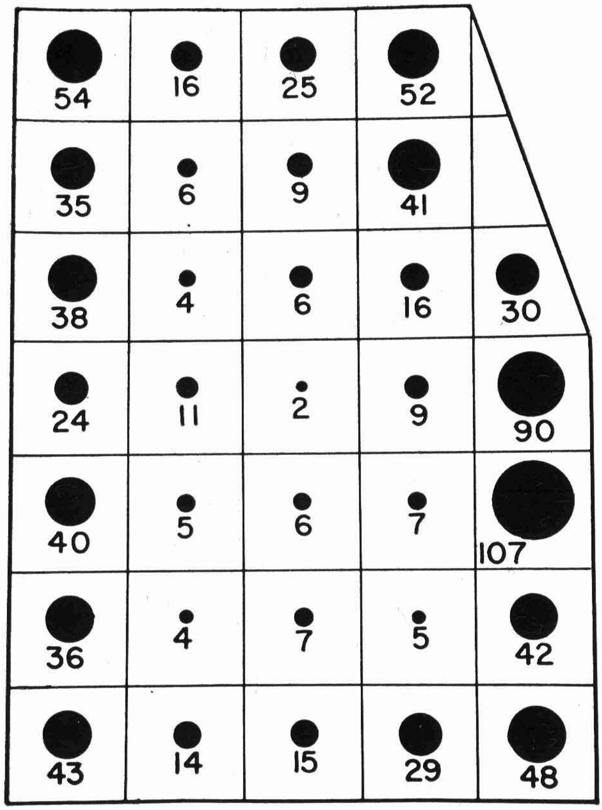

FIGURE 10. Variation in abundance of stung fruits in different parts of a tomato field. Sizes of dark circles are roughly proportional to the number of stung fruits per 25 X 45 foot blocks. Figures below each circle represent actual number of stung fruits.

The variation in susceptibility of the host plant also influences the extent to which fruits are attacked. The most favored plants are in the Cucurbitaceae, a family which contains crop plants such as watermelons, cantaloupes, cucumbers, and squashes. When these crops are planted within the same area with a less susceptible crop such as the tomato, the cucurbits are invariably attacked to the greatest extent.

Fruit maturity as a factor of susceptibility to attack was investigated. It has been observed that as the fruit approaches maturity it becomes less susceptible to attack. In order to determine whether hardness of the rind was the factor a series of tests were made to determine whether the hardness of rind increased as the fruit matured. Size was used as a measure of maturity on the assumption that the larger fruits were closer to maturity than the smaller ones. To obtain an index of size, the diameter of tomato fruits and the length of cucumber and watermelon fruits were measured. Fruits of various sizes were collected in the field and the resistance to puncture

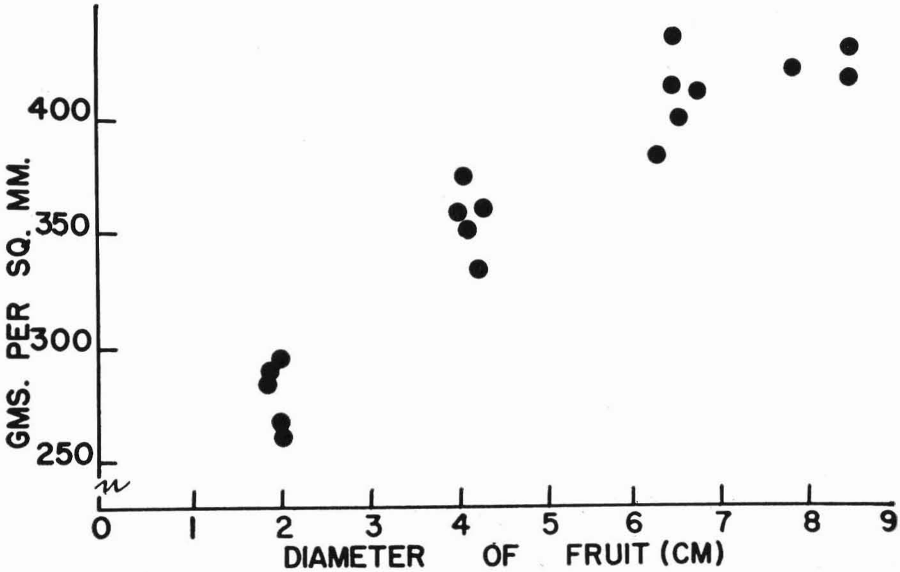

FIGURE 11. Relationship between fruit size and resistance to puncture with a corn tester.

measured by means of a corn tester. The results of these tests, shown in figure 11, indicate that the resistance to puncture increased with fruit maturity. In addition to these data, field observations also indicate that hardness is a factor which affects the susceptibility of attack. In certain fruits such as the tomato and watermelon oviposition occurs in any part of the immature fruit, but in the mature fruit oviposition occurs almost entirely in the calyx scar or in cracks and wounds. Although hardness of rind probably accounts for much of the difference in oviposition between immature and mature fruits, it does not account for the differences in oviposition observed among immature fruits. In figure 12 is shown the percentage of stung fruits in various size categories of immature tomato and cucumber fruits. It is evident that the incidence of stung fruits was not highest in the smallest fruits even though they are the least resistant to puncture.

The problem was studied further to determine the effect of the abundance of fruits available to the ovipositing females on the incidence of stung fruits. In the field cucumber fruits of various sizes were examined to determine whether or not they were stung and each fruit measured. The data obtained were then plotted to show the relationship between the proportion of total fruits in the respective size ranges and the percentage of stung fruits. It is apparent from figure 13 that the percentage of stung fruits increased, though not linearly, as the proportion of fruits in the respective size categories increased. It is evident that the percentage of stung fruits depended upon the number of fruits available to the gravid female or upon frequency at which the fly encountered the fruits.

