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ADAP
PROJECT

Agricultural Development in the American Pacific
Pacific Land Grant Programs

HITAHR • COLLEGE OF TROPICAL AGRICULTURE AND HUMAN RESOURCES • UNIVERSITY OF HAWAII

PREFACE

The Crop Protection Conference was sponsored by the USDA funded project **Agricultural Development in the American Pacific (ADAP).** Its overall purpose was to provide crop protection researchers in the Pacific Basin an opportunity to share recent findings as well as provide a forum for issues of impending interest. ADAP participants include researchers from Hawaii, Guam, Federated States of Micronesia, Northern Mariana Islands and American Samoa. The symposium topics, *Determining Impact of Pest Injury on Crop Yields* and *Methodologies of Rearing and Introducing Biological Control Agents*, were selected by the ADAP researchers to assist them in addressing important problems in the Pacific Basin. We hope that ll participants found the conference to be a valuable and rewarding xperience.

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WELCOME

AGNES M. VARGO

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The first Agricultural Development in the American Pacific (ADAP) Conference is a landmark achievement for the Land-Grant Colleges and Universities of Oceania. Conceived by the *ADAP Crop Protection Taskforce*, it is the result of collaborative efforts between scientists of both Oceania and the U.S. Mainland.

The Crop Protection Taskforce was established in the initial phases of the development of the ADAP Project by the Pacific Land-Grant Directors. It is composed of a representative from each of the Land-Grant Institutions in the American Pacific. These Institutions include the College of Micronesia, College of Northern Marianas, University of Guam, University of Hawaii at Manoa, and American Samoa Community College. Early on, it was evident that a forum was needed for the formal presentation of research results, and for interaction among researchers from these remote institutions. A conference was suggested as the mechanism to meet this need.

Several people were instrumental in making this conference a reality. First, my sincere thanks to Dean Noel P. Kefford, College of Tropical Agriculture & Human Resources, University of Hawaii at Manoa, who spearheaded the development of ADAP, and the supporting Directors at each Land-Grant Institution. Their cooperative efforts were crucial to the successful establishment of the project. I also wish to acknowledge the leadership of Director Ishmael Lebehn, Land-Grant Program, College of Micronesia, Pohnpei, who served as the first Crop Protection Taskforce Coordinator. Thanks are also extended to Linda Hamilton and her staff, College of Tropical Agriculture & Human Resources, University of Hawaii at Manoa, for all the assistance provided in organizing the conference.

The logistics of setting up a conference such as this is a tremendous undertaking. So it is with warmest thanks that I acknowledge the outstanding efforts of Marshall W. Johnson in his role as lead coordinator. His mark of excellence was seen in all aspects of this conference, from designing the announcements to recruiting renowned leaders in integrated pest management as conference speakers. Finally, I would like to thank all the presenters and participants for their hard work and preparations. By allowing us to share research findings and providing for open and lively discussions, we hope this conference has opened the door to future inspirations and discoveries that will benefit us all.

THE ROLE OF ADAP IN THE FUTURE OF AGRICULTURE IN THE AMERICAN PACIFIC

NOEL P. KEFFORD

Chairman, American Pacific Land-Grant Directors
Dean, College of Tropical Agriculture and Human Resources
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The Agricultural Development in the American Pacific (ADAP) project had its origin in the recognition that the Land-Grant institutions in the American Pacific can best achieve their missions through cooperation. If these institutions were to carry out their roles locally and regionally, additional funding was needed to assist them, particularly as some of the institutions had achieved Land-Grant status very recently. Special financial attention was needed because the new institutions must bring their agricultural industries to a competitive condition, comparable with states on the U.S. Mainland that have benefited from the activities of a Land-Grant institution for decades. At the regional level, the costs of interaction and cooperation across thousands of miles of ocean were much greater than is the case in mainland regions.

Clearly, gaining the support of the USDA was necessary for subsequent funding from the U.S. Congress. This was obtained in 1985 when the Administrator of the Cooperative State Research Service (CSRS), Dr. John Patrick Jordan, visited Hilo, Hawaii. A group of us gathered for dinner at a local restaurant and described our plans for the manifestation of the Land-Grant theme in the American Pacific. He was immediately supportive. He advised us to prepare a sound case and to be persistent in seeking funding -- I recall him saying "Take *no* to mean *maybe* and *maybe* to mean *yes*."

Initiation of ADAP did not require too much persistence; a proposal for a planning grant was submitted in 1986 and funded in 1987. However, persistence will be needed to establish permanent funding and a broader base of support.

The program of ADAP has some unique features. It returns to the basic Land-Grant theme of integrating research, extension, and instruction. It has the vision of agriculture contributing optimally to the culture and society that the citizens of each of the units of the American Pacific desire. It recognizes that the achievement of this vision will require cooperation between the units and federal government agencies. It dares to organize close cooperation across the vast reaches of the Pacific Ocean.

ADAP does not exist to support Land-Grant institutions; it exists to help these institutions play their unique roles in building societies. The foundation of these Pacific societies, as they evolved over hundreds of years, was agriculture and fisheries. This foundation must be rebuilt for new societies based on values that the people determine.

ADAP is funded, is in operation, and is building the needed infrastructure of communications, human resources, planning, and management through various *Task Forces*. In addition, some of the critical program areas have been defined. One of these, crop protection, is in your hands. You have the opportunity to express the spirit of cooperation and to experience the deep satisfaction that comes from accomplishments that only a team can achieve.

I thank the members of the ADAP Crop Protection Task Force for organizing this conference. I wish you, individually and particularly collectively, every success because the vision of ADAP will become reality only through your efforts.

STRATEGIES FOR LIMITING THE SPREAD OF APHID-TRANSMITTED VIRUSES IN ZUCCHINI

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ABSTRACT Aphid transmitted nonpersistent viruses are a serious problem in a variety of cucurbit crops. Zucchini growers in Hawaii frequently experience 100% infection by first harvest. This level of infection represents complete economic loss. A complex of viruses, including Zucchini yellow mosaic (ZYMV), watermelon mosaic viruses 1 and 2 (WMV-1 & WMV-2, respectively) and cucumber mosaic virus (CMV), can be responsible for the epidemic. The viruses are nonpersistently transmitted by several species of aphids.

Aphid landing rates in zucchini field plots were determined using horizontal pan traps positioned level with the plant canopy. Spread of the four aforementioned viruses were monitored using enzyme-linked immunosorbent assay (ELISA). The influence of stylet oil and the synthetic pyrethroid Karate on aphid landing and virus spread was evaluated. Stylet oil significantly reduced virus spread when compared to the control. The pyrethroid did not reduce virus spread when compared to the control although it did delay initial onset of virus.

Stylet oil offers a control measure that does not negatively impact existing integrated strategies for control of other crop problems. Other strategies, including removal of virus sources such as abandoned crops are still critical to management of these viruses.

Aphid-transmitted nonpersistent plant virus epidemics in agricultural ecosystems are among the most difficult plant-pathogenic virus epidemics to control. The difficulty in controlling spread of nonpersistently transmitted viruses is more readily understood when one considers the nature of the aphid-plant-virus interaction that governs successful movement of virus from plant to plant. The transmission cycle is characterized by a series of rapidly occuring events in which a particular aphid species *acquires* virus within seconds of probing an infected plant, becomes immediately *infective* (no latent period), and *inoculates* noninfected plants within seconds of probing. Moreover, short duration probes by aphids have been shown to be most efficient in both acquiring and transmitting nonpersistent viruses (Sylvester 1962).

It follows then, that transient, noncolonizing aphid species are often the most important vectors as they make the greatest number of short probes and move most frequently from plant to plant (Schultz et al. 1985). Colonizing species are generally less important as vectors because they enter a field, make a few short sample probes on a plant and then rapidly settle to feed in one spot for a long period. In addition, they seldom move from plant to plant. Under crowded conditions alate aphids will be produced, but they generally make long flights and do not feed within the colonized field. As a result of the short transmission cycle and the afore mentioned characteristics of aphid behavior, pesticides are seldom effective in limiting virus spread. The aphid transmits the virus so quickly that the damage is done before any pesticide could kill the aphid. Furthermore, alate aphids entering the crop on a continuous basis are little affected by weekly or biweekly pesticide treatments. Indeed, many aphicides stimulate aphid movement prior to death and consequently cause increases in virus spread. Innovative strategies for control need to be aimed at compounds that repel aphid landing, prevent, inhibit or alter probing behavior or that have antiviral properties.

In Hawaii, growers of cucurbit crops cite aphid-transmitted viruses as one of their most important pest problems. For example, zucchini is frequently 100% infected prior to the first harvest date. As a consequence, growers are only able to harvest marketable zucchini for 3-7 days. This is in contrast to 4-6 weeks of harvest in a noninfected crop. Epidemics of similar proportion and economic impact are experienced by watermelon, squash, cucumber and bitter melon growers on Maui, Oahu and Molakai. In Guam, where watermelon is the number one cash crop, growers have experienced increasing problems with aphid-transmitted viruses. The goal of our research is to identify strategies for managing virus spread that can be readily interfaced with effective integrated pest management (IPM) programs that utilize cultural and biological control measures (Johnson et. al. 1989). The focus of this paper will be the preliminary results of field trials which examined the efficacy of JMS Stylet Oil®, a nontoxic oil that alters either aphid probing or virus transmission from aphid stylets, and Karate®, one of a new generation of pyrethroids thought to have repellent properties, in limiting virus spread in zucchini.

Materials and Methods

Zucchini, *Cucurbita pepo* cv. Ambassador, seed was provided by Petoseed Co., Inc.2 . The four treatments included in this experiment were JMS Stylet Oil, Karate, JMS Stylet Oil + Karate, and an untreated

control. A randomized block design was used with 6 replications of each treatment. Plots were planted at the Pulehu site of the University of Hawaii Maui Branch Experiment Station, Kula, Hawaii, during late June 1988. Commercial practices were followed for plant spacing and drip irrigation.

Plots were sprayed with the various pesticide treatments on a weekly basis. JMS Stylet Oil and the combination JMS Stylet Oil + Karate were applied at 100 psi. Karate alone was applied at 50 psi. Aphids were trapped on a continuous basis using modified horizontal green tile landing traps kept at plant canopy level (Irwin et. al. 1987). Aphid traps were emptied 2 times per week from planting through the end of harvest. Plots were mapped and each plant assigned a coordinate. First apparent visual symptoms were recorded from each plant twice per week throughout the experiment. As soon as a plant showed symptoms it was sampled and tested with enzyme-linked immunosorbent assay (ELISA) for the presence of zucchini yellow mosaic virus (ZYMV), watermelon mosaic virus 1 and 2 (WMV-1 and WMV-2, respectively) and cucumber mosaic virus (CMV) (Cho et. al., these proceedings). These data were then used to estimate disease incidence, composition of the viral epidemic, and to determine the relationship between aphid landing and epidemic development. An ANOVA was used to compare aphid landing and disease incidence between treatments.

Results

ELISA results demonstrated that the epidemic in our test plots was dominated by ZYMV. WMV-1 was present, but of secondary importance. Surveys of farmers' fields during a two-year period suggest that this is the trend across the island of Maui (Ullman & Cho, unpublished data). Preliminary results of this experiment strongly suggest that stylet oil delayed initial infection and significantly reduced virus incidence (> 20%) when compared to the untreated control during the last week of the experiment. Karate also delayed initial infection, but following the first infection the rate of virus increase was more rapid in Karate treated plots than in untreated controls. In addition, final disease incidence was slightly higher in Karate treated plots than in the untreated control. There was no significant difference in virus incidence between plots treated with JMS Stylet Oil and plots treated with a combination of JMS Stylet Oil + Karate.

Aphids migrated into the crop continuously although in low numbers. There were no significant differences in aphid landing rates among treatments. *Aphis gossypii* Glover, *Brevicoryne brassicae* (L.), *Aphis craccivora* Koch and *Myzus persicae* (Sulzer) composed 90% of the trap catches. Following first harvest (6th week of experiment), *A. gossypii* was the only aphid species found in traps and their numbers increased significantly. This increase in the number of alate *A. gossypii* trapped corresponded closely to the steepest slope in our disease curves.

Discussion

JMS Stylet Oil clearly reduced virus incidence in zucchini and offered a control measure that does not negatively impact exisiting IPM strategies. Furthermore, it was relatively inexpensive and safe to apply. Aphids were not repelled from landing on plants in any treatments. Reduction of virus incidence in stylet oil treated plots was probably due to changes in aphid probing after landing. Synthetic pyrethroids are somewhat repellent and can stimulate aphid movement and activity. Therefore, decreased aphid landing in Karate treated plots was expected. Although landing rates did not differ statistically between treatments, there was a noticeable increase in Karate treated plots. It is probable that this result and the increased virus incidence observed in these plots occurred due to increased aphid movement and activity.

As data on seasonal abundance of aphid vectors trapped in yellow pan traps previously indicated (Ebesu & Ullman, these proceedings), vector species migrated into the crop almost continuously, although in low numbers relative to aphid flights in more temperate climates. Disease curves from all treatments suggest that very few aphids entered the crop in a viruliferous state and there were few initial infections. The remainder of the epidemic developed within the field fostered by transient aphids landing on diseased plants and moving short distances to other plants within the field. It is likely that a single aphid in this type of transient mode could infect in excess of 4 plants. With this in mind, one can understand the exponential rate at which cucurbit virus epidemics develop, even when there are relatively few aphids present.

The Pulehu area is somewhat isolated from commercial agricultural areas, thus, the dramatic increase in *A. gossypii* trapped following first harvest suggests that these alates were produced within the experimental plots. It is likely that these alates contributed very significantly to in-field virus spread because their increase in numbers correlates with the highest rate of virus increase across all treatments. It is somewhat unusual for alates produced within an area to make short flights. The role of *A. gossypii* with respect to in-field epidemics and the possible importance of controlling this aphid within zucchini crops will be a topic of further investigation.

The tropical climate and continuous cropping practices used in the Hawaiian islands promotes the presence of the cucurbit virus complex in cucurbit crops and cucurbitaceous weeds throughout the year (Cho et al., these proceedings). Vector populations are prevalent and continuously dispersing (Ebesu and Ullman, these proceedings). Clearly, growers cannot readily achieve control of cucurbit virus epidemics in Hawaii or elsewhere in the tropics by controlling or avoiding vector populations alone. Instead, it is likely that growers will need to take an integrated approach in which they control for weeds acting as virus and aphid sources; separate cucurbit crop plantings both spatially and temporally; and remove infected crops representing

large sources of virus inoculum and aphid vectors promptly following harvest (Ullman, Cho & German, *In Press*). Our data indicate that use of stylet oil in conjunction with these cultural practices will limit virus spread. Our continuing research will focus on additional alternatives, including reflective mulches, repellents to aphid landing, use of mild virus strains for cross protection, as well as development of varieties resistant to the cucurbit viruses.

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COMPARISON OF INSECT POPULATIONS ON TRELLISED AND NON-TRELLISED CUCUMBER

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ABSTRACT The response of certain components of the insect community associated with cucumber was compared on vertically and horizontally grown plants on Guam. Responses varied depending on the species involved. The fleahopper *Halticus tibialis* Reuter and the melon aphid, *Aphis gossypii* Glover, were much more abundant on cucumbers grown on the ground. *Liriomyza* mines and the melon thrips, *Thrips palmi* Karny were more abundant on the vertical cucumbers. Aphid predators such as syrphids were significantly more common on cucumbers grown on the ground while ladybeetles were more common on trellised plants. Melon fly, *Dacus cucurbitae* Coquillett, was not apparently affected by height. The amount of damaged fruit not significantly different in either treatment.

The architecture or structure of a plant has been proposed as one factor influencing the diversity and structure of an herbivore community (Lawton 1983). Diversity of an arthropod community associated with a host plant increases as the size and complexity of a plant increases. Of the three general classes of vegetation (trees, shrubs and herbs), trees have the highest herbivore diversity and herbs the lowest (Lawton & Schröder 1977, 1978, Strong & Levin 1979). The form or way an individual plant grows, its age, and seasonal growth changes affect specialist herbivores (Lawton 1983). In cucumbers, plant architecture can be altered by growing the plant vertically on trellises or horizontally on the ground. On vertically-grown plants, the beetle *Acalymma vittata* (F.) is more abundant than on horizontally grown plants (Bach 1981). In Micronesia, both growing methods are used, so we compared them to determine the effects on selected members of the arthropod community.

Methods and Materials

Cucumber plants were grown in 4 m X 4 m plots either horizontally on the ground or vertically trained on nylon nets. Treatments were alternated. The experiment was conducted in July - August 1983 and repeated in February - March 1984. Each treatment was replicated three times in 1983 and four times in 1984.

Plots consisted of 4 rows 4 m long and one m apart. In each row, cucumbers were planted in hills 1 m apart. After germination, plants were thinned to 3 plants per hill.

We selected certain elements of the herbivore and predator community for study. These were orange pumpkin beetle, *Aulacophora similis* (Olivier), black island fleahopper, *Halticus tibialis* Reuter, melon aphid, *Aphis gossypii* Glover, leafminers, *Liriomyza* spp., and melon thrips, *Thrips palmi* Karny. We also compared the distributions of the general predator *Orius niobe* Herring (Hemiptera: Anthocoridae) and two melon aphid predators, the lady beetle *Menochilus sexmaculatus* (F.) and the syrphid fly *Ischiodon scutellaris* (F.).

To estimate populations of orange pumpkin beetle and black island fleahopper, one row in each plot was randomly chosen and sampled using a D-Vac suction apparatus. Melon aphid and melon thrips populations were estimated by randomly collecting 15 leaves per plot and counting all individuals on the leaf. *Liriomyza* spp. were estimated by counting the number of mines on 40 leaves. To select the leaves, a vine tip was randomly selected, and then the number of mines on the tenth leaf back from the tip was counted. Numbers of lady beetles and syrphids were also counted on these leaves. Melon fly punctures were counted on each cucumber at harvest.

Results

The numbers of black island fleahopper were similar in all plots before the cucumbers began to climb the trellise. After the plants had separated in height, *H. tibialis* showed a distinct preference for horizontal cucumbers (Table 1, Fig. 1a, b). Many of the fleahoppers present on vertically growing cucumbers were on the leaves close to the ground. Higher leaves were nearly free of *H. tibialis*. Consequently, there was little change *H. tibialis* populations over the season (Figure 1a, b). In contrast, there were more *H. tibialis* present in the horizontal cucumbers plots. Extensive feeding damage to the leaves was noted.

Orange pumpkin beetle was slightly more abundant on horizontal plots than on vertical ones (Figure 1c,d), but there was considerable variability between plots and differences were not statistically significant. The difference became more pronounced as height difference increased.

Table 1. Mean number of insects found on vertically- and horizontally-grown cucumber plants.

Sample Unit	Insect Species	Mean No. Individuals[a]	
		Horizontal Growth	Vertical Growth
	Herbivores		
Leaf	*Aphis gossypii*	15.7	6.6
	Liriomyza mines	2.0	3.3
	Thrips palmi	8.3	19.8
Row[b]	*Aulacophora similis*	4.8	2.4
	Halticus tibalis	308.0	136.0
Percent Fruit Injury	*Dacus cucurbitae*	22.3	30.0
	General Predators		
Thirty leaves	*Ischiodon scutellaris*	13.5	2.1
	Menochilus sexmaculatus	2.6	8.6
	Orius niobe	33.8	57.8

[a] Mean densities expressed with respect to sample unit.
[b] D-Vac sample per 4 row-meters.

Melon aphids did not exhibit a consistent preference for either vertical or horizontal cucumbers. In 1983, high numbers of melon aphids were initially present in the vertical plots, but as the season progressed the differences in melon aphids among ground and trellised plots disappeared. Initially, there were about 4 times as many aphids per leaf in the vertical plots as compared to the horizontal plots. Within two weeks, aphid populations decreased dramatically, and there were no differences between treatments. In 1984, there were more aphids in the ground plots.

Predators attacking aphids and other insects showed a distinct response to plant height (Table 1). The lady beetle *M. sexmaculatus* and the anthocorid *O. niobe* were more abundant on vertical plants. Nearly three times as many lady beetle larvae and adults were present on the vertical plants compared to the ground plants. *O. niobe* did not show as strong a preference, but was consistently higher on vertical plants. On the other hand, the syrphid *I. scutellaris* was more abundant on horizontal plants. An average of nearly one syrphid larvae per two leaves was present on plant foliage on the ground while only one larvae per 15 leaves was present in vertical cucumbers.

Early in the season, the leafminers *Liriomyza trifolii* Burgess and *L. sativae* Blanchard were similar in number among cucumber growth types, but became significantly more abundant on the vertical cucumbers as they grew. About 1.7 times as many leafminers were found on the vertical cucumbers compared to the horizontal ones.

No discernible trends were found in the numbers of fruit damaged by the melon fly or in the numbers of melon thrips. This thrips species was first detected in Guam in 1983, but was rare during the first experiment. In 1984, there were more melon thrips in the vertical plots, but differences between treatments were variable and non-significant.

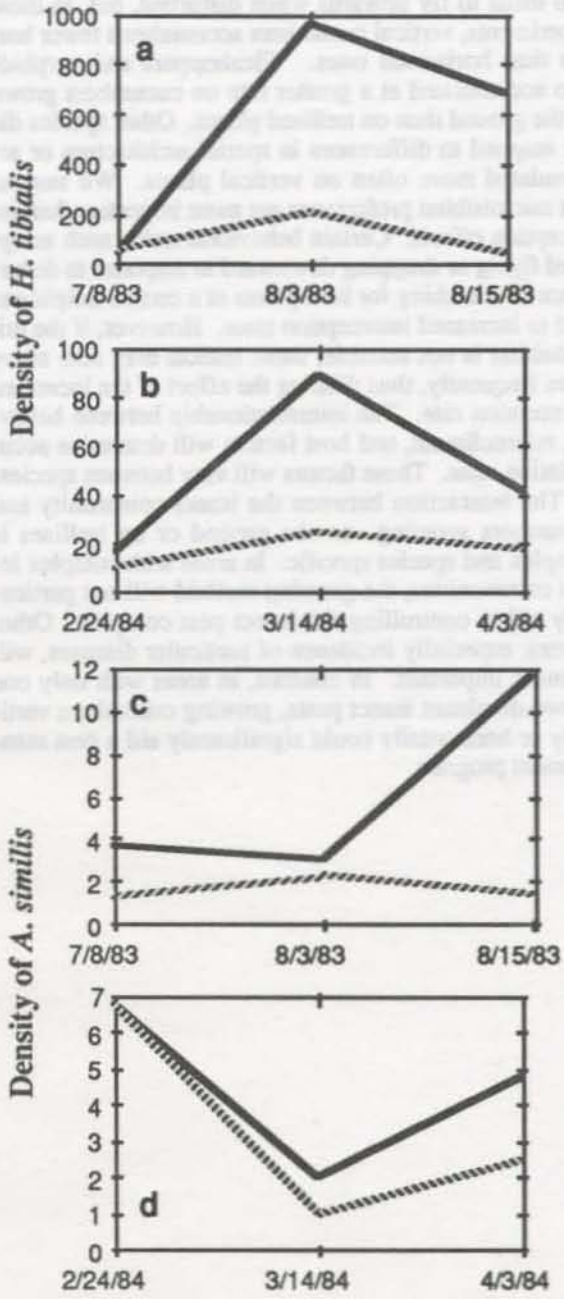

Fig. 1. Numbers of *H. tibialis* and *A. similis* on vertically and horizontally grown cucumbers. Solid line is horizontal plants, dashed line is vertical. a,b) *H. tibialis* c,d) *A. similis*.

Discussion

Bach (1981) suggested that the flight pattern of the beetle *A. vittata* was one of the causal mechanisms increasing beetle numbers on vertical cucumbers compared

to horizontal ones. Observation on a closely related *Acalymma* species revealed a tendency for beetles to fly upward when disturbed. Presumably vertical plants intercept more beetles than horizontal ones. *A. similis* also tends to fly upwards when disturbed, but, in these experiments, vertical cucumbers accumulated fewer beetles than horizontal ones. Fleahoppers and syrphids also accumulated at a greater rate on cucumbers grown on the ground than on trellised plants. Other species did not respond to differences in spatial architecture or accumulated more often on vertical plants. We suspect that microhabitat preferences are more important than interception effects. Certain behavioral traits, such as upward flying or dropping downward in response to disturbance or searching for host plants at a certain height can lead to increased interception rates. However, if the microhabitat is not suitable, these insects may also move more frequently, thus diluting the effect of the increased interception rate. The interrelationship between behavior, microclimate, and host factors will determine accumulation rates. These factors will vary between species.

The interaction between the insect community and cucumbers growing on the ground or up trellises is complex and species specific. In areas with complex insect communities, the growing method will not particularly aid in controlling the insect pest complex. Other factors, especially incidence of particular diseases, will be more important. In contrast, in areas with only one or two dominant insect pests, growing cucumbers vertically or horizontally could significantly aid a pest management program.

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CHROMOLAENA ODORATA (ASTERACEAE) IN THE REPUBLIC OF PALAU

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ABSTRACT *Chromolaena odorata* (L.) R. M. King & H. Robinson is a serious weed problem throughout Southeast Asia. In the past ten years, this weed has spread to several island groups in the western Pacific. A native of Central and South America, *C. odorata* has no natural enemies in the Pacific region.

The presence of *C. odorata* in the Republic of Palau was first confirmed in October 1988. At that time, the weed was widespread on the island of Peleliu and in limited areas on the islands of Malakal and Babeldaob. Small infestations have since been found in the village of Mongami on the island of Babeldaob and on the island of Angaur.

A natural enemy of *C. odorata*, the eriophyid mite, *Acalytus adoratus* Keifer, was discovered in Palau in October 1988. In March 1989, an unidentified small caterpillar was discovered eating the flowers. In January 1989, another natural enemy of *C. odorata*, the arctiid moth *Pareuchaetes pseudoinsulata* Rego Barros, was introduced to Palau from Guam. Since that time a systematic program of mass rearing and establishment of this moth has been conducted. At the end of four months (April 1989), the moth had not established. However, based on the effectiveness of *P. pseudoinsulata* in controlling *C. odorata* in the Mariana Islands, the outlook for biological control of *C. odorata* in Palau is good.

Chromolaena odorata (L.) R. M. King & H. Robinson is a member of the family Asteraceae (Compositae), native to tropical and subtropical America. Although it occurs naturally from southern Florida to the northern border of Argentina, it is not considered a significant weed problem in this region. It is widespread and shows weedy characteristics such as rapid takeover of cleared forest or abandoned pasture (Cruttwell 1988a, 1988b).

C. odorata is an herbaceous perennial weed with a vigorous and spreading growth habit. It tends to form thick tangled stands which crowd out or smother less vigorous plants. Stored starch in the crown and root enables the plant to recover very quickly from cutting or burning, so that it is often the first plant to recover from land clearing operations (Cruttwell 1988a). As a result of its ability to quickly invade cleared areas, this weed is most often a problem in pastures, plantation crops, roadsides, and other disturbed areas. Problems associated with stands of *C. odorata* include impeded access, fire risk, and reduced crop yields (CAB IIBC 1988). The allelopathic properties of this plant species contribute to its interference with other plants (Muniappan & Marutani 1988c). It has also been reported to be poisonous to livestock (Aterrado & Talatala-Sanico 1988). *C. odorata* is seldom found under forest canopies because it is not shade tolerant (Cruttwell 1988b, Muniappan & Marutani 1988a). As this plant is well adapted to humid tropical regions, it has the potential to invade all or most of the islands in the Pacific as well as northern Australia (Cruttwell 1988a, Muniappan & Marutani 1988a).

Flowering of *C. odorata* is photoperiod dependent (Cruttwell 1988a). In the northern hemisphere, flowering begins in November or December and is nearly complete by the end of March. Most seed production occurs in February (Muniappan & Marutani 1988a). The inflorescence is a cluster of pale lavender to white flowers. Inflorescences are both terminal and axillary, covering the entire plant with masses of flowers. It is quite conspicuous at flowering time, and is known in Trinidad as "Christmas Bush" (Cruttwell 1988b). Seed production is very prolific. Each seed (a single-seeded achene) is topped by a ring of persistent whitish awns which catch the wind (Moody et al. 1984). They can be carried considerable distances by wind and can also stick to animal fur and/or clothing. There is no seed dormancy, and seeds germinate immediately if given adequate moisture (Cruttwell 1988a).

C. odorata was introduced to southern Asia in the late 1800's or early 1900's. Its introduction has been blamed on the ballast of ships from the West Indies, but it may actually have spread from cultivated specimens (Cruttwell 1988a). By 1940, *C. odorata* had become a problem in several countries in Southeast Asia, and by the 1960's, it was found in Africa as well. It spread to the Philippines in the 1960's, and quickly became a problem there (Aterrado & Talatala-Sanico 1988). In 1980, it was reported to be a problem on the island of Rota in the Mariana Islands and by 1984-85 it was a problem throughout the Marianas (Muniappan & Marutani 1988a). In 1987, it was reported to be in Yap (R. Muniappan, personal communication) and its presence in Palau was confirmed in October 1988. *C. odorata* was observed by one of the authors in Pohnpei in 1988, and he was told that it is present in Kosrae. In all these areas, *C. odorata* is now or is becoming a serious problem, particularly in pastures, grasslands, and other open or disturbed areas (Aterrado & Talatala-Sanico 1988, Cruttwell 1988a,

Muniappan & Marutani 1988a, R. Muniappan, personal communication).