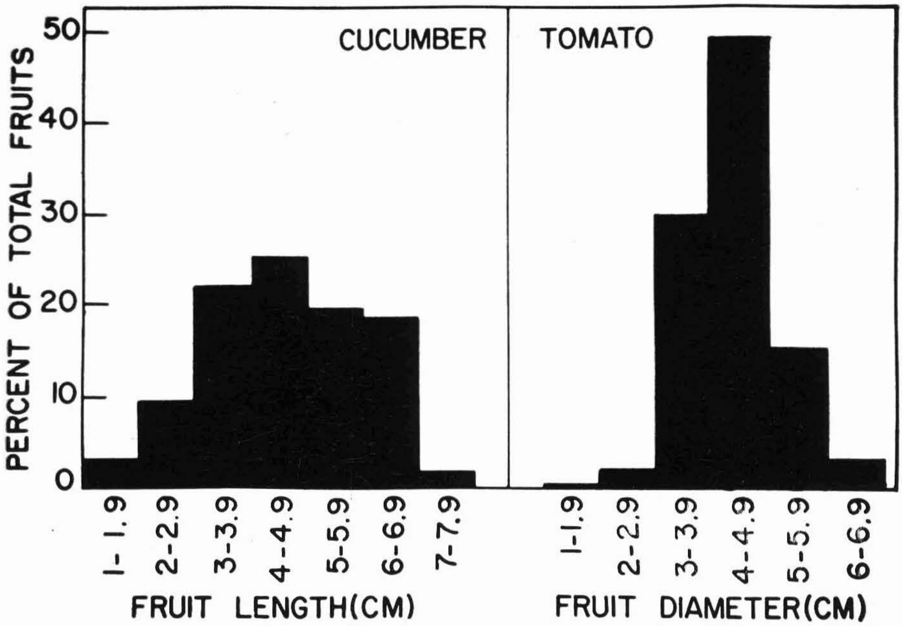

FIGURE 12. Proportion of stung cucumber and tomato fruits in various size categories.

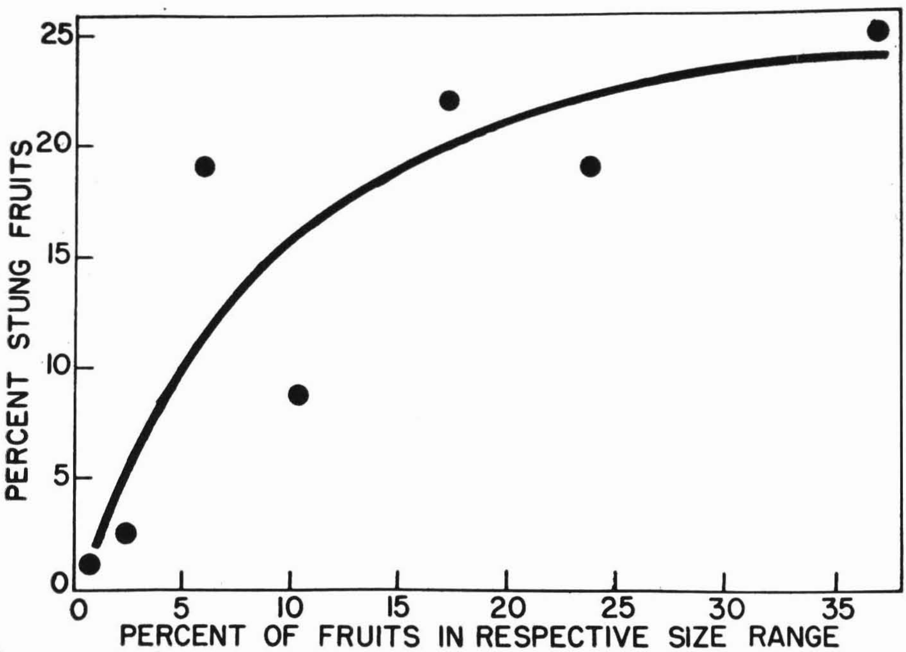

FIGURE 13. Relationship between the percentage of stung watermelon fruits and the proportion of fruits in the various size categories.

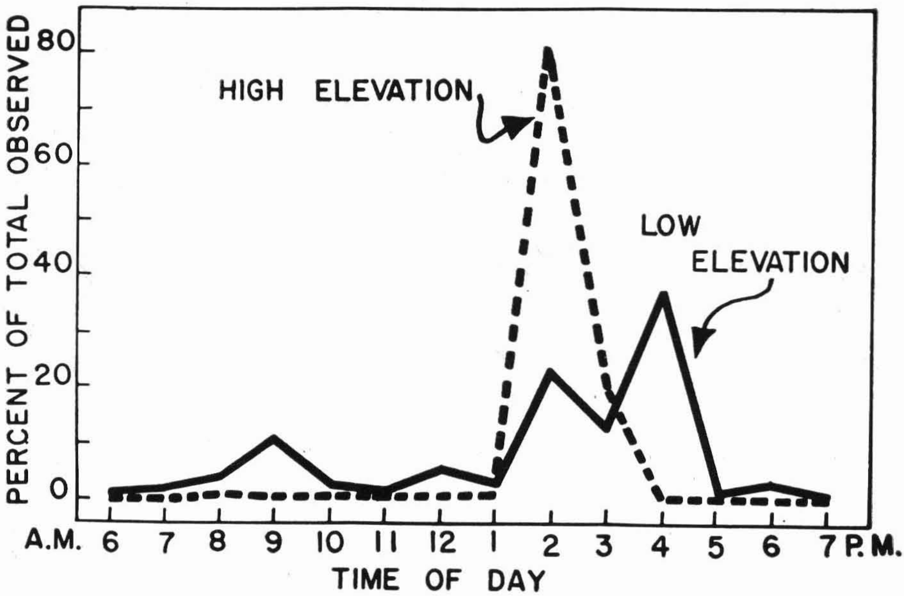

FIGURE 14. Changes in ovipositional activity of the melon fly during the day at high and low elevations.