Chromolaena odorata in Palau

Although *C. odorata* was first reported in Palau in October 1988, it had obviously been present for some time as evidenced by its spread. It definitely was not in Palau prior to 1980, when a complete list of vascular plants in Palau was completed by Fosberg et al. (1980). It could, however, have been introduced at any time since then.

The failure of residents and farmers to notice the plant earlier may have been due to its similarity to another common roadside weed, wedelia (*Wedelia biflora* var. canescens (Gaud.) Fosberg). Wedelia has a growth habit very similar to that of *C. odorata*, and many people on the island of Peleliu, where both weeds are common, still do not recognize the difference between the two.

C. odorata is now found on five islands in Palau: Peleliu, Babeldaob, Angaur, Koror and Malakal. It was apparently introduced first on the island of Peleliu, as evidenced by its presence on virtually the entire island, and its limited spread on the other islands. This is something of a paradox because there are no international ports on the island of Peleliu. However it got there, it has now spread over virtually the entire island. During our October 1988 survey of Peleliu, we found *C. odorata* as the dominant weed along the roadsides from one end of the island to the other. It is common in gardens and cleared areas there as well. Residents complain that mechanical control (cutting) is difficult because its odor makes them dizzy, and its sap makes their skin itchy. They report that in addition to its ubiquitous presence on roadsides, *C. odorata* has invaded their farms and gardens, and is difficult to control there as well.

The spread of *C. odorata* from Peleliu to Babeldaob may be explained by the twice-daily flights of small aircraft between the islands. The infestation is apparently at least two years old. Airai International Airport on Babeldaob is now surrounded by small and large patches. There are several other large patches near the airport. The potential for further spread is great because the airport is surrounded by grasslands. *C. odorata* has spread along the roadside between the airport and Koror. Scattered patches can be found for a distance of three to five kilometers.

On Babeldaob, two small *C. odorata* patches in the village of Mongami (ca. 8 km from the Airai airport) are apparently the result of movement of seeds by roadworking equipment. There are also grasslands in this area which are now threatened.

On Koror there is presently only one small patch of *C. odorata*, along the road from the airport. This is in a mostly forested area, but there are many cassava gardens and small farms nearby which could be easily infested.

Attached to the island of Koror by a causeway is the island of Malakal, where Palau's seaport is located. This is also the destination for most boats coming to Koror from Peleliu. There are two areas of infestation on this island, one quite limited but very dense, and the other an entire hillside which is farmed by several families.

On Angaur, which two of the authors visited in March 1989, three small areas of infestation were found. The weed was apparently introduced by road grading equipment sent from the island of Peleliu to work on the Angaur airport. One large and very dense patch was found at the side of the airport. A second, much smaller infestation was found in the middle of the one village on the island, consisting only of a few plants. The third infestation, consisting of two small plants at the side of the road, was eradicated by the survey team.

Chromolaena odorata Control in Palau

Since the confirmation of the presence of *C. odorata* in Palau in October 1988, steps have been taken to control its spread. The weed is too widespread for effective mechanical or chemical control, so the decision was made to attempt to control it biologically. This decision was also based on the successful biological control of *C. odorata* in the Mariana Islands (CAB IIBC 1988, R. Muniappan, personal communication). A third factor was economics; biological control is less expensive. The great potential for spread makes this weed a serious threat, and action was therefore taken as quickly as possible.

In the Mariana Islands, the arctiid moth *Pareuchaetes pseudoinsulata* Rego Barros provided good control of *C. odorata* (R. Muniappan, personal communication). It was therefore decided to attempt to introduce the moth to Palau. Muniappan and Marutani (1988c) recommend that a detailed survey and mapping of the infestation be completed prior to release in order to facilitate documentation of control (Muniappan and Marutani 1988c). This objective, unfortunately, could not be attained under the circumstances of limited financial and personnel resources. Mapping is therefore being undertaken simultaneously with releases of *P. pseudoinsulata*, and is not detailed. One attempt was made to obtain funding, but it was unsuccessful, and officials of the government of the Republic of Palau felt that control measures should be undertaken at once rather than take the time necessary to obtain additional funding. They therefore requested larvae of *P. pseudoinsulata* from Dr. R. Muniappan, University of Guam.

One hundred seventeen larvae of *P. pseudoinsulata* were introduced to Palau in January 1989 for mass rearing and release. *P. pseudoinsulata* has since been released at several sites. Based on the results in the Marianas, we were very optimistic about our chances for success. As of the end of April 1989, however, we have been unable to establish the moth in any location. A similar lack of success occurred in Yap, where the moth was first introduced in January 1988, and did not become established until October 1988 (R. Muniappan, personal communication). At this time, the cause of the failure is not known. We are continuing to rear and release both larvae and adults. Muniappan and Marutani (1988b) recommend repeated and frequent releases, so we are now concentrating on larger releases in a single location. One large release of larvae was destroyed by a brush fire, so we are now concentrating on the heavy infestation on the

island of Malakal which is not subject to fire risk. Larval predation by an unidentified species of spider has been observed, but its importance is unknown. We hope to work with our colleagues at the University of Guam on discovering the cause of difficulty in establishing *P. pseudoinsulata* in Yap and Palau.

In addition to the introduced agent, *P. pseudoinsulata*, two other arthropods have been found on *C. odorata* in Palau. The eriophyid mite *Acalytus adoratus* Keifer was discovered in Palau in October 1988 and was also found in Yap. Secondly, a small unidentified caterpillar was found feeding on *C. odorata* flowers. The caterpillar was first noted in Palau in March 1989. Apparently, neither of these agents is capable of controlling *C. odorata*, but perhaps they can contribute to its control. Various aphids and grasshoppers have also been observed feeding on *C. odorata* in Palau, but their impact on the weed appears minimal.

Conclusions

On the basis of previous experience, the most obvious conclusion to be drawn is that *C. odorata* is in Palau to stay. Even if all existing plants could be killed, the seeds have had several years to become widespread. We therefore have no hope of eradicating this weed. We can and do, however, hope to control it. We are fortunate in having at least two biological control agents appear fortuitously, but these are apparently unable to control it on their own. We are therefore still pinning our hopes on classical biological control through more releases of *P. pseudoinsulata*. Despite the difficulties we have encountered, we believe it is possible to successfully establish this moth in Palau. The long term outlook therefore is for continued presence of *C. odorata* in Palau, but under control as it is in the Mariana Islands.

The CAB International Institute of Biological Control has recommended that a wide range of enemies of *C. odorata* be utilized for more effective control (CAB IIBC 1988). We are interested in introducing other biological control agents for *C. odorata* if such are available.

The introduction and spread of *C. odorata* in Palau and various other islands in the Pacific provides an important lesson for our governments. The importance of good quarantine measures cannot be overstated. Palau now has two flights weekly from the Philippines, and at least one per day from Guam. Both are potential sources of numerous weeds, insects, and diseases not currently found in Palau. It is to be hoped that quarantine regulations will be strictly enforced to protect our fragile ecosystems from invasion.

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The introduction of *Pareuchaetes pseudoinsulata* to Palau could not have taken place without the generous assistance and cooperation of Dr. R. Muniappan, Dr. Mari Marutani and Dr. Gary Denton, University of Guam. These individuals also were very helpful in providing information and references needed for this paper.

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CONTROL OF THE LEAFMINER *LIRIOMYZA TRIFOLII* BURGESS (DIPTERA: AGROMYZIDAE) AND COWPEA APHID, *APHIS CRACCIVORA* KOCH (HOMOPTERA: APHIDIDAE), ON YARDLONG BEANS WITH SOME INSECTICIDES

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ABSTRACT The leafminer *Liriomyza trifolii* (Burgess) infested bean foliage from seedling emergence to harvest. In contrast, the cowpea aphid, *Aphis craccivora* Koch, did not infest beans until plants started to climb on a vertical trellis. Good control of both pests was achieved by foliar sprays of dimethoate at 1 kg ai/ha. Yields of clean pods were signigicantly higher from plants that received foliar sprays of dimethoate and methomyl at 1 kg ai/ha and from plants that received granular diazinon at planting followed by post-emergence foliar sprays of dimethoate than from those plants sprayed with malathion and diazinon and those from unsprayed plants.

The leafminer *Liriomyza trifolii* (Burgess) is an important insect pest of beans in Micronesia. Adult females insert their eggs into upper leaf surfaces. Upon hatching, the maggot or larva mines between the upper and lower surfaces of a leaf. Mines appear as blotches of irregular winding tunnels. When leafmines merge, the entire leaf may be hollowed out. Young seedlings may die due to damage caused by the larvae. Seedlings and older plants that survive severe leafminer-induced injury become less vigorous resulting in the production of smaller pods. The cowpea aphid, *Aphis craccivora* Koch, is an oligophagous species which feeds on breadfruit, citrus, cucurbits, mango and beans. On beans, cowpea aphids suck the sap from stems, leaves and pods. Infested leaves curl and cease to grow. Infested pods also curl, appear unhealthy, and fail to attain full size resulting in low market value of pods.

The standard practice for controlling insect pests of beans such as the cowpea aphid and *L. trifolii* in Micronesia is to spray malathion at the recommended label rate. Spraying is initiated when plants show damage due to these pests. Spray application frequency is dependent on the extent of infestation and if new infestations occur following initial spray applications.

This paper presents results of a study aimed at determining the efficacy of insecticides presently used for bean insect control in other countries for bean pest suppression on Pohnpei, Federated States of Micronesia.

Materials and Methods

This study was conducted at the College of Tropical Agriculture and Sciences Experiment Station, Kolonia, Pohnpei, in September 1988. Plot size for each treatment was 2 rows x 10 plants. Three bean (yardlong variety) seeds were planted in each planting hole with a distance of 0.6 m between plant sites and 1 m between rows. Soil within plots was a sandy loam containing 3% organic matter content with a pH of 5.2. Fertilizer was applied at the rate of 1 kg 50-50-50 NPK/ha. One-half of the recommended rate of fertilizer was placed adjacent to plants when 1) seedlings emerged and 2) plants flowered. Hand weeding was done whenever necessary to prevent weeds from competing with beans for nutrients. Seedlings were trained to climb on a vertical trellis of nylon netting to facilitate spraying and bean pod harvest.

Efficacies of seven pesticide treatments were examined with respect to application method and timing. Four treatments consisted of biweekly foliar sprays of each of the following compounds applied at 1 kg ai/ha: dimethoate, diazinon, malathion and methomyl. Treatments were initiated at seedling emergence. The three remaining treatments consisted of a granular soil application of diazinon at 2 kg ai/ha at planting followed by post-seedling emergence applications of 1) granular diazinon [2 kg ai/ha] initiated five weeks after seedling emergence; 2) biweekly diazinon [1.0 kg ai/ha] foliar sprays initated three weeks after seedling emergence; and 3) biweekly dimethoate [1 kg ai/ha] foliar sprays initiated 3 weeks after seedling emergence. An untreated check was included. Treatments were replicated four times in a randomized complete block design. Pre-plant diazinon granular applications were made by placing a given amount of diazinon in each planting hole. Insecticide granules were covered with soil on top of which bean seeds were placed. Bean seeds were then covered with soil. The five-week post-seedling emergence granular application was placed in a shallow ditch two inches in diameter around the plant and then covered with soil. Foliar sprays were applied in 400 liters water/ha using a knapsack sprayer. Spreader-sticker (Triton B–1956) was added to pesticide solutions at the rate of 1 ml/4 liters solution. The last date on

which foliar sprays were applied was two weeks before peak harvest.

Leafminer infestation counts were taken three weeks after seedling emergence and three days before peak harvest. Aphid infestation was determined from counts taken three days before peak harvest. Infestation by both pests was visually estimated by using the following rating scale: 0 = no pest damage; 1 = light damage, 1 to 25% of leaves on each plant infested with pests; 2 = moderate damage, 26 to 50% of leaves on each plant infested with pests; 3 = heavy damage, 51 to 75% of leaves on each plant infested with pests; and 4 = severe damage, 76 to 100% of leaves on each plant infested with pests. Insecticide induced phytotoxic symptoms on plants were also recorded.

Marketable pod yields were reported in kilograms per plot.

LSD values ($P = 0.05$) were calculated for treatment mean yields.

Results and Discussion

Leafminer-induced foliar injury was highest in the untreated check at the first and second counts (Table 1). Progressing from the best leafminer control to the least was dimethoate foliar spray > diazinon granules + dimethoate foliar spray > foliar methomyl sprays, foliar diazinon sprays, diazinon granules + diazinon foliar sprays > diazinon granules + diazinon granules, foliar malathion sprays. On the other hand, cowpea aphid populations were consistently lower on all plants that received insecticidal treatments as compared to the unsprayed check (Table 1). However, dimethoate applications should be tested again at lower rates to determine rates which do not induce phytotoxic responses of bean seedlings.

Clean bean pod yields were significantly higher on plants treated with dimethoate, methomyl and malathion foliar sprays and granular diazinon + dimethoate foliar sprays than the unsprayed check and granular diazinon + granular diazinon treatments (Table 1).

Results of this study illustrate the importance of controlling *L. trifolii* and cowpea aphid which can influence successful production of bean pods when pest densities are high. Based on this study, it is recommended that dimethoate, diazinon and methomyl be further tested to find out whether lower rates of these insecticides would be effective in controlling both insect pests.

Table 1. Effects of various insecticides on aphid and leafminer infestation and resulting bean yields.

Treatment	Leafminer Counts[a] 1st	2nd	Aphid[a] Infestation	Mean Pod Yield: Clean No.	Clean Wt.[b] (kg/plot)	Infested No.	Infested Wt.[c] (kg/plot)
Check	1.50	3.80	3.40	13.5	0.167	55.5	0.450
Foliar sprays							
Dimethoate	0.40	1.00	0.10	161.0	3.535	0.5	0.015
Diazinon	0.80	2.00	0.80	85.2	2.088	2.2	0.039
Malathion	1.10	2.80	1.20	90.5	2.012	10.8	0.270
Methomyl	0.60	2.10	0.40	151.5	3.175	12.8	0.260
Diazinon granules + Post-emergence treatment							
Diazinon Granules[d]	0.80	3.00	1.80	34.8	0.592	31.2	0.364
Diazinon[e]	0.60	2.20	1.50	73.8	1.556	8.0	0.200
Dimethoate[e]	0.90	1.20	0.20	133.8	2.669	0.3	0.004

[a] Infestation by both pests was visually estimated by using the rating scale as follows: 0 = no pest damage; 1 = light, 1 to 25% of leaves on each plant infested with pests; 2 = moderate, 26 to 50% of leaves on each plant infested with pests; 3 = heavy, 51 to 75% of leaves on each plant infested with pests; and 4 = severe, 76 to 100% of leaves on each plant infested with pests.

[b] LSD (P=0.05) = 1.29

[c] LSD (P=0.05) = 0.279

[d] Applied five weeks post-seedling emergence.

[e] Foliar sprays applied 3 weeks post-seedling emergence.

PESTICIDE SURVEY OF THE COMMONWEALTH OF NORTHERN MARIANAS

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ABSTRACT Vegetable production in the Commonwealth of Northern Mariana Islands (CNMI) is intensifying because of institutional market demand (i.e. hotels, restaurants and garment factories). Purchase of local produce is encouraged by the Government through the Food Stamp Program.

Like many tropical islands groups, CNMI is beset with many diverse pest and disease problems, and effective control measures are imperative in order to produce high yields and good quality products. A survey conducted from 25 March to 20 April 1988 showed that most pesticides used by CNMI farmers were insecticides. Thirty percent of the individuals surveyed used fungicides while 6 percent used herbicides. Fifty percent indicated they used protective garments during spraying operations. The majority of the farmers questioned applied pesticides on a biweekly schedule. However, 12 percent sprayed every three days, especially if infestations were heavy. An average of eleven treatments were put on both wet and dry season plantings.

Most respondents spent an average of $42.00 (U.S. currency) on pesticides per growing season. Pesticides available in CNMI were formulated as either wettable powders or emusifiable concentrates.

Vegetable production in the Commonwealth of Northern Mariana Islands (CNMI) is intensifying with increases in potential market demand (e.g., hotels and garment factories). Furthermore, purchase of local produce is encouraged by the government through the Food Stamp Program. To compete with imported products, however, local farmers not only have to grow sufficient quantities of produce but also produce of equal quality to that imported. Like many tropical island groups, CNMI is beset with pest and disease problems, and effective control measures are imperative in order to produce high yields of good quality. This paper reports the results of a survey investigating pesticide use by CNMI farmers.

Materials and Methods

A survey questionaire was developed and distributed to farmers on Saipan, Tinian and Rota. Topics covered by the survey included: 1) types of pesticides used; 2) time period (years) over which chemicals were used; 3) safety precautions used during and following pesticide spraying; 4) crop types and associated pests for which chemicals were used; 5) application frequency; 6) cost and procurement of materials; and 7) material formulations available. Farmers were instructed to fill out the questionnaires with the help of their extension agents. Twenty survey forms each for Saipan, Tinian and Rota were distributed. The survey was conducted from 25 March to 20 April 1988.

Results and Discussion

Out of 60 survey questionaires distributed, 33 were returned. All respondants indicated they used pesticides on their farms. Most pesticides used were insecticides. Thirty percent of the farmers used fungicides while 6 percent used herbicides. Pesticide formulations available in CNMI were either wettable powders or emusifiable concentrates. About 9 percent of the farmers have used pesticides for 20 years while 27 percent have used pesticides for only a year. Remaining respondents used pesticides for 5 to 10 years. Eighty-one percent used pesticides for pest and disease control to obtain higher yields compared to 19 percent who used pesticides on the advice of their extension agents.

With respect to safety precautions practiced, 50 percent indicated they used protective garments, masks and gloves during spraying operations while 45 percent did not use any protective garments. Some of the reasons given for not using protective gear were that 1) the weather was too hot for comfortable use of gear; and 2) they did not possess protective garments. However, all farmers said they washed and changed clothes after spraying. All respondents claimed that they did not smoke while spraying insecticides.

CNMI farmers encountered more insect pests than diseases in their vegetable production. They reported beetles, worms, leafminers, thrips, aphids and weevils as pests on cucumber, watermelons, beans, bell peppers, sweet potatoes, tomatoes, eggplants, cabbage, radish and taro. Diamondback moth was cited as the most serious pest on crucifers, especially cabbage. Most respondents followed the manufacturer's dosage

Table 1. Dosage pesticide manufacturers recommend for control of various vegetable pests.

Vegetable	Pest/Disease	Pesticides	Dosage Formulation[a]	Dosage lbs gal
Sweet Potato	Worms	Diazinon	EC	4
		Malathion	EC	4
	Beetles	Diazinon	EC	4
		Malathion	EC	4
Taro	Aphids	Malathion	EC	4
		Diazinon	EC	4
		Sevin	WP	4
	Worms	Malathion	EC	4
		Diazinon	EC	4
		Sevin	WP	4
Chinese Cabbage	DBM	Cygon	EC	3–4
Beans	Aphids	Cygon	EC	2
	Leafminer	Cygon	EC	2
Onions	Thrips	Malathion	EC	2
Okra	Rose Beetle	Sevin	WP	7
Pepper	Aphids	Cygon	EC	1
	Leafminer	Cygon	EC	1
Raddish	Leafhopper	Malathion	EC	2–3
		Diazinon	EC	1
Eggplant	Lady Beetle	Sevin	WP	3–4
	Mites	Kelthane	WP	3
Tomato	Lady Beetle	Cygon	EC	3–4
Cabbage	DBM[b]	Sevin	WP	3–4
		Dipel	WP	3–4
	Black Rot	Kocide	WP	2
Watermelon	Leafminer	Malathion	EC	3–4
	Leafspot	Dithane M-22	WP	2
Long Beans	Anthracnose	Benlate	WP	2
Cucumber	Powdery Mildew	Bravo 75	WP	1.5

[a] WP and EC indicate wettable powder and emulsifiable concentrate respectively. Percentage value preceeding "WP" indicates percentage of wettable powder composed of the pesticide.

[b] DBM = Diamondback moth.

recommendation (Table 1). The majority of the respondents said they applied pesticides at bi-weekly intervals, although 25 percent stated they sprayed weekly. Twelve percent treated every 3 days, especially if infestations were heavy. An average of 11 treatments for both wet and dry season plantings were applied. Most farmers harvested their produce an average of 4–5 days after the last pesticide application (Table 2). All farmers washed harvested produce before marketing it. About 75 percent sold their products at the farmers' market and local stores. The rest sold their products directly to hotels or to Guam markets.

Table 2. Time interval farmers allowed from termination of pesticide spray applications to harvest

Vegetable Crop	Days from application to harvest	Pesticide
Taro	3	Diazinon
Sweet Potato	3	Sevin
Beans	10	Cygon
Onions	8–10	Malathion
Chinese Cabbage	8–10	Cygon
Okra	8	Sevin
Peppers	12	Cygon
Raddish	12	Malathion
Tomato	12	Malathion
Cucumber	2	Malathion
Cabbage	2	Malathion
Eggplant	3	Sevin
Watermelon	14–21	Malathion
		Sevin

When asked about reasons for selecting specific pesticides and where pesticides were procured, 45 percent indicated that availability of the pesticides determined which materials they used, and 21 percent said they procured their pesticides as regular customers of distributors. The rest obtained their pesticides from the nearest source. With regard to problems farmers encountered in procuring pesticides, 36 percent reported they had limited funds to purchase materials; 30 percent mentioned high prices of materials; and 9 percent stated pesticide non-availability. Most respondents spent an average of $42.00 (U.S. currency) on pesticides per growing season. When questioned as to "what would happen to their crop if they did not use pesticides?", 87 percent answered they would have lower crop yields. Twelve percent indicated total crop losses without pesticide use.

Conclusions

In many of the vegetable farms visited it was apparent that the use of pesticides is a vital input to production operations. The abundance of serious pests attacking vegetable crops made many farmers too dependent on pesticides as the sole tactic in controlling insect pests. As indicated by the survey, without the use of pesticides many farmers would either have lower crop yields or totally lose their crops. The lack of a wide range of various pesticides is also a limiting factor. The CNMI farmers are confronted with the problem of few materials (types of pesticides) from which to choose.

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BAIT EFFICACY, REINFESTATION RATES AND COLONY COMPOSITION FOR *PHEIDOLE MEGACEPHALA* (F.) IN PINEAPPLE IN HAWAII

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ABSTRACT *Pheidole megacephala* (F.) is a serious pest in pineapple throughout the world due to its behavior of tending mealybugs. The mealybugs are associated with a wilt disease of pineapple. Control of mealybug infestations in pineapple is economically unfeasible in Hawaii unless ants are controlled.

Bait formulations of hydramethylnon and fenoxycarb were tested against *P. megacephala*. Hydramethylnon eliminated ants from treated plots within one week. Ant colonies moved into these ant-free plots by budding from colonies along field perimeters. Fenoxycarb acted as an insect growth regulator. Treated colonies shifted from production of workers to males resulting in significantly reduced densities of foraging ants. The consequences of this caste shift are discussed.

Mealybug Wilt Disease is a problem in most pineapple production areas throughout the world (Carter 1973). In Hawaii, the disease was first recorded in the early 1900's (Larsen 1910). Pineapple growers in Hawaii experienced heavy losses as high as 100% (Illingworth 1931) until control was achieved in the 1930's by eliminating ants from the field with chlorinated hydrocarbon insecticides (Rohrbach et. al. 1988).

Mealybug wilt is always associated with mealybugs and ants. The relationship between mealybug feeding on pineapple plants and wilt was described by Carter (1933), but the etiology has not been determined. Recently, a closterovirus-like particle was found in diseased plants and is suspected to be the causative agent (Gunasinghe & German, *In Press*). This virus has also been detected in the mealybug *Dysmicoccus neobrevipes* Beardsley (D. Ullman & T. German, personal communication).

Mealybugs prosper in pineapple fields due to the tending behavior of three main species of ants, *Solenopsis geminata* (F.), *Iridomyrmex humilis* (Mayr), and *Pheidole megacephala* (F.)(Carter 1973). *P. megacephala*, the big-headed ant, is the most troublesome because it is the dominant species in areas in which pineapple is grown (Phillips 1934, Rohrbach et. al. 1988). Control of heavy mealybug infestations in pineapple fields is not economically feasible unless ants are eliminated. Without ants, few mealybugs become established in fields (Carter 1960) and wilt disease does not spread (Beardsley et. al. 1982). Mealybugs introduced on infested planting stock die or remain confined to small patches, presumably because of their natural enemies (Carter 1932). The few loci of survivors can easily be removed with spot applications of insecticides. However, when ants are present, mealybug populations rapidly increase after spraying due to survival, immigration and ant attendance.

In recent years, control of the ants has been achieved with Mirex®, heptachlor, and hydramethylnon (Amdro®). However, the registrations for Mirex and heptachlor were canceled by the Environmental Protection Agency and Amdro is registered for use only as a border treatment. Border treatments can effectively stop ant movement into fields free of ants but are useless in infested fields. Acceptable methods for ant suppression in infested fields are currently not available. This paper describes changes in *P. megacephala* densities and the mode and rate of reinfestation of ants into pineapple fields after the application of fenoxycarb and hydramethylnon baits.

Materials and Methods

Plots of 1.4 ha each (3 replications) were set up in a completely randomized design in ant infested third ratoon pineapple fields on Lanai island, Hawaii. Thirty redwood stakes were placed in a grid pattern in each treatment plot such that 16, 8 and 6 stakes were 7, 33 and 60 m from plot edges, respectively (Fig.1). Control plots had six center stakes each but no perimeter stakes. A peanut butter:soy bean oil solution (1:1) was painted near the base of each stake at 1 to 2 wk intervals. The number of ants feeding on the baited stakes were counted approximately 4 h after bait application. The six center stakes were used to monitor treatment effects. The 24 perimeter stakes were used to monitor ant populations throughout the plot and immigration into fields.

Amdro (American Cyanimid Co., Wayne, NJ) (0.88% hydramethylnon by weight) and Logic (Maag Agrochemicals Inc., Vero Beach, FL) (1% fenoxycarb by weight) were broadcast at a rate of 1.67 kg bait per ha

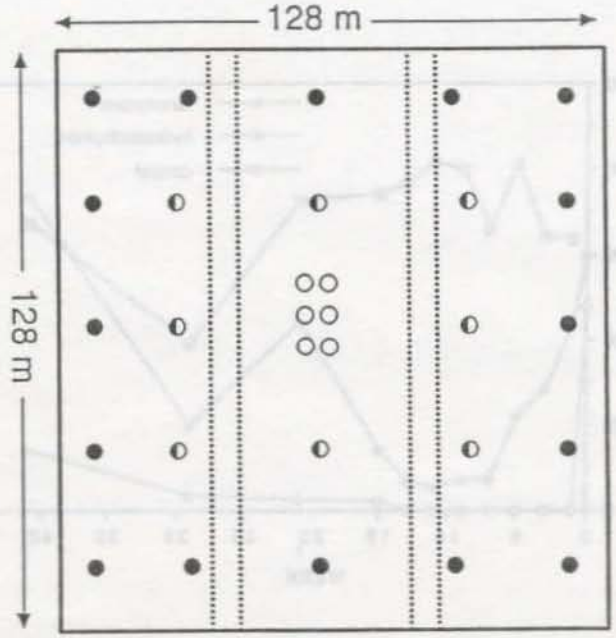

Fig. 1. Plot layout for pineapple field trials on Lanai Island, Hawaii. Diagram represents bait stake placement in one replication of the experiment such that ● = out perimeter stakes; ◐ = inner perimeter stakes; and ○ = center stakes.

using a Buffalo turbine blower. Amdro was applied in the late afternoon to avoid breakdown by photolysis (Vander Meer et. al. 1982, Mallipudi et. al. 1986). A road 4.5 m wide was bulldozed along plot perimeters and a 5 m swath of Amdro was applied along road sides opposite the plots. This provided a buffer zone to retard ant immigration from border areas into the plots. Treatment effects for each sample date were analyzed by Analysis of Variance and means were compared with Duncan's (1951) multiple range test (P=0.05)(Sokal & Rohlf 1981).

Three colonies each were collected from fenoxycarb and control plots before treatment and at 3, 11 and 13 weeks after treatment. Each colony was selected at random from areas within the plots excluding areas within a 5 m radius of the monitoring stakes. Hollow pineapple stumps containing active big-headed ant colonies were placed into plastic bags and taken to the laboratory. Colonies were extracted from stumps by shaking the ants into a Berlese funnel. Numbers of workers, soldiers, males, queens, eggs, worker larvae, worker pupae, male pupae and alate queens were recorded for each colony. Differences in caste numbers between treatments were analyzed by Analysis of Variance (Sokal & Rohlf 1981).

After reviewing the first field tests, I suspected that the 1% fenoxycarb bait may have had some repellent effects against big-headed ant. Therefore, baits consisting of 1, 0.5, 0.25 and 0% fenoxycarb, and 0.88% hydramethylnon were placed in piles of 10 granules each on the ground within the foraging area of a big-headed ant colony in a pineapple planting infested with ants. Bait piles were about 25 cm apart. The number of bait granules remaining in each pile were counted at 5-minute intervals for the first 20 minutes and at 10-minute intervals thereafter, for a total of 60 minutes. Bait repellency was tested for eight big-headed ant colonies. A t-test was used to analyze treatment differences in mean number of bait granules remaining after one hour (Sokal & Rohlf 1981).