Diurnal ovipositional behavior

The diurnal ovipositional behavior was investigated during the summer months in the lowland areas of Waianae, Oahu, and Baldwin Packers, Maui, and in the high areas of Kula, Maui, at an elevation of 3200 feet. In melon and cucumber fields in which only very young fruits were present transect lines approximately 100 feet long were staked out. Along these lines all fruits and vines within five feet on each side of the lines were examined from morning till evening at intervals of one hour and all adults in the act of ovipositing counted.

Data obtained in this manner (fig. 14) indicate that egg laying was greater during the afternoon hours than at any other time both in the lowland and high areas. In the lowland areas, however, ovipositional activity began as early as 5 to 6 a.m., increased slightly during 8 to 9 a.m., declined during 9 to 12 a.m. and increased markedly during the mid-afternoon hours. A few individuals were found ovipositing as late as 7 p.m. In the high areas the trend was slightly different. Here ovipositional activity did not occur until as late as 2 to 3 p.m. and it ceased completely by 4 p.m. Consequently, the duration of the period of ovipositional activity in the high areas was only about three hours, whereas, in the low coastal areas the activity continued at varying intensities almost the entire day.

These differences in the ovipositional activity patterns are no doubt related to ecological differences between the areas concerned. Of prime importance appear to be temperature and sunlight intensity. In the coastal areas the early morning temperatures are never too low to inactivate the adults and consequently, ovipositional activity begins at an early hour in the morning and continues until mid-day when the activity decreases. Oviposition is resumed again during the late afternoon when sunlight becomes less intense. Activity in the evening ceases when the absence of light probably becomes the critical factor. At elevations of 3200 feet in Kula the morning temperature during the summer drops to approximately 59° F. at 6 a.m. At this hour there was adequate light but the adults remained inactive under foliage. When the plants were shaken the adults fell to the ground and were unable to fly. Even after sunrise, the temperature in the sheltered spots where the adults were present remained low for some time and hence, the flies did not become active for several hours after sunrise. After the temperature had risen sufficiently to activate the flies, light became so intense that they remained for the most part in the shade. It was not until 2 to 3 p.m. that ovipositional activity reached its peak. At this time the entire western slope of Haleakala is covered by a heavy blanket of cloud which drifts inland from the south daily with great regularity. In addition, under conditions of heavy overcast and slight drizzle in lowland areas many females were observed ovipositing during mid-day hours.

Fly Populations in Abandoned and Cultivated Fields

A great variability in the abundance of melon flies on different farms has been frequently observed. To determine some of the causes of this variability population trends were studied on several individual farms at Waianae and Waimanalo during 1951. These studies showed that the fly population was in many cases correlated with cultural practices. On those farms on which crops susceptible to melon fly attack were grown successively for long periods, melon flies were more numerous than on those on which crops were grown sporadically. Increase in melon fly abundance on certain farms was associated with an abundance of host material in which the fly breeds and suitable shelter plants, which may also provide adult food such as glandular exudation, pollen, and honeydew from certain homopterous insects. Frequent plowing and irrigating promote the growth of succulent herbaceous weeds of the type favored by the adult fly as roosting or shelter sites and from which they obtain food. In addition certain non-host crops grown by farmers also provide suitable shelter plants and food. However, when such favorable crop areas were abandoned there was a disappearance of both host fruits and plants with which the adults are associated. Correlated with this change was the disappearance of the melon flies. Apparently as conditions became unfavorable due to lack of fruits and favored plants, the melon fly dispersed into other more favorable areas.

FIELD EXPERIMENTS ON CHEMICAL CONTROL

To bring into focus some of the problems, objectives, and approaches pertaining to the chemical control of the melon fly, some aspects already discussed in previous sections will be recapitulated. In a broad sense the melon fly occurs principally in those areas devoted to the production of diversified crops. These crops are not planted at the same time during any particular season; and hence, there are small scattered plants of various crops such as tomatoes, watermelons, and cucumbers throughout the year. Outside of these plantings the plant cover is principally non-host plants including annual and perennial weeds as well as volunteer cultivated plants. The melon fly, which breeds in crops grown by the grower, moves into these weeds soon after emergence. Consequently, the melon fly is found in largest numbers among certain favored plants. When gravid, the females move during the day into crop areas where egg deposition occurs in the crops concerned and they move back into the weeds in the evening. The principal problem that confronts the grower is how these migrating females can be destroyed so that egg deposition in the crop to be protected will not occur.

The above mentioned considerations suggest two approaches to the problem of chemical control of the melon fly: (1) the application of the insecticide to the crop to be protected and (2) the application of the insecticide to plants with which the adults are closely associated. The first approach has been found to be ineffective. For reasons not clear at the present time, the application of a toxic residue to the crop has been inadequate to afford protection against melon fly attack. In general the second approach has been more successful than the first in reducing the fly population within localized crop areas and thus reducing melon fly damage. The results obtained using this approach in controlling the melon fly attacking tomatoes, cucumbers, and watermelons are presented in this section. These investigations were conducted since 1949 in various areas of Oahu where crops susceptible to melon fly attack are grown commercially. Certain aspects of these investigations have already been reported (Nishida and Bess, 1950; Ebeling *et al.*, 1953; Nishida, 1954*a*; and Nishida, 1954*b*).