Results and Discussion

Hydramethylnon caused a rapid decrease in ant densities within one week (Fig. 2). No ants were recovered from the center of these treated plots between one and 13 weeks after treatment. However, ants were again recorded from center stakes at 16 weeks after treatment. Their densities then gradually increased until the termination of the monitoring at 41 weeks but remained at levels significantly below controls. The increases in density were due to immigration of colonies from field edges. After their complete elimination throughout the plots at 1 week (Fig. 3), ants began reappearing at the outer stakes (7 m within fields) at 3 weeks. Ant densities gradually increased as more colonies moved in from field borders. Ants were first recorded at the inner stakes (33 m within fields) at 11 weeks after treatment and at the center stakes (60 m within fields) at 16 weeks. Based on these biweekly ant counts, it was estimated that *P. megacephala* moved into areas free of ants at a mean rate of 0.46 ± 0.09 (±SD) m/day.

Fenoxycarb significantly reduced ant densities but acted much slower compared with hydramethylnon. Fenoxycarb caused a gradual reduction in mean ant counts to densities significantly lower than the control 5 weeks after treatment (Fig. 2). Mean number of ants per

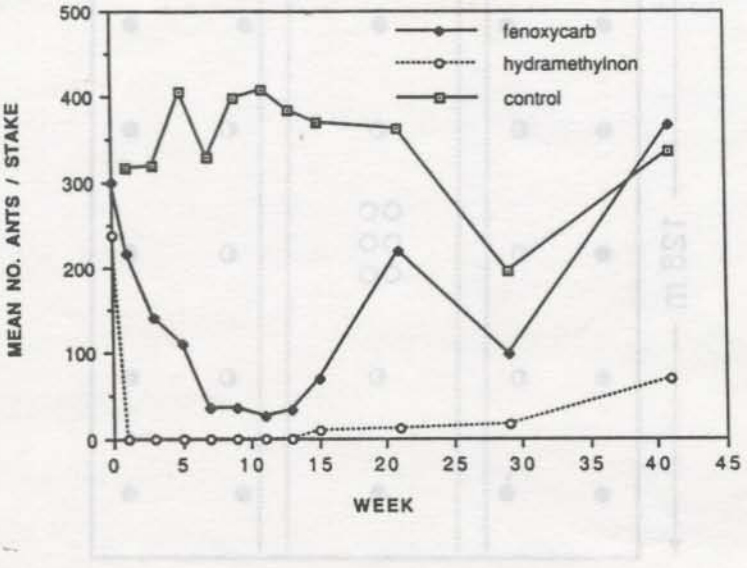

Fig. 2. Mean number of *Pheidole megacephala* at center stakes in bait treated pineapple on Lanai Island, Hawaii.

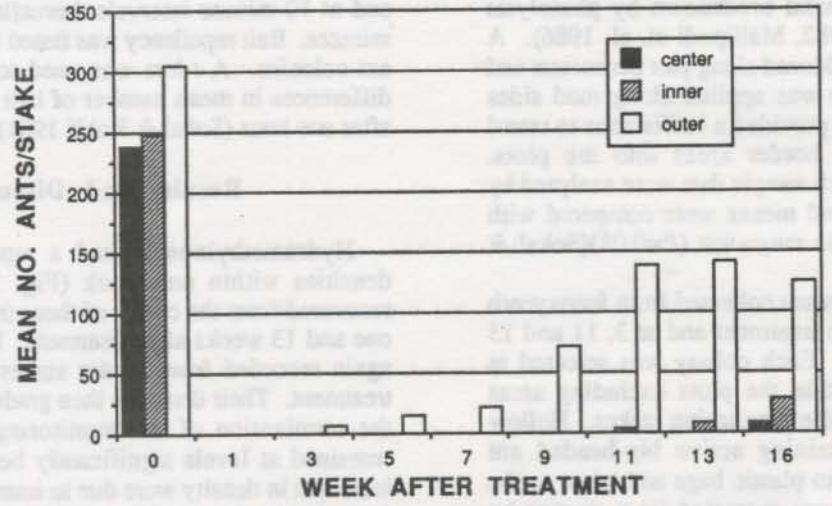

Fig. 3. Mean number of *Pheidole megacephala* at outer perimeter, inner perimeter, and center stakes in hydramethylnon treated pineapple on Lanai Island, Hawaii..

stake reached the lowest level 11 weeks after treatment before rising to densities comparable with those in control plots. Counts in fenoxycarb and control plots 21 weeks after treatment were not significantly different.

Differences between fenoxycarb and hydramethylnon effects on *P. megacephala* populations can be explained by differences in their modes of action. Hydramethylnon acts as a stomach poison against all castes and stages which feed on it. Fenoxycarb, however, was demonstrated to exhibit insect growth regulator (IGR) activity on queens when fed to *P. megacephala* colonies (Glancey et al. 1990). This can explain the shift in caste production from workers to males in fenoxycarb treated colonies at 11 weeks after treatment (Fig. 4). No males were ever found in control colonies at this time. The effects of fenoxycarb must have been on the queen because the sex of the progeny is determined by whether she fertilizes an egg (female) or not (male).

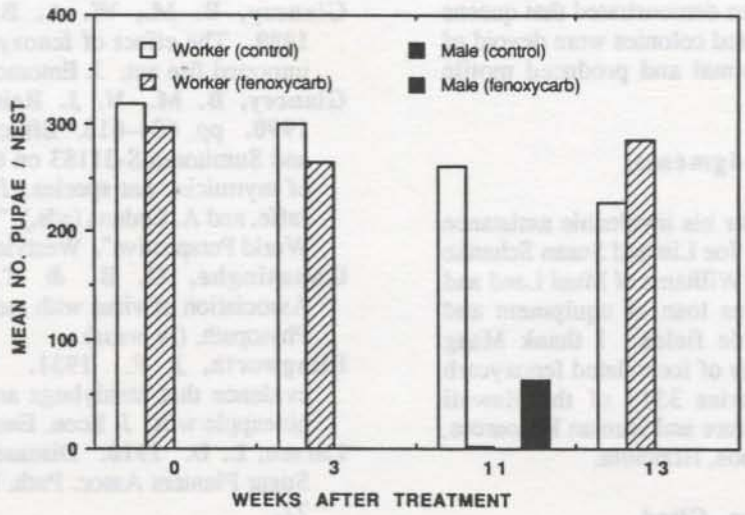

Fig. 4. Mean number of *Pheidole megacephala* pupae/nest from untreated and fenoxycarb treated plots on Lanai Island, Hawaii..

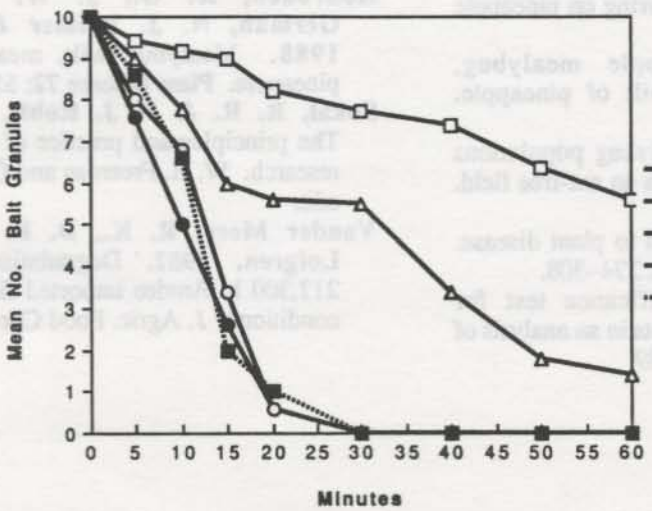

Fig. 5. Mean number of bait granules remaining within foraging area of *Pheidole megacephala.*

Although significantly reduced in numbers, active *P. megacephala* colonies were always found in plots treated with fenoxycarb. Also, at 13 weeks after treatment, the colonies had recovered from the fenoxycarb effects observed at 11 weeks after treatment (Fig. 4). The less than desired reduction in ant populations and subsequent recovery were most probably due to a partial repellency to fenoxycarb as demonstrated in the studies with baits containing various fenoxycarb concentrations. Hydramethylnon, and 0%, and 0.25% fenoxycarb bait granules were removed more quickly than 0.5% or 1% fenoxycarb baits (Fig. 5). No hydramethylnon, 0%, or 0.25% fenoxycarb bait granules remained after 30 minutes, in contrast with a mean of 5.6 and 7.8 granules of 0.5 and 1% fenoxycarb bait, respectively. Significantly fewer 0.5% (1.4) than 1% (5.6) granules remained after 1 h (t=6.4, df=14, P<0.01).

The effectiveness of baits formulated with less than 0.5% fenoxycarb should be studied in the field to avoid the repellency of the baits with higher concentrations. In addition, the viability of the males produced by the fenoxycarb treated colonies should be studied. Studies

with *Solenopsis invicta* Buren demonstrated that queens produced in fenoxycarb treated colonies were devoid of ovaries but males were normal and produced motile sperm (Glancey et al. 1989).

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GENE FLOW IN DIAMONDBACK MOTH: IMPLICATIONS FOR INSECTICIDE RESISTANCE EVOLUTION AND MANAGEMENT

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ABSTRACT The objectives of this study were to: 1) quantify the amount of gene flow between populations of the diamondback moth (DBM), *Plutella xylostella* (L.), in Hawaii; and 2) determine the effect of gene flow on the evolution of pyrethroid resistance in DBM in Hawaii. Gene flow was measured by analysis of electrophoretic variation at four polymorphic loci. Computer simulation of dispersal was used to estimate effects of gene flow among spatially distributed, finite populations (both treated and untreated) on the rate of resistance evolution. Results indicated that DBM population exchange of ca. 5-10 migrants per generation was sufficient gene flow to spread resistant genes throughout the populations, but not sufficient to significantly retard resistance evolution. Simulations indicated that the role of gene flow will depend on the initial resistance allele frequency and population size. If the initial resistance allele frequency is high, resistance will develop locally and migration from susceptible populations, if sufficiently high, may delay its evolution. If resistant alleles are rare, resistance may only evolve in a small number of populations and spread by migration. Under these conditions, migration will hasten the overall rate of resistance evolution. The implications for the management of insecticide resistance are emphasized.

Evolution of resistance to pesticides has become a major problem in pest management programs. As the costs of developing new pesticides rise, efforts to delay resistance via pesticide resistance management programs increase. In Hawaii, the diamondback moth, *Plutella xylostella* (L.), a serious pest of cruciferous crops, has yet to develop strong resistance to pyrethroid pesticides. While variation in resistance to these pesticides exists among Hawaiian populations (Tabashnik et al. 1987), serious control failures are not a common occurrence. Any attempt to manage resistance in this species depends on a knowledge of how various factors affect the speed at which resistance evolves. Because field experimentation in this area is difficult, and undesirable due to the potential for hastening the development of resistant strains, computer and mathematical models have been used extensively to simulate resistance evolution (Comins 1977a, 1977b, 1979, Georghiou & Taylor 1977, Plapp et al. 1979, Taylor & Georghiou 1979, Tabashnik & Croft 1982, Tabashnik 1986). Such models have generally concluded that the rate of resistance evolution is primarily dependent on the strength of selection, dominance of resistance, frequency of spray applications, refugia presence and size, and immigration. The importance of resistance dominance and immigration have been substantiated in laboratory experiments (Flexner et al. 1989, Taylor et al. 1983, Prasittisuk & Curtis 1982).

Some models suggest that migration of susceptible individuals from untreated to treated populations has the potential to retard resistance evolution (Georghiou & Taylor 1977, Taylor & Georghiou 1979, Tabashnik & Croft 1982). These models assume a continent-island model, where migration occurs only from untreated areas into a single treated population of infinite size. Comins (1977a, 1977b) modeled a two-field system consisting of one treated and one untreated field. He demonstrated that while migration will retard resistance in treated fields, it will also speed resistance evolution in the untreated fields. On the basis of a multilocus model, Uyenoyama (1986) suggested that migration from untreated to treated fields would increase the effective population size and genetic variability of the treated populations, potentially reducing pleiotropic costs associated with pesticide resistance. Emigration from treated fields could also preadapt untreated fields so that resistance would develop rapidly if those fields were ever treated.

Population geneticists have also established that gene flow will tend to limit adaptation to local selection regimes. Pollak (1974) found that an allele adaptive to local conditions will only survive if migration falls below a critical value, while Hanson (1966) found that the preservation of pockets of adaptation are subject to similar conditions. Spieth (1979) suggested that migration is not a force (it alone cannot change allele frequencies), but a mediator adjusting the relative role of local vs. global selection. In an island model, intermediate levels of gene flow were most efficient at retaining genetic variation (Takahata 1983). If gene flow was too great, the population behaved as one unit and no local adaptation occurred. If gene flow was too low, mutant alleles were not transported between subpopulations and genetic variance decreased.

The objectives of our research were to: 1) quantify gene flow among diamondback moth populations in Hawaii; 2) determine how gene flow affects resistance evolution among subdivided, finite treated populations, and 3) determine what effect gene flow has on resistance allele frequencies when treated and untreated populations coexist in approximately equal numbers. The latter objective addresses a situation that is a more appropriate model of most agricultural pests than the continent-island model employed in many previous simulations.

Materials and Methods

A computer simulation program (POPGEN) was developed to simulate resistance evolution among multiple, finite fields (Caprio & Tabashnik, *in press*). This simulation differs from most resistance models in three significant areas. First, resistance evolution was simulated in more than two fields simultaneously. This allows us to simulate untreated populations as well as treated, allowing migration to occur in both directions between these fields. Secondly, field populations were considered to be finite and inheritance particulate. As a consequence, alleles existed only in whole units, and rare alleles could become extinct in populations. Finally, stochastic events were included in the dispersal, aging, reproduction, and mating routines. This allowed rare events and genetic drift to occur. Such processes can be important for rare alleles, even among large populations.

This model was based on life-table analysis, similar to a multi-regional Leslie matrix model with fixed stage duration (Caswell 1989). Individuals were also classified by sex and genotype (and females by the genotype of their mate). Life table parameters were based on the diamondback moth, using minor modifications of the parameters given by Tabashnik (1986). Insecticide sprays were applied every 10 days. Residues decayed with a half-life of three days and could be ignored after seven. The dosage applied killed 95 percent of susceptible individuals (44 percent of heterozygotes) and affected only the larval stage.

The rate of resistance evolution was measured by two methods. The first measure was the average resistance allele frequency among all fields of one type (treated or untreated) as a function of time. The second measure was the amount of time required for 50 percent of the fields of one type to have a resistance allele frequency >50 percent and a population of more than 1000 individuals. Due to the stochastic nature of the simulation, all experiments were replicated three times.

Gene flow among treated populations. Simulations were conducted among 25 fields, all of which were treated. The initial resistance allele frequency (IRAF) varied over three levels (0.002, 0.0002 and 0.00002) while gene flow rates were 0.071, 0.0143, 0.00143 and 0.000143 in a 3 X 4 factorial design. Gene flow rates corresponded to the probability that an individual adult will disperse per day.

Gene flow among treated and untreated fields. To determine the effect of untreated fields on resistance evolution, further simulations were conducted among 49 fields, 25 of which were treated, 24 untreated. The experiment was conducted with a 3 X 4 factorial design, gene flow with four treatment levels (0.0143, 0.00143, 0.000143 and 0.0000143/per day) and the IRAF with three treatment levels (0.02, 0.002 and 0.0002).

Results and Discussion

Gene flow among treated populations. Effects of gene flow, initial resistance allele frequency, and their interaction were significant (Table 1). When the IRAF was high, many resistance alleles were present, and there was sufficient genetic variance for most fields to develop resistance locally. With high IRAF, gene flow had little effect on resistance evolution (Fig. 1). As the IRAF decreased, two things happened. First, the lowered initial frequency alone increased the time for resistance to develop and was responsible for the significant IRAF effect. As the IRAF decreased, at some point it became rare enough so that the allele was lost in some or all of the fields. Under these conditions, resistance developed initially only in those fields which by chance had sufficient genetic variance. Other fields depended on either mutation or gene flow from resistant fields to provide resistance alleles. The higher the gene flow, the faster resistance evolved. This effect only occurred when the IRAF was low and was partly responsible for the significant interaction term in the ANOVA.

Table 1. Analysis of variance for treated fields.[1]

Parameter	*DF*	*F*	*P*
Initial Resistance Allele Frequency	2	116.20	0.000
Gene Flow	3	18.08	0.000
Interaction	6	4.37	0.004

[1] Data log transformed

Gene flow among treated and untreated fields. Results with 25 treated and 24 untreated were similar to those with all fields treated. As before, effects of IRAF, gene flow, and the gene flow x IRAF interactions were significant (Table 2). There was, however, a decrease in the rate of resistance evolution at high gene flow rates (Fig. 2). The large number of susceptible migrants from untreated populations delayed resistance

Table 2. Analysis of variance, treated and untreated fields.[1]

Parameter	*DF*	*F*	*P*
Initial Resistance Allele Frequency	2	213.40	0.000
Gene Flow	3	6.76	0.002
Interaction	6	2.90	0.028

[1] Data log transformed

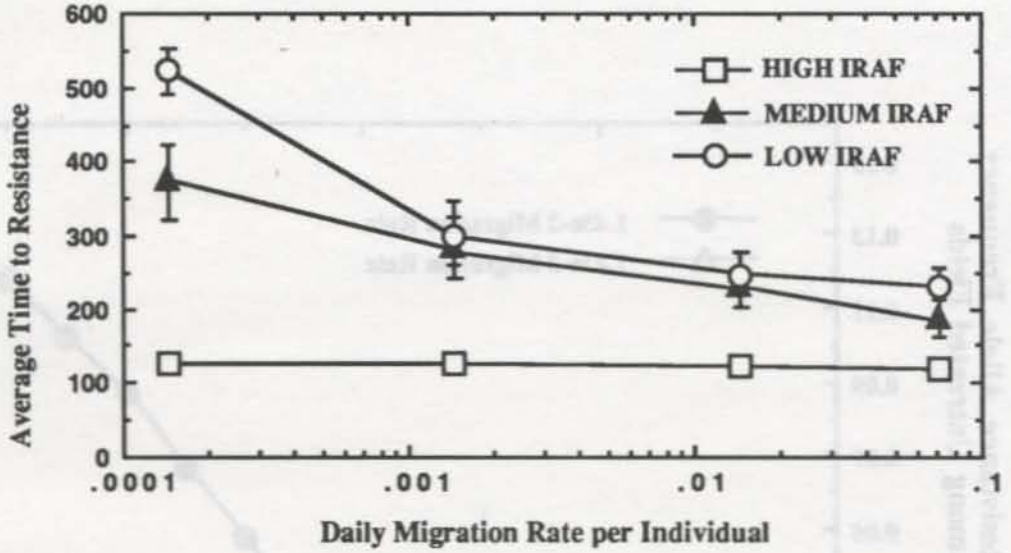

Fig. 1. Effect of migration rate at three different levels (0.002, 0.0002 & 0.00002 equals high, medium & low frequency) of initial resistance allele frequency (IRAF) when all fields were treated.

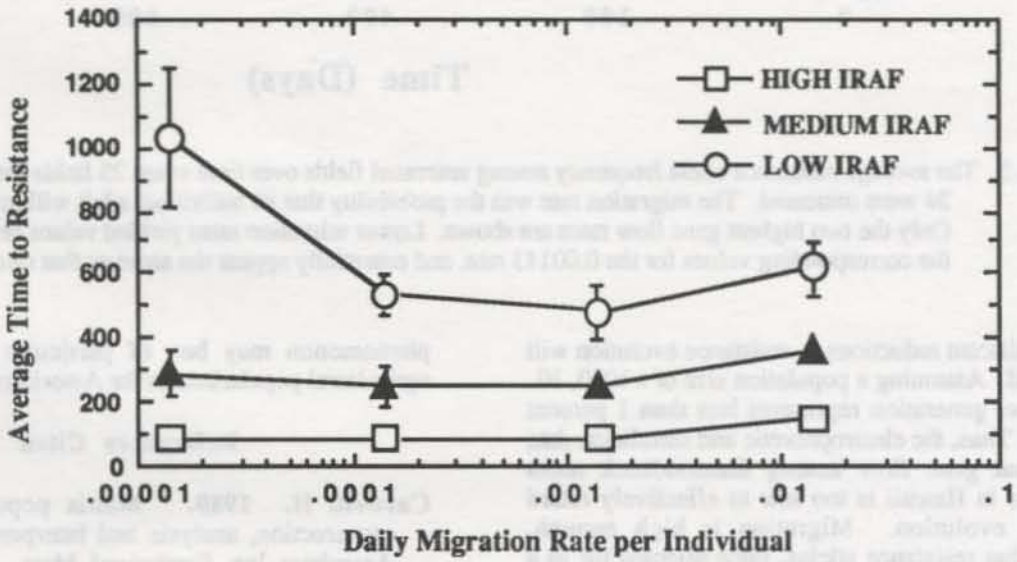

Fig. 2. Effect of migration rate at three different levels (0.002, 0.0002 & 0.00002 equals high, medium & low frequency) of initial resistance allele frequency (IRAF) when 25 fields were treated and 24 fields were left untreated.

evolution in treated fields. The gene flow rates at which this began correspond to approximately 10 percent migration per generation. Under these same conditions of high gene flow, the resistance allele also became common among untreated fields (Fig. 3). When the migration rate was 1.4 percent per day, the average resistance allele frequencies among untreated populations exceeded 10 percent by day 600. Subsequent application of pesticides in these fields would rapidly select for high resistance levels.

Electrophoretic measurements of gene flow among diamondback moth populations in Hawaii (Caprio, personal observation) indicate that on the order of 5 - 10 migrants are exchanged between populations per generation. The simulations indicate that over 10 percent of the population must migrate per generation

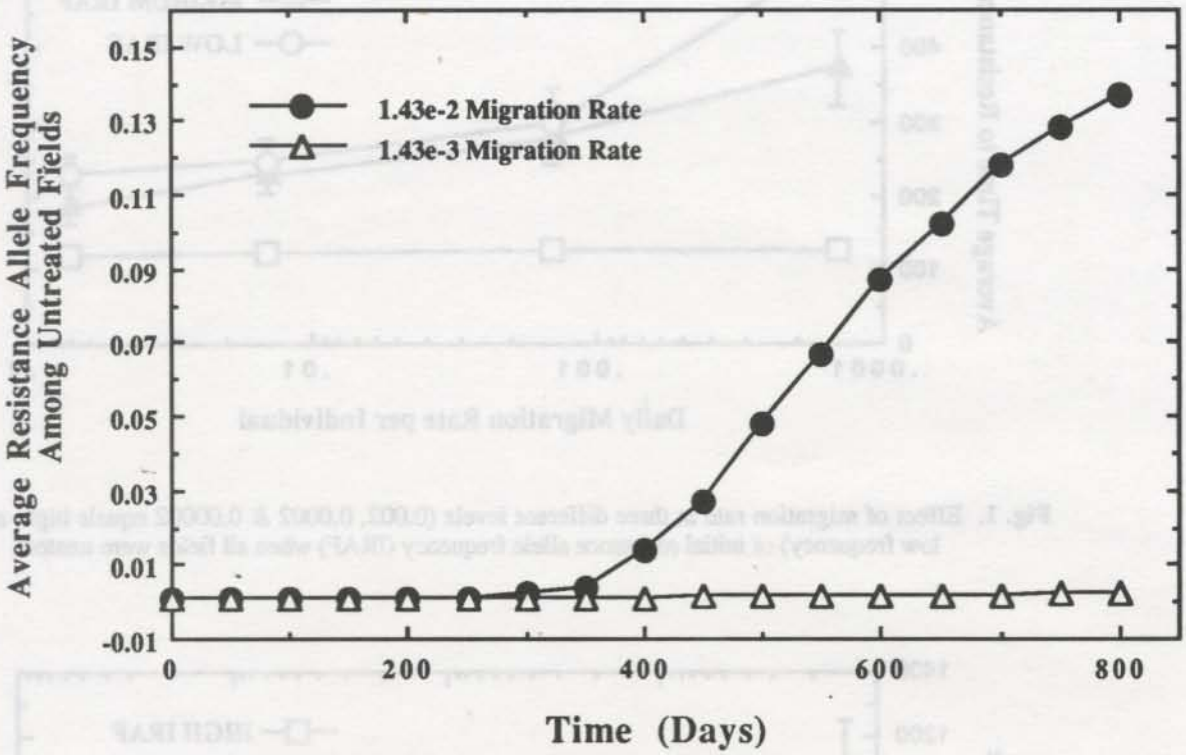

Fig. 3. The average resistance allele frequency among untreated fields over time when 25 fields were treated and 24 were untreated. The migration rate was the probability that an individual adult will migrate per day. Only the two highest gene flow rates are shown. Lower migration rates yielded values between zero and the corresponding values for the 0.00143 rate, and essentially appear the same as that rate on the graph.

before significant reductions in resistance evolution will be observed. Assuming a population size of >1000, 10 migrants per generation represents less than 1 percent migration. Thus, the electrophoretic and simulation data suggest that gene flow among diamondback moth populations in Hawaii is too low to effectively retard resistance evolution. Migration is high enough, however, that resistance alleles, once selected for in a population, will spread relatively rapidly to other populations.

The results of this paper demonstrate that migration can have a significant negative impact on resistance management strategies when resistant alleles are initially rare or field populations are small. Under these conditions, fields that have developed resistance should be recognized as potential inoculant sources of resistant alleles. They should be managed so as to minimize the potential of emigration of resistant alleles to other fields. Because insect pest populations in the American Pacific tend to be small relative to continental populations, and may have lost rare alleles due to founder events (Rosenheim et al. 1990), this phenomenon may be of particular importance in agricultural populations in the American Pacific.

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A METHOD FOR CREATING CUSTOM-MADE STANDARD AREA DIAGRAMS TO ASSESS CROP PEST DAMAGE

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ABSTRACT Severity of angular leaf spot of bell pepper, caused by *Xanthomonas campestris* pv. *vesicatoria*, and cassava blight, *X. campestris* pv. *manihotis*, were measured with a drafting tablet (Summagraphics MacTablet®) attached to an Apple Macintosh® computer. The software used was a drafting program (MacDraft®). An evaluation of this equipment and software for direct measurement of disease severity revealed that accuracy and precision were both dependent on the operator. However, this relatively inexpensive computer attachment proved to be very accurate, flexible and useful in the preparation of field keys or standard area diagrams, which can in turn serve to assess the severity of pest damage on plants. Field keys can be prepared from actual leaf samples. These can be custom-made for each particular cultivar to be assessed, if necessary.

Foliar diseases pose a serious threat to various crops on Guam. Among them, angular leaf spot, *Xanthomonas campestris* pv. *vesicatoria*, on bell peppers (Russo et al. 1985) and bacterial blight, *X. campestris* pv. *manihotis*, of cassava are significant (Wall & Santos 1987). To evaluate various control methods, it becomes necessary to evaluate disease severity. A popular and practical method for doing so is with the use of standard area diagrams (Zadoks & Schein 1979). However in contrast to temperate zone crops, when dealing with tropical crops, it is difficult to find well developed field keys or area diagrams already developed, as in the case of most temperate crops (James 1980). Therefore, one must either create these field keys or devise other ways of evaluating disease severity. Recent advances in the field of electronics may offer plant pathologists faster and more accurate ways of determining severity of foliar diseases. Our objective was to evaluate one of the latter options, namely a Macintosh® computer fitted with a Summagraphics MacTablet® and a MacDraft® software package, for its applicability in determining foliar disease severity.

Materials and Methods

Three different operators were given a bell pepper leaf affected by angular leaf spot and a cassava leaf with lesions caused by the bacterial blight organism. They traced each leaf six times and estimated the leaf area using the drafting tablet and software package mentioned above. The area readings for each operator and each leaf were then subjected to statistical analysis.

In another test, six geometric figures were drawn on millimetric grid paper. Each of the three operators traced the geometric figures six times each and estimated their area by means of the instrument being evaluated. Figures consisted of two circles (small = 19.60 mm^2; large = 1125.38 mm^2), two squares (small = 2.02 mm^2; large = 225.00 mm^2) and two triangles (small = 4.17 mm^2; large = 377.29 mm^2). The exact areas of the figures were calculated from the grid paper and compared to the areas estimated by the drafting tablet method.

Results and Discussion

Mean leaf area readings for the bell pepper leaf differed significantly (pooled *t*–test; P=0.05) depending on operator. Operator 2 obtained higher readings than the others (Fig. 1). The same situation occurred with the cassava leaf. The box plots illustrate the range of readings obtained by each operator, and give an idea of the degree of precision the drafting tablet can offer, which again, varied with operator.

With the geometric figures, comparisons were made between operators and between estimated and actual areas. Comparisons were made between the three operators estimating the areas of six different figures (Table 1). Certain figures, such as the large square and small circle, were given identical area estimates by all operators. However, the small triangle was read differently by all operators. While all operators obtained different readings for the large circle, triangle and small square, only one was significantly different from the others (Fisher's LSD).