Methods and Materials

In all the experiments the so-called "border" treatment method was employed. This method entails the application of an insecticide to all plants that harbor flies, both inside and outside the crop areas, rather than the application of the insecticide to the crop which is to be protected. Plants that harbor flies have already been discussed and are listed in table 1.

The treatments were made with power sprayers mounted on a truck. The sprayers included conventional power sprayers that developed a pressure of at least 250 psi at the pump and delivered five gallons of spray per minute as well as a large Lawrence mist sprayer (fig. 15) which delivered a concentrated insecticide spray in a blast of air at the rate of 48 gallons of insecticide per hour. In applying the insecticides the truck was driven around the periphery of the field and the spray directed onto the plants that harbored flies. The materials used were both emulsions and wettable

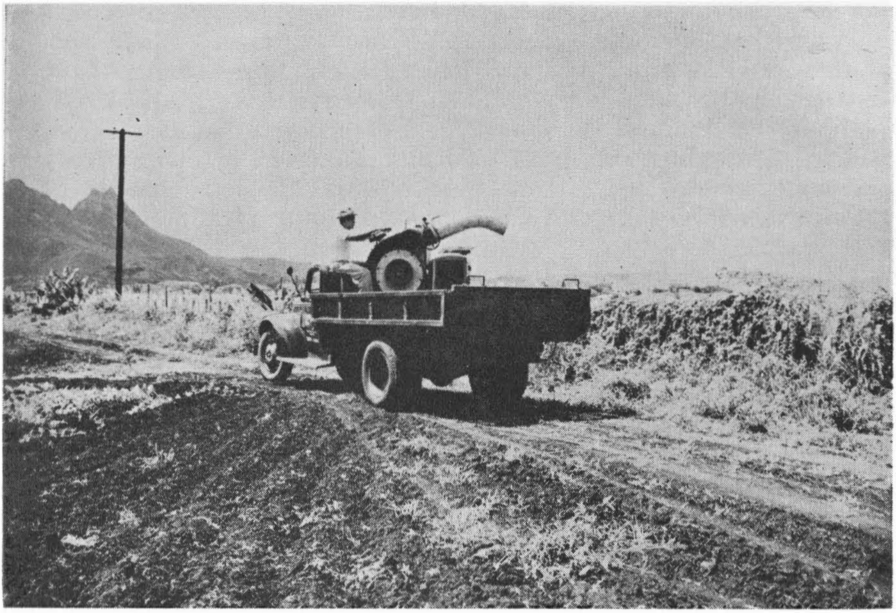

FIGURE 15. A Lawrence mist blower mounted on a truck. Applications of insecticides were made by having one man drive the truck along the periphery of the field while the other directed the spray into the surrounding vegetation.

powders of DDT, parathion, and malathion. The concentrations and the formulation used are given under their respective experiments.

The evaluation of the effectiveness of the treatments was based on the percentage of infested fruits in samples taken from various parts of the fields. In establishing a criterion of damage, each fruit which showed evidence of melon fly damage was considered infested regardless of whether or not it contained eggs or larvae. The size of the cucumber fruits sampled ranged from 3 to 10 cm. in length; that of the tomato, 2 to 4 cm. in diameter; and that of the watermelon, 2.5 to 8 cm. in length. As a basis for comparison, where possible, parallel data were taken from both border-treated fields and from fields without such treatment. Where the latter were unavailable the evaluation was based on comparisons between pre-treatment and post-treatment data.

In addition, in certain experiments traps were also used to measure the effectiveness of the treatments. The traps used were the glass invaginated traps, which are known locally as McPhail traps. The lure used was a fermenting type which contained 1 pound of sugar, 2 cakes of Fleischmann's yeast, and 50 cc. of vinegar per gallon of water. Traps containing this lure were suspended on wooden stakes in the field at about 8 to 12 inches above the ground. The traps were examined at intervals of twice a week and fresh lure placed in the traps at weekly intervals. It was found that trap catches could be correlated with treatment; however, they could not be satisfactorily correlated with infestation. This lack of correlation indicates that infestation is not necessarily correlated entirely with fly abundance as measured by traps. Besides fly abundance, the extent of infestation may be influenced by the abundance of fruits available for oviposition. For example, in a small field even a very low population can damage a very high proportion of fruits. However, in a very large area this same population can cause only a small amount of damage. Trap records, therefore, were taken as a supplement to infestation data whenever possible.

It was not feasible to use randomized field-plot techniques in these experiments because of the small size of the available fields and the intra-field movements of the fly (Ebeling *et al.,* 1953). Rather than subdividing a field into plots, the entire field was considered an experimental unit. The use of individual fields as experimental units made it necessary to limit the number of replications. This limitation, although inevitable, is an obvious weakness in the procedure used as there is usually variation in fly population between fields largely due to differences in the kind and condition of the vegetation present and also to the frequency at which susceptible crops were grown in the immediate vicinity. However, in areas where these studies were made, the fly population in any individual field was usually high enough to cause appreciable damage in the absence of satisfactory control practices.

Preliminary tests designed to determine the effectiveness of the mist blower in killing adult flies were made in 1948. These tests consisted of (1) making visual counts of adults on *Crotolaria* plants, (2) treating the plants, and (3) counting the adults again after the treatments. The results from one of these tests in which a 10 percent DDT emulsion was applied show that most adult flies were effectively destroyed (table 4). Possibly, some of the adults escaped without being killed; however, the presence of many dead individuals on the ground indicated that the reduction in the number of adults on the treated plants was largely due to kill rather than to their escape into other untreated areas.

Experiments on Tomatoes

The first experiment on the control of the melon fly was conducted in a 3-acre tomato field at Waianae, Oahu. The predominant vegetation around this field was Pigeon Pea (*Cajanus cajan* Millsp.), *Datura stramonium* L., *Euphorbia geniculata* Ortega, Koa haole (*Leucaena glauca* (L.) Benth.), and *Momordica balsamina* L. on which there were many adult flies, particularly on the first three plants. A 10 to 12 percent DDT emulsion was applied to the border vegetation by means of the mist blower at intervals of about once a week. The spraying was usually done in the morning before sunrise. At the time the experiment was initiated, the largest fruits were about two inches in diameter, and practically all fruits were being stung even though the crop was being dusted twice a week with a 3 percent DDT dust. The dustings were, however, discontinued three days before the first mist blower treatment was made. After four applications

TABLE 4. Number of melon flies on individual pigeon pea plants before and after applying DDT with a mist blower

Plant No.	Before Treatment	30 Min. After Treatment	24 Hrs. After Treatment
1	10	0	0
2	8	0	0
3	18	0	0
4	22	0	0
5	29	0	0
6	40	0	0
7	25	0	2*
8	15	0	4*
9	40	0	1*
10	35	0	3*

*Plants near fruit dump.

10 samples of 25 fruits each were taken each week for the following three weeks to determine the degree of infestation. At the same time similar fruit samples were also taken from three check fields located less than a mile away. The tomato crops in these check fields were dusted twice a week with DDT throughout the period. The result showed that the average percentage infestation of the samples from the test field was 2, 2, and 4 percent and that from the check fields was 68, 63, and 63 percent. These results were especially encouraging because they were obtained in an area where there was widespread damage by the melon fly in the entire area.

Following this experiment, another one was conducted using a series of tomato fields bordered by succulent wild plants favored by the melon fly, chiefly fuzzy rattle-box (*Crotolaria incana* L.), Jimson weed (*Datura stramonium* L.), and cocklebur (*Xanthium saccharatum* Wall.). The plants along the periphery of the tomato field, designated as the treated field, were thoroughly sprayed with parathion at a concentration of 1 pound of a 25 percent wettable powder per 100 gallons of water at intervals of roughly once a week. The check fields received no border treatment, but the tomato plants were sprayed with DDT at irregular intervals ranging from twice a week to once in 10 days. At the time this study was initiated there were young fruits on the plants, and data on infestation were taken before the first border treatment and four times thereafter from the treated field and check field C. Only three records were taken from check field B.

The results showing the differences in infestation trends between the treated and check fields are presented in figure 16. Prior to the initial treatment 27 percent of the fruits sampled were infested in the treated

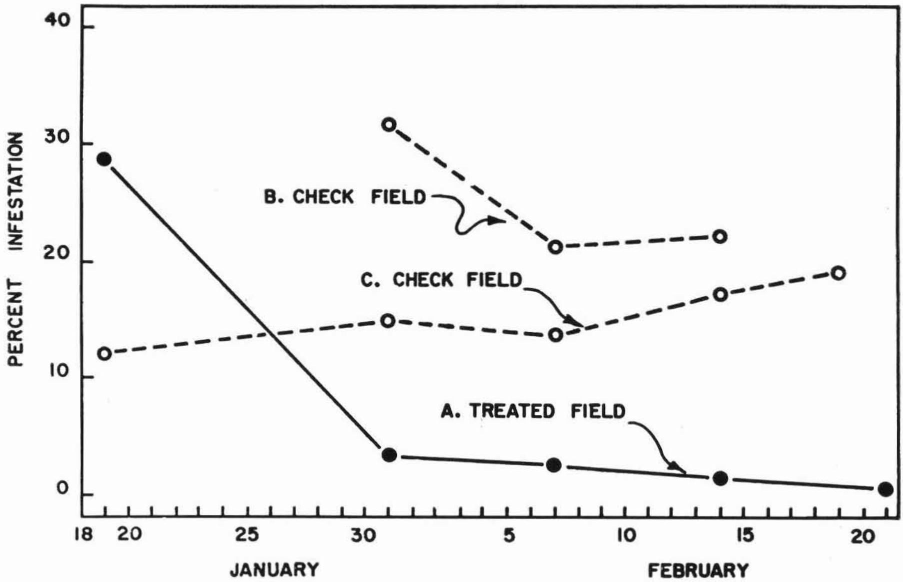

FIGURE 16. Percentage of stung tomato fruits in border-treated and check fields.

field. After the first two treatments the infestation was reduced to 3 percent. The four treatments made thereafter caused a slight but consistent decline in the percentage of damaged fruits. In check field C, the initial infestation was lower than that of the treated field, but it showed no decline. In check field B, the percentage of infestation declined, but it was appreciably and consistently higher than the treated field.

In addition to the infestation data, at various intervals throughout the experimental period, counts were made on the number of adults that were seen along the border-treated field. Prior to the first treatment 75 adults were counted per 200 feet of border. One week after the first treatment only 3 adults were observed. Similar counts made subsequently at various intervals showed that the number of adults did not exceed 4 except on one occasion when 15 were suddenly counted. However, the treatment made on the following morning brought the adult count down to 2 and thereafter it never exceeded 2 per 200 feet of border plants.