Comparing area estimates to the actual areas, the drafting tablet and drafting software gave precise and accurate readings for the large square (mean = 225.00 mm^2; 225 to 225 mm^2 = 95% CI) and small circle (mean = 19.60 mm^2; 19.60 to 19.60 mm^2 = 95% CI). The large circle was estimated to be 1125.38 mm^2 (753.64 to 1497.12 mm^2= 95% CI). Estimates provided for the small and large triangles were 4.17 mm^2 (-4.89 to 13.22 mm^2 = 95% CI) and 377.29 mm^2 (335.24 to 419.35 mm^2 = 95% CI), respectively. The small square was consistently underestimated (mean = 2.02 mm^2; -0.48 to 6.53 mm^2 = 95% confidence interval) by all operators compared to its actual area

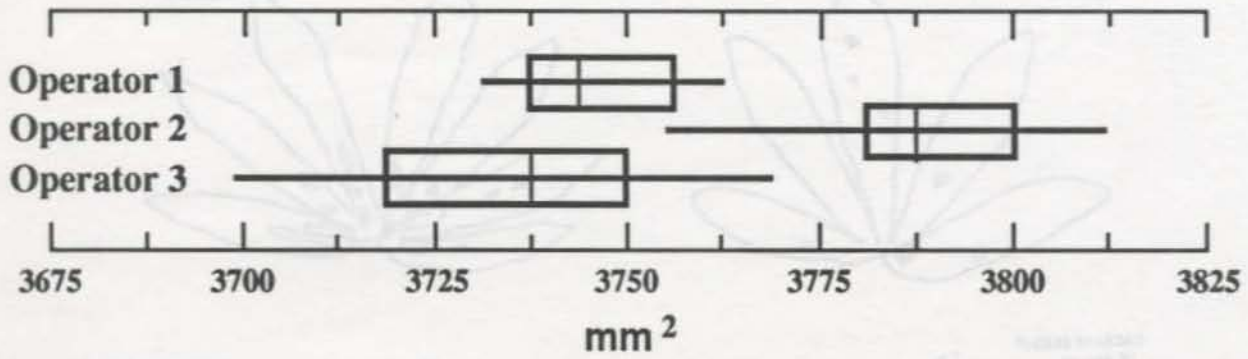

Fig. 1. Box plots of bell pepper leaf areas measured by different operators using MacTablet®.

(6.25 mm^2). The reason for this seems to be that the length chosen for the sides of this square were either under or near to the limit of instrument sensitivity. Additionally, when using the ready-made figures option, only 5 mm increments were read accurately for rectangles and circles. However, it was possible to read in-between sizes if the figures were hand-traced rather than read by the ready-made figures option. In general, given the three different types of geometric figures tested, the drafting tablet was able to read their area with relatively little or no error. The main limitation found in using this instrument for direct readings of leaf samples was the time required for tracing leaves with lesions, and then obtaining the area readings.

In conclusion, we found that leaf area readings can be made with this instrument, but its accuracy and precision are influenced by the operator. Each individual reading was also time-consuming. In contrast, we found that the MacTablet-MacDraft combination was better fit for developing standard area diagrams because it offered a certain degree of accuracy and precision in the hands of a trained operator. It is capable of giving instant area readings of drawn objects of any shape and printing these. Indeed, we created our own custom-made diagrams for cassava and bell pepper cultivars (Fig. 2). These were designed to represent the levels of disease severity desired in our field keys and the correct leaf shapes according to our cultivars. In cassava, particularly, there is a wide variation in leaf shape between cultivars.

With this drafting tablet and software, the operator has an almost unlimited freedom for tracing leaves and spots or lesions of varied shapes and sizes. Actual leaf samples can be traced and the amount of damage represented can be adjusted to the desired levels and printed. An additional advantage is that both the MacTablet and MacDraft are readily available commercial products.

Acknowledgment

This work was funded in part by a USDA Special Grants Program for Tropical and Sub-tropical Agricultural Research (83-CSRS-2-2246).

Table 1. Area of various objects measured by different operators with MacTablet®.

		Operator No.					
		1		2		3	
Object	Size	Mean	(±SD)	Mean	(±SD)	Mean	(±SD)
Square	6.25	4.05**	(2.13)	1.45	(1.61)	2.74	(0.33)
	225.00	225.00	(0.00)	225.00	(0.00)	225.00	(0.00)
Triangle	3.13	8.31**	(0.30)	1.45**	(0.32)	2.74**	(0.33)
	400.00	395.32**	(10.86)	361.73	(8.93)	374.83	(15.37)
Circle	19.60	19.60	(0.00)	19.60	(0.00)	19.60	(0.00)
	1256.00	1256.00	(0.00)	962.10**	(0.00)	1158.03	(151.77)

** Differences among operators ($P = 0.01$) as determined by LSD.

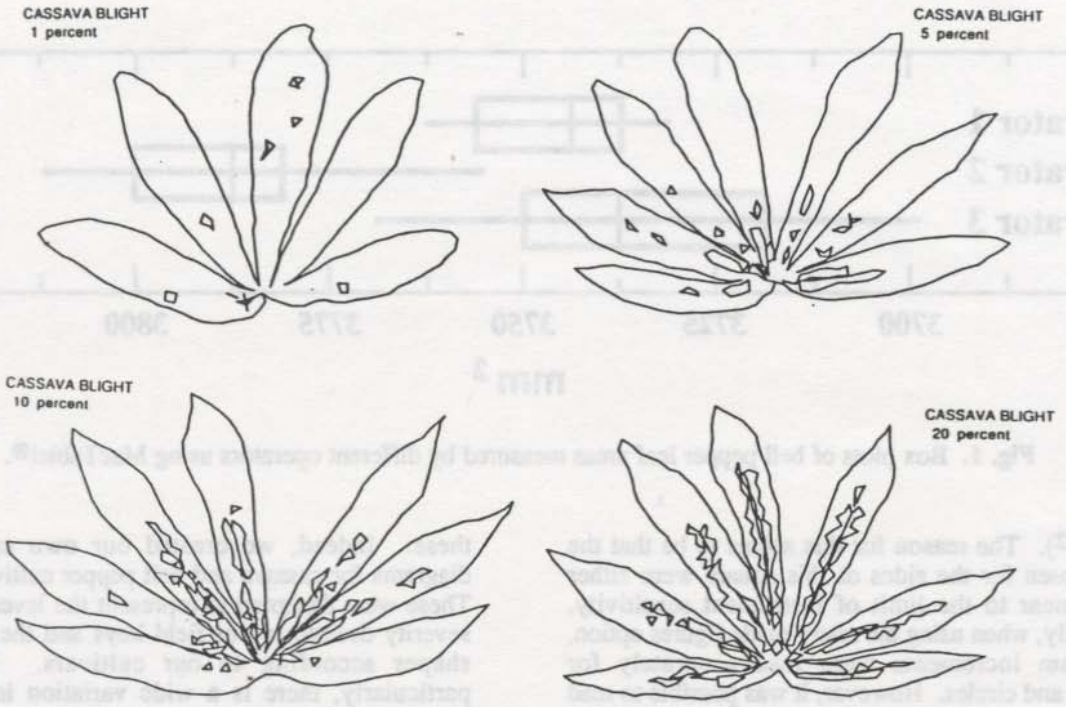

Fig. 2. Standard area diagrams or field keys created with MacTablet® for evaluating cassava blight severity.

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THE BIOACCUMULATION OF OXYFLUORFEN IN HAWAIIAN GROWN TARO AND ITS MOVEMENT WITH WETLAND FLOOD WATERS

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ABSTRACT In preliminary screening experiments with wet and dryland taro (*Colocasia esculenta*), thiobencarb (4 to 6 kg ai/ha) and oxyfluorfen (0.3 to 0.6 kg ai/ha) were not injurious when applied at planting and as directed postemergence sprays. Oxyfluorfen was superior in performance to the other herbicides tested. A subsequent experiment determined residues of oxyfluorfen in edible plant parts. In dryland taro, oxyfluorfen was applied at 0 and 98 days after planting (DAP) at 0.38, 0.56 and 1.11 kg ai/ha. Edible leaves and corms were sampled 186 days after the last herbicide application. No oxyfluorfen residues were found in plant tissues (limit of detection 0.02 ppm). In wetland taro, oxyfluorfen was applied at the same rates at planting and 95 DAP. Corms were sampled 282 days after the last herbicide application, and no detectable levels of oxyfluorfen were found. To determine oxyfluorfen movement from flooded fields, water samples flowing from treated plots were analyzed. Flood waters leaving plots immediately after treatment with oxyfluorfen at 0.56 and 1.11 kg ai/ha contained an average of 0.008 ppm and 0.009 ppm, respectively (limit of detection, 0.001 ppm). Water samples taken 24 hours later had no detectable levels of oxyfluorfen.

Taro is a tropical crop grown for edible corms, leaves and stems. The natural habitat of taro is south-eastern Asia and Malaysia (Allen 1940). In Hawaii, taro is generally classified into two distinct groups. Dasheen (*Colocasia esculenta* var. antiquorum) is grown for small edible auxiliary corms that are boiled and eaten. Dasheen was promoted by the USDA in 1910 as a promising wet-land crop for the southern United States (Barrett & Cook 1910). Chinese taro (*Colocasia esculenta* var. esculenta) is grown in Hawaii for consumption of young leaves and edible main corm (derived from seed piece). Large corms (3 to 4 kg) are the desired commodity for fresh market and chip production (deep fried slices, similar to potato chips). Taro,*Colocasia esculenta* var. esculenta, grown under flooded wetland conditions is cooked and ground into a thick paste (poi) and eaten.

Unchecked weed growth during dry and wetland taro production reduces yields and makes harvesting difficult. Herbicides provide a cost effective alternative to expensive manual labor (prevalent throughout Hawaii).

In a preliminary experiment (unpublished data) in Hawaii, several preemergence herbicides were evaluated on chinese taro and dasheen. The herbicides evaluated were diuron (1.1 and 2.2 kg ai/ha), metribuzin (0.6 and 1.1 ai kg/ha), oxyfluorfen (0.6 and 1.1 ai kg/ha), metolachlor (2.3 kg ai/ha), pronamide (2.3 kg ai/ha), thiobencarb (4.5 kg ai/ha) and diethatyl (2.3 kg ai/ha). All treatments were applied at 0, 69 and 172 days after planting (DAP). All applications made after planting were directed to the base of plants. Metribuzin caused unacceptable crop injury on chinese taro which reduced yield. None of the herbicide treatments adversely affected dasheen yield, in contrast to a previous report (Kasasian 1967) showing crop injury with diuron. Short term (35-40 days) activity of diethatyl, pronamide, metolachlor and metolachlor prevented their inclusion in subsequent studies. Diuron and thiobencarb were dropped from further study due to problems in obtaining legal use of these materials in the USA. Oxyfluorfen emerged from this study as the most promising herbicide for use in commercial taro production. The objective of this research was to determine the bioaccumulation of oxyfluorfen in edible taro corms and leaves from plants growing in wetland paddies and upland soils. The amount of oxyfluorfen in paddy flood waters was also determined.

MATERIALS AND METHODS

Upland taro study

The experiment was conducted at the University of Hawaii Waimanalo Research Farm, Oahu, on Waialua stony silty clay (vertic haplustolls, 2% organic matter and pH 6.3). The study began on 21 May 1987 with oxyfluorfen applied (7 and 105 DAP) at three rates; 0.38, 0.58 and 1.11 kg ai/ha. A control treatment consisted of hand weeding 25, 48 and 70 DAP. Herbicide treatments applied after planting were directed to the base of plants on plots that were weed free. In all experiments, herbicides were applied in a spray volume of 350 l/ha at 125 kPa using flat fan spray tips (Spraying Systems Co. Wheaton, IL 61820, USA). Fertilization, irrigation and other pesticides were applied

as needed for commercial crop production (Mitchell & Maddison 1983). Taro (cv. `Niue') planting material consisted of an axial corm with a 25-30 cm petiole attached. An experimental unit was 2 m wide X 4.6 m long with a double row of taro (within row spacing was 0.5 m and between row spacing was 0.6 m). Treatments in all experiments were replicated four times using a randomized complete block design. Taro leaves and corms were sampled 186 days after the final herbicide application. Standard procedures (Adler & Hofman 1980, Adler et al. 1978, Pesticide Analytical Manual 1983) were used for quantifying oxyfluorfen in edible taro leaves and corms.

Wetland taro

Oxyfluorfen in corms. An experiment was initiated on the Kauai Rice Experimental Field on the island of Kauai on 12 May 1987. The soil type was Hanalei silty clay (tropic fluvaquents, 6.6 % organic matter at pH 4.6). Oxyfluorfen was applied to drained wetland plots (0 and 95 DAP) at three rates; 0.38 .56, and 1.11 ai kg/ha. An experimental unit consisted of enclosed plots (1.8 m wide X 6.1.m long) with a double row of taro (cv.`Lehua maole') spaced 0.3 m within the row and 0.6 m between rows. Plots were formed so that water could continuously flow through each plot without cross treatment contamination. Weeds in control plots were removed by hand to avoid competitive effects on the crop. Taro corms were sampled for residue analysis 282 days after the final herbicide application. Analytical procedures used on wetland taro corms were the same as those described for the upland corms.

Oxyfluorfen in exiting paddy flood waters. On 30 September 1988 an experiment was initiated on the Kauai Rice Experimental Field to determine the concentration of oxyfluorfen in flood water exiting treated plots 0 and 24 hours after herbicide application. Oxyfluorfen was applied to drained wetland plots (0 and 81 DAP) at the rates of 0.56 and 1.11 ai kg/ha. Control plots were hand weeded as necessary to avoid crop competition. An experimental unit was 1.8 m wide X 6.1 m long and contained a double row of taro (cv.`Maui Lehua'). Immediately after the second herbicide application, flood waters entered treated plots. The 0 hour samples were taken when flood water began exiting through plot drains and 24 hours later. Each sample passed through a clean sheet of filter paper (D.B. Eaton-Dikeman Co. Filter Paper, 533 cm. grade 615) supported by a stainless steel funnel. Treatment sampling began with untreated controls and progress through increasing rates of oxyfluorfen. Samples taken 0 hours after application were placed in glass bottles wrapped in aluminum foil and refrigerated at 4°C over night, 24 hours samples were treated in a similar manner.

Results and Discussion

Two applications of oxyfluorfen on taro grown under upland and flooded wetland cultivation did not result in detectable bioaccumulation in edible leaves (dryland only) or main corms. When oxyfluorfen was applied to paddy soil, traces (0.008 and 0.009 ppm for 0.38 and 0.56 kg ai/ha, respectively) appeared in water exiting plots 0 hours after application. No traces were detected at 24 hours. Due to strict rules governing pesticides in moving water, trace levels of oxyfluorfen in exiting flood water will preclude legal (in USA) use in the manner documented here. Research will be initiated to define a wetland cultural practice which will prevent detectable levels of oxyfluorfen in waters leaving treated taro paddies.