Experiments on Cucumbers

A series of five fields ranging from 1/4 to 1 acre in area were used in experiments on the control of the melon fly attacking cucumbers. The bordering vegetation of two fields, designated as fields D and E, was sprayed by means of a conventional sprayer with parathion at a concentration of 1 pound of a 25 percent wettable powder per 100 gallons of water at intervals of roughly twice a week from the time the runners appeared up to the time of harvest. During the harvest period the frequency of treatment

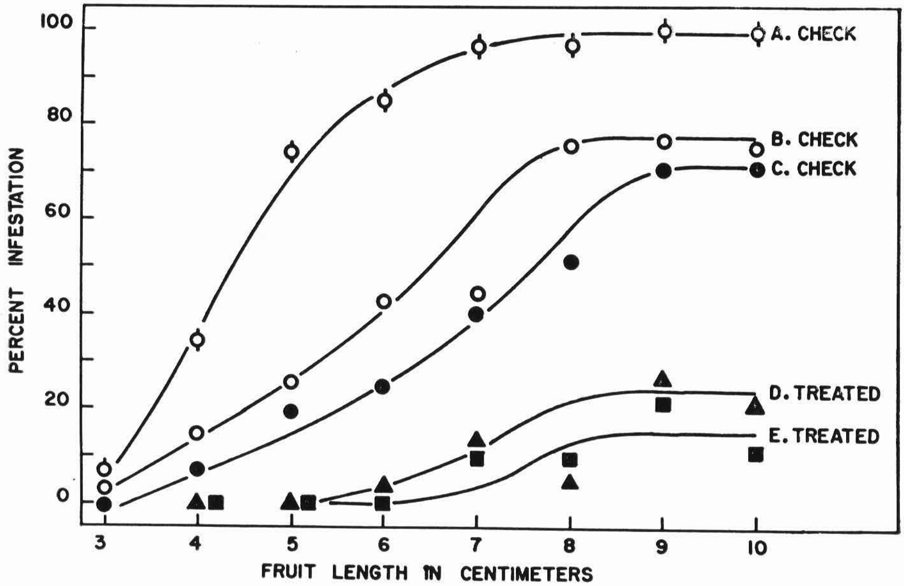

FIGURE 17. Effect of border-treatments on the percentage of cucumber fruits punctured by the melon fly.

was reduced to once a week. The kind of vegetation bordering these two fields was typical of many lowland areas on Oahu where cucumbers are grown commercially. Field D was bordered on three sides by a corn field. The vegetation along the fourth side consisted of a narrow strip of miscellaneous weeds along a roadside. In field E, a few volunteer corn plants were present, but the vegetation bordering it consisted of wild plants, chiefly fuzzy rattle-box (*Crotolaria incana* L.), spiny amaranth (*Amaranthus spinosus* L.), and castor bean (*Ricinus communis* L.).

The remaining three fields, designated as fields A, B, and C in which no border treatments were made, were check fields. The cucumber plants in these fields were sprayed with parathion at a concentration of 1/4 to 1/2 pound of a 25 percent wettable powder per 100 gallons of water. The frequency of application varied from twice a day to once every 3 days.

The infestation data obtained from border-treated and control fields, shown graphically in figure 17, revealed that the percentage of stung fruits in the border-treated fields was considerably lower than that in the control fields. In the check fields where the crops were sprayed, but not the border vegetation, even the very young fruits were infested. However, in the border-treated fields, infestation did not take place until the fruits were 6 to 7 cm. long. It was observed that in the check fields where the cucumber crop was treated the plants showed evidences of insecticidal injury, particularly in fields where frequent applications were made. The foliage of the injured plants appeared grayish white, and the fruiting period of these plants

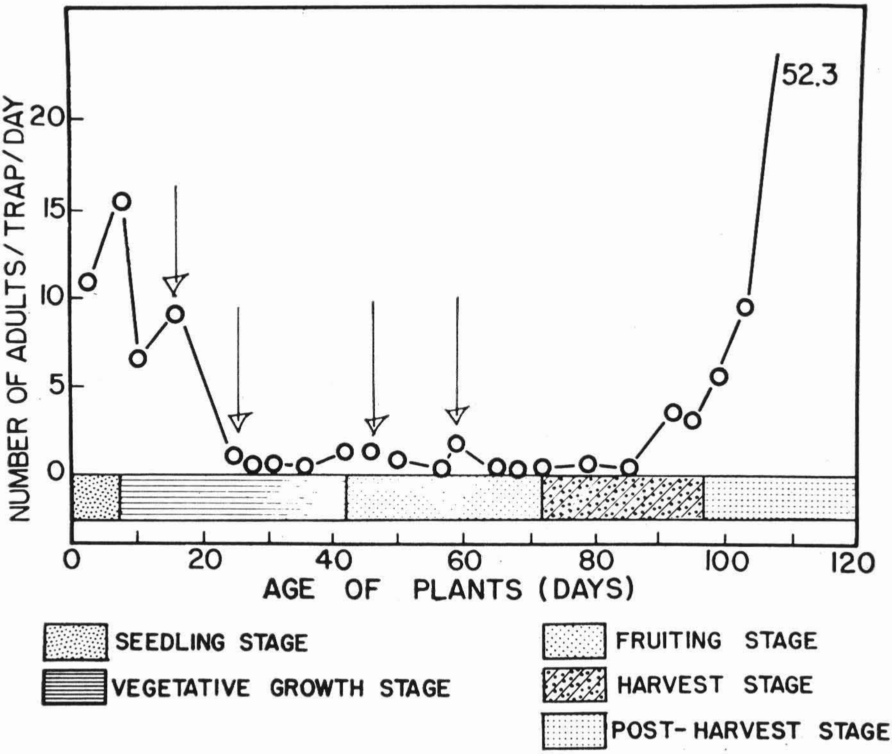

FIGURE 18. The effect of malathion applied on border vegetation by means of a mist blower on the population of melon fly. Arrows indicate dates of treatment.

was very much shortened. Although no yield data were obtained, it was apparent that, because of the combined effect of fly damage and the adverse effect of the insecticide on the plant, the yield of plants in the check fields was less than that in the border-treated fields. It should be mentioned, however, that although the data show that the percentage of stung fruits was as high as 100 percent in one of the check fields, the farmer did not lose that proportion of his crop because not all fruits decompose when stung and, furthermore, fruits with oviposition scars are marketable even though they are not of the best quality.

Experiments on Watermelons[1]

Studies on the control of the melon fly attacking watermelons were made during 1957 in two fields, one 3 and the other 7 acres. These fields were bordered on all sides by various species of plants, including castor bean

[1] The malathion supplied by the American Cyanamid Company and the field assistance of Dr. Ryoji Namba, Assistant Entomologist, Hawaii Agricultural Experiment Station, and Assistant Professor of Entomology, University of Hawaii, are gratefully acknowledged.

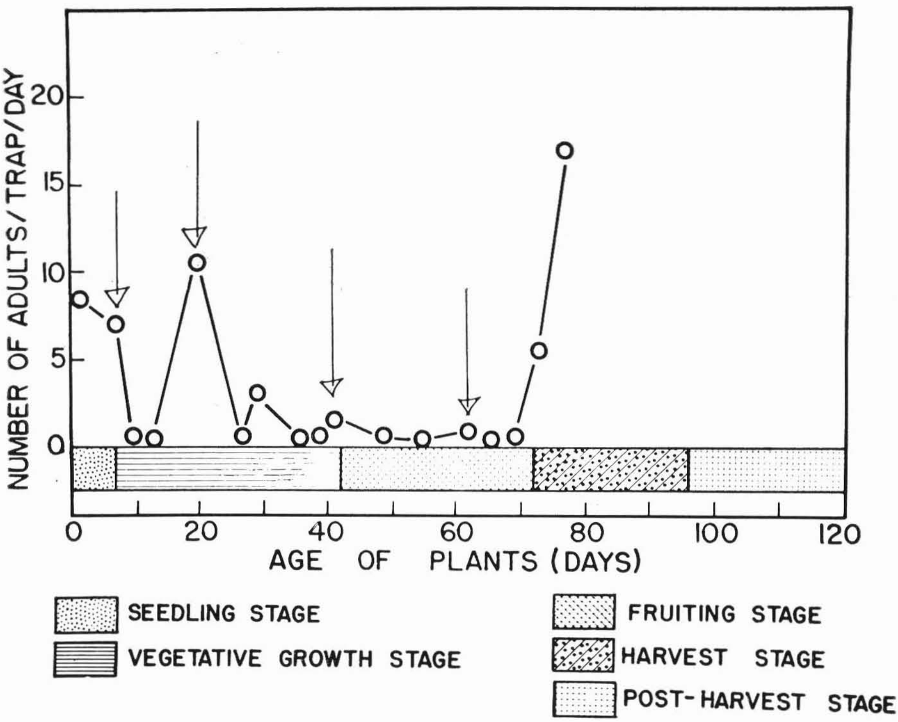

FIGURE 19. The effect of malathion applied on border vegetation by means of a mist blower on the population of melon fly. Arrows indicate dates of treatment.

(*Ricinus communis* L.), corn (*Zea mays* L.), balsam apple (*Momordica balsamina* L.), spiny amaranth (*Amaranthus spinosus* L.), and para grass (*Panicum purpurascens* Raddi). These plants were sprayed with malathion emulsion at concentrations ranging from 0.5 to 4 percent by means of a Lawrence mist blower.

To determine the effectiveness of the treatments, indices of fly abundance were obtained by means of the glass invaginated traps containing fermenting lure. Eight traps were placed among the watermelon plants along the periphery of each field. These traps, which were in continuous operation from the beginning to the end of the crop, were examined before and after each treatment. The frequency of application was based on need as indicated by a rise in the trap catch. In addition, data were taken periodically on the extent of damage to melon seedlings, terminal shoots, and fruits from various parts of the field.

The data on trap catches (figs. 18 and 19) indicated that in both fields A and B there was a decline in trap catch with each application. It can also be seen that the treatments reduced the fly population during the vegetative growth period to such an extent that by the time the plants had begun to fruit the population was reduced markedly. However, after the treatments were discontinued there was an increase in trap catches. This increase indicates that the fly population would have been considerably higher than that shown in figures 18 and 19 if no treatments were made at all.

The data obtained on the infestation also indicated that the treatments were effective. The damage to seedlings was negligible even though the trap catches were highest during that stage. The damage to terminal shoots of the mature vines ranged from 0.5 to 0.8 percent. The damage to the young melon fruits amounted to about 7 percent, a figure comparable to that obtained by Ebeling *et al.* (1953) in a similar experiment. Comparative data from nearby fields which received no border treatment were not available because all farmers in the area covered their fruits.

The data shown in figures 18 and 19 indicate another important point. They show that the adult flies were present in the vicinity of the crop areas at the time of planting the seeds or even prior to it. Such information suggests that early treatment, even before planting, to destroy the adults present in the wild vegetation may be worthwhile in controlling the melon fly.

Discussion

Among the insects of truck crops in Hawaii, the melon fly is without doubt the most destructive insect and also the one most difficult to control. The female of this pest possesses a high egg-laying capacity and also has the ability to move rapidly from fruit to fruit. Thus, a single female is capable of stinging and destroying a great many fruits during her lifetime. Because of these characteristics, the level of fly abundance (often referred to as the "economic threshold") that must be maintained throughout the crop period by use of insecticides is exceedingly low. For example, an average population index of 0.5 fly per trap per day resulted in a damage of 7 percent of young watermelon fruits. Usually in crops which bear large numbers of fruits, such as tomatoes and passion fruit, economic control can be obtained by less drastic reduction in fly population than in highly susceptible crops, such as cantaloupe and watermelon which bear relatively few fruits.

It has been shown that there is a marked decline in melon fly population in localized crop areas following the application of insecticides to vegetation with which the flies are associated. The mechanism as to how this reduction is brought about is largely speculative at the present time. To a certain extent this reduction might be due to the presence of a large part of the population among certain plants and where many adults are killed by space action at the time of application. Residual action may play an important role in such situations because of the close association between the adults and the treated plants. Due to this close association the flies may acquire toxic residues by merely walking over the treated surface. They may also ingest toxic residues by their habit of regurgitating droplets of liquid and taking in the contaminated droplets again. Toxic residues may also be ingested by their habit of extending the proboscis and touching the treated leaf surface periodically as they walk. Such action no doubt would result in the entry of the residue into the insect through the mouth. It should also be mentioned that when the insecticides are applied to plants which harbor the flies, dewdrops, pollen, honeydew, feces of birds and plant exudations are contaminated with the sprayed insecticide and flies feeding on them would be killed. Finally, it should be pointed out that when insecticides are applied to the vegetation favored by adults, the honeydew-producing insects are no doubt destroyed, thus cutting off an important food source of the melon fly.

The failure to obtain satisfactory control when residual crop treatments are made is an anomalous situation about which little is known. This failure was ascribed to the inability of the gravid females to "pick up" lethal amounts of the toxic residue by Ebeling *et al.* (1953) for they found that although the treatments failed to control the melon flies, those flies caged on the treated cucumber plants gave a 100 percent kill. Gravid females, apparently stimulated by certain ovipositional stimuli, enter the field when ready to oviposit. They apparently do not remain on the treated plants for long periods and do not carry on activities such as regurgitating and feeding to the same extent on crop plants as they do on plants with which they are closely associated.

Variation in the effectiveness of control has been observed in different fields. In some fields, adequate control has been obtained with relative ease, often with only few applications. In others, however, control has been very difficult requiring frequent applications. These differences exist because of the differences in the fly population and also the distributional patterns and abundance of the favored plants in the vicinity of the crop areas. Treatments would be most effective when the adult population is localized in small areas along the edges of the field as shown in figure 7*A*. However, in situations where the fly population is widespread (fig. 7*D*) and beyond the effective range of the equipment on hand, control would be difficult, more frequent treatments would be necessary, and probably less effective control would be obtained.

In situations where favorable plants do not occur in the immediate vicinity of crop areas, control is often difficult. Under such circumstances it may be desirable to plant certain plants such as corn, *Crotolaria,* and castor bean. Such plantings need not surround the crop completely; they may be planted in clumps or rows at various intervals throughout the field. In situations where wild plants suitable to the adults are present, there is no advantage in planting additional plants. Furthermore, when favorable wild plants were present, the treatment of the corn plants alone when such plants were planted was not adequate to give satisfactory control. It is necessary, under such a situation, to treat the corn plants as well as the wild vegetation.

In addition to those mentioned in this bulletin other insecticides may be used, for it has been shown by Ebeling (1953) that many insecticides are toxic to melon fly adults. Comparative field tests have not been made; hence, the relative merits of each of the insecticides are not known. Factors such as toxicity to the fly, health hazards to the operators, and cost must be taken into account before specific recommendations can be made as to the best insecticide to use.

The method of controlling the melon fly by treating plants favored by the adults has its advantages and limitations. Its principal advantages are: (1) elimination of toxic residues in the produce, (2) elimination of phytotoxic effects of the insecticides on the crop, (3) elimination of the possibility of destroying pollinating insects, and (4) rapidity of treatment. Its limitations are: (1) the degree of control in small areas such as in backyard conditions is not as high as to be desired, (2) the investment in insecticides and power equipment in small plantings would be far in excess of the value of the crop, and (3) power equipment would be necessary.

In conclusion it may be stated that the method of controlling the melon fly by spraying plants which harbor the adults is a means of utilizing insecticides in an effective manner. Its limitations exist not because the method is faulty in principle but because the insecticides may be inadequate in certain situations.

SUMMARY

The melon fly is a serious pest of many truck crops such as tomatoes, cucumbers, cantaloupes, squashes, and watermelons. The damage is caused by the females depositing eggs in the plant tissues and the maggots hatching from the eggs feeding on the tissues. On Oahu, during 1951, the incidence of stung fruits in tomato crops ranged from 2 to 40 percent and in cucumber crops from 10 to 100 percent. The melon fly is also a serious pest in other areas: China, Formosa, Okinawa, the Philippines, Malaya, Burma, India, Ceylon, Mauritius, Kenya, and Guam.

In Hawaii various methods have been used in attempts to control this pest. These methods are: (1) mechanical control using various protective coverings on the fruits, (2) cultural control using resistant varieties, trap crops, and practicing field sanitation to prevent fly breeding, (3) biological control using natural enemies imported from other countries, and (4) chemical control using insecticides. Mechanical control, although effective, is costly because of the hand labor involved. Biological control has been effective only in the wild areas where the melon fly breeds in the wild *Momordica balsamina* L. fruits. In the cultivated areas, a combination of cultural and chemical control appears to be the most promising method of control at the present time.

Ecological studies on the melon fly revealed information useful in formulating sound control procedures. Some of the pertinent information is: (1) the movement of the newly emerged adults out of the field into the wild vegetation, (2) the diurnal movement of the gravid females into and out of the crop area, (3) the close association of the adults with certain

non-host plants, and (4) the usually higher populations outside than inside of the fields. On the basis of these findings it appeared that the most logical approach to the control of the melon fly was to spray the plants with which the adults are associated rather than the crop to be protected.

Studies on chemical control employing the above-mentioned approach showed that this pest can be effectively controlled by spraying plants favored by the flies. In tomato, cucumber, and watermelon fields, the spraying of favored plants with DDT, parathion, and malathion by means of a Lawrence mist blower and conventional sprayer has resulted in a marked reduction in fly population and a corresponding low incidence of fruit infestation.

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