Acknowledgment

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SURVEY OF ORIENTAL FRUIT FLY AND MELON FLY (DIPTERA: TEPHRITIDAE) INFESTATIONS IN PAPAYA

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ABSTRACT An extensive field survey was conducted on the island of Hawaii to determine infestation levels of oriental fruit fly, *Dacus dorsalis* Hendel, and melon fly, *D. cucurbitae* Coquillett, in `Kapoho Solo' papaya (*Carica papaya* L.), using fruit colorimetry as an index of fruit ripeness. Papaya ripeness was quantified with HunterLab Labscan Spectrocolorimeter® b readings taken at the external surface of the blossom end and at the most yellow spot. Colorimetric b readings measure fruit yellowness which is a good indicator of fruit ripeness. Data gathered provide information on oriental fruit fly and melon fly natural infestation rates in papaya at varying stages of ripeness. The data presented herein are pivotal in assessing efficacy of quarantine treatments being developed against oriental fruit fly and melon fly in papaya.

The present quarantine treatment for papaya (*Carica papaya* L.) produced in Hawaii and destined for market in the continental United States requires careful fruit selection and a two-stage hot-water immersion treatment, referred to as the "double-dip" method (Couey & Hayes 1986). The double-dip quarantine procedure involves selecting less than quarter-ripe fruit prior to the application of an initial 30-minute immersion in water at 42°C, followed immediately by a second hot-water immersion at 49°C for 20 minutes (Animal and Plant Health Inspection Service 1988). Random samples of double dipped fruits are checked for their conformation to the colorimetric fruit selection protocol which is acceptance of fruits with blossom end colorimeter b values of $\leq$ 23.4 and yellow spot b values of $\leq$ 27.4. The b values are measures of yellowness of the fruits, obtained by using the HunterLab LabScan Spectrocolorimeter® (Hunter Associates Laboratory, Inc., Reston, Va.). The yellow spot is the most yellow spot (outside the blossom end) on the fruit's skin surface, usually in the equatorial region. Fruit with blossom end b $\leq$ 23.4 and yellow spot b $\leq$ 27.4 are mature green and color break fruit whereas those with blossom end b $\geq$ 23.5 and yellow spot b $\geq$ 27.5 range from quarter to fully ripe fruit (unpublished data). Because the current quarantine protocol for papaya fruit relies heavily on the external coloration of the blossom end and the most yellow spot, a field survey was conducted at major commercial orchards on the island of Hawaii to determine the levels of oriental fruit fly, *Dacus dorsalis* Hendel, and melon fly, *Dacus cucurbitae* Coquillett, infestations in papaya of varying degrees of ripeness, using the fruits colorimetric b readings as indices of ripeness.

Materials and Methods

Papaya (`Kapoho Solo') fruit samples were collected from five major orchards in the District of Puna, Hawaii. Orchards were divided into equal quadrats measuring 30 by 30 m. One hundred quadrats were selected in each orchard. Trees at the middle of each quadrat were selected for sampling and inspected biweekly. To aid in sampling, fruit on trees were categorized visually as mature green, color-turning, one-fourth, one-half, three-fourths, and fully ripe based on the degree of the skin's yellow coloration (Liquido et al. 1989). Only those trees with either three-fourths or fully ripe fruit were selected during each sampling occasion; one fruit of each available ripeness category was picked from each tree. Data presented are biweekly samples collected between September 1985 to July 1988.

Each fruit sample was wiped to remove the dirt and fungicide (Dithane M45; Rohm and Haas Co., Philadelphia, Pa.) regularly applied by the farmers. Color readings were obtained from the blossom end and from the most yellow spot on the fruit, either in the equatorial or subequatorial regions, using the HunterLab Labscan Spectrocolorimeter®. Being a tristimulus colorimeter, it outputs three color readings: L, a, and b (Francis & Clydesdale 1975). The L value measures the lightness of the surface being tested. The a value measures the blueness to redness (i.e., it is negative at blue and becomes positive towards the red spectrum). The b value measures the blueness to yellowness; negative value indicates blueness, lower positive value indicates greeness, while higher positive value indicates yellowness. The colorimeter was standardized with a yellow tile (L = 77.8, a = -2.0, b = 23.8).

After determining the colorimetric readings, fruit were individually placed inside 5 liter plastic buckets which contained a 5-cm layer of wheat bran at the bottom. The methods of fruit holding and determining the density of oriental fruit fly and melon fly in each fruit followed the procedures described by Liquido et al. (1989).

For data analyses, fruit samples were sorted using b values read at the blossom end and the most yellow spot and grouped following the class limits used by Couey & Hayes (1986). The blossom end b (hereinafter referred to as Bb) value class limits are : ≤ 14.4; 14.5 - 17.4; 17.5 - 20.4; 20.5 - 23.4; 23.5 - 26.4; 26.5 - 29.4; 29.5 - 32.4; 32.5 - 35.4; ≥ 35.5. The yellow spot b (hereinafter referred to as Yb) value class limits are: ≤ 18.4; 18.5 - 21.4; 21.5 - 24.4; 24.5 - 27.4; 27.5 - 30.4; 30.5 - 33.4; 33.5 - 36.4; ≥ 36.5. The number of oriental fruit fly and melon fly in infested fruits were summarized by Bb and Yb classes. Data management and analyses were performed using DATA STEP and PROC STEP, FREQ, and MEANS of SAS Version 5 (SAS Institute, 1985a,b).

Results and Discussion

Frequency distributions of fruit infested with oriental fruit fly and melon fly per Bb and Yb class limits are presented in Fig.s 1a and 1b, respectively. Oriental fruit fly and melon fly infested and survived in papaya fruit of all Bb and Yb class limit combinations. Fruit with Bb ≤ 23.4 and Yb ≤ 27.4 (i.e., mature green to color break) were relatively less infested with oriental fruit fly and melon fly than those with higher b readings for the blossom end (> 23.4) and the most yellow spot (> 27.4). Most oriental fruit fly and melon fly infestations occurred in fruit with Bb and Yb > 30 (i.e., three-quarters to fully ripe). These results differ from those obtained by Seo et al. (1982) and Couey et al. (1984), but are consistent with those reported by Keck (1942) and Liquido et al. (1989). Seo et al. (1982) reported that mature green, color-break and quarter-ripe field collected papaya fruit were free of oriental fruit fly infestation all year round and that half- to fully ripe fruits were infested. Couey et al. (1984) reported a slightly different infestation rate of papaya by oriental fruit fly: mature green and color-break fruits were never infested while quarter-ripe fruit were rarely infested. Seo et al. (1982) did not report any infestation of papaya by melon fly, while Couey et al. (1984) found melon fly infestation only in half- to fully ripe fruits. Keck (1942) reported infestation of Mediterrranean fruit fly, *Ceratitis capitata* (Wiedemann), in papaya of all levels of ripeness. Likewise, Liquido et al. (1989) reported oriental fruit fly and melon fly infestations in papaya fruit of all visual ripeness categories.

Fruits with Bb ≤ 23.4 and Yb ≤ 27.4 had an average of 0.1 to 1 oriental fruit fly per fruit, while those with Bb ≥ 23.5 and Yb ≥ 27.5 averaged 1 to 24 oriental fruit flies per fruit (Fig. 1b). The mean number of melon fly in fruits with Bb ≤ 23.4 and Yb ≤ 27.4 ranged from ≤ 0.004 to 1; while the melon fly mean density in Bb ≥ 23.5 and Yb ≥ 27.5 ranged from 0.2 to 2 (Fig. 2b).

Calculation of mean numbers of oriental fruit fly and melon fly based only on infested fruit samples showed a different distribution of the means of the oriental fruit fly and the melon fly per Bb and Yb class limits. Fruits with Bb ≤ 23.4 and Yb ≤ 27.4 had 16 - 90 oriental fruit flies and 1 - 25 melon flies; those fruits with Bb > 23.4 and Yb > 27.4 had 10 - 118 oriental fruit flies and 7 - 45 melon flies per infested fruit (Figs. 1c, 2c).

Data presented in Figs. 1 and 2 suggest that the oriental fruit fly is the dominant fruit fly pest of papaya in Hawaii, and that melon fly infestation in papaya is rare compared with that of the oriental fruit fly. Although oriental fruit fly and melon fly infestations are extremely low in fruits with Bb ≤ 23.4 and Yb ≤ 27.4, these fruits, if infested, are capable of supporting as many larvae as those fruits with higher b readings (Fig.s 1c, 2c).

Fruit with Bb ≤ 23.4 and Yb ≤ 27.4 had a maximum oriental fruit fly density range of 176 - 200 (Fig. 3) and a maximum melon fly density range of 1 - 25 (Fig. 4). Fruit with Bb ≥ 23.5 and Yb ≥ 27.5 had a maximum oriental fruit fly density range of 426 - 450 and a maximum melon fly density range of 151 - 175. The maximum numbers of oriental fruit fly and melon fly in infested fruits were observed in fruits in which these two *Dacus* species did not coexist. Eighty six percent of fruit fly-infested fruit with Bb ≤ 23.4 and Yb ≤ 27.4 had oriental fruit fly only, while 4 percent had only melon fly and 10 percent had both oriental fruit fly and melon fly. Seventy seven percent, 2 percent, and 21 percent of fruit fly-infested fruits with Bb ≥ 23.5 and Yb ≥ 27.5 had oriental fruit fly only, melon fly only, and both the oriental fruit fly and melon fly, respectively.

Data shown in Figs. 3 and 4 can be used as guidelines for expected densities of oriental fruit fly and melon fly in papaya per quantitative ripeness index. For instance, current procedures for developing quarantine treatment for papaya rely on arbitrary densities of oriental fruit fly and melon fly to test for treatment efficacy. To preserve the maximum quarantine security, the arbitrary values are often higher than natural infestation rates. Use of such inflated density values may result in a treatment with overkill that consequently damages many marketable fruits. Conversely, a test situation may occur in which the arbitrary fruit fly density is lower than the expected natural infestation rate, resulting in a treatment without the necessary quarantine security. Therefore, by comparing natural infestations against the expected infestation rates shown (Figs. 3, 4), a quarantine treatment could be formulated and developed to provide the desired quarantine security without sacrificing fruit quality.

Conclusions from the survey were that oriental fruit fly and melon fly were capable of infesting papaya fruits at all levels of maturity or ripeness as measured by the fruits' Bb and Yb; and that oriental fruit fly and melon fly natural infestations in papaya rarely occur in fruit acceptable by the double-dip quarantine procedure (Bb ≤

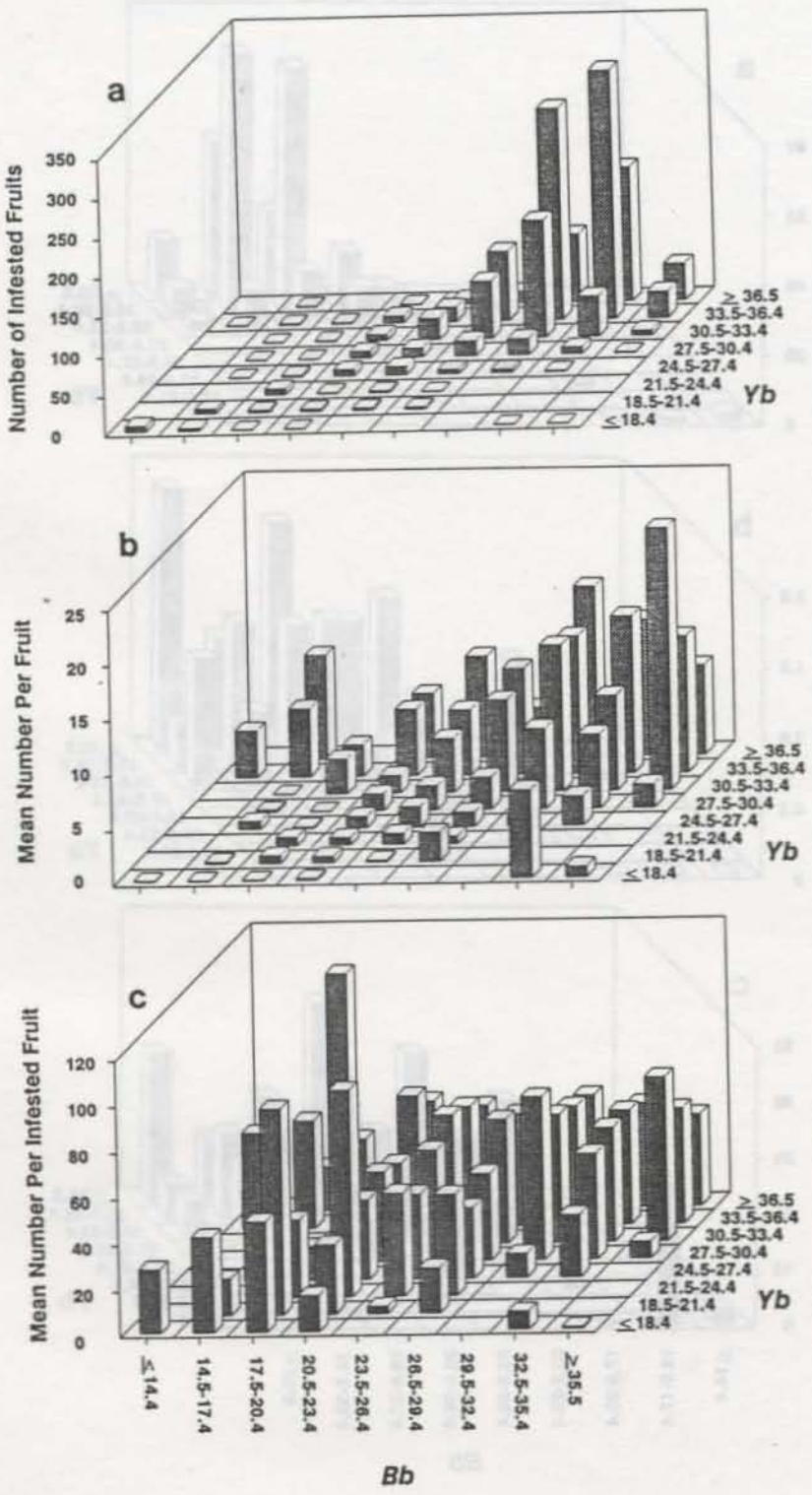

Fig. 1. Infestation rate of papaya fruit by oriental fruit fly per blossom end and the most yellow spot b value classes: (a) number of infested fruit; (b) mean number per fruit; and (c) mean number per infested fruit. Reprinted by permission of the Entomological Society of America from the Journal of Economic Entomology 83(2): 479, Fig. 3.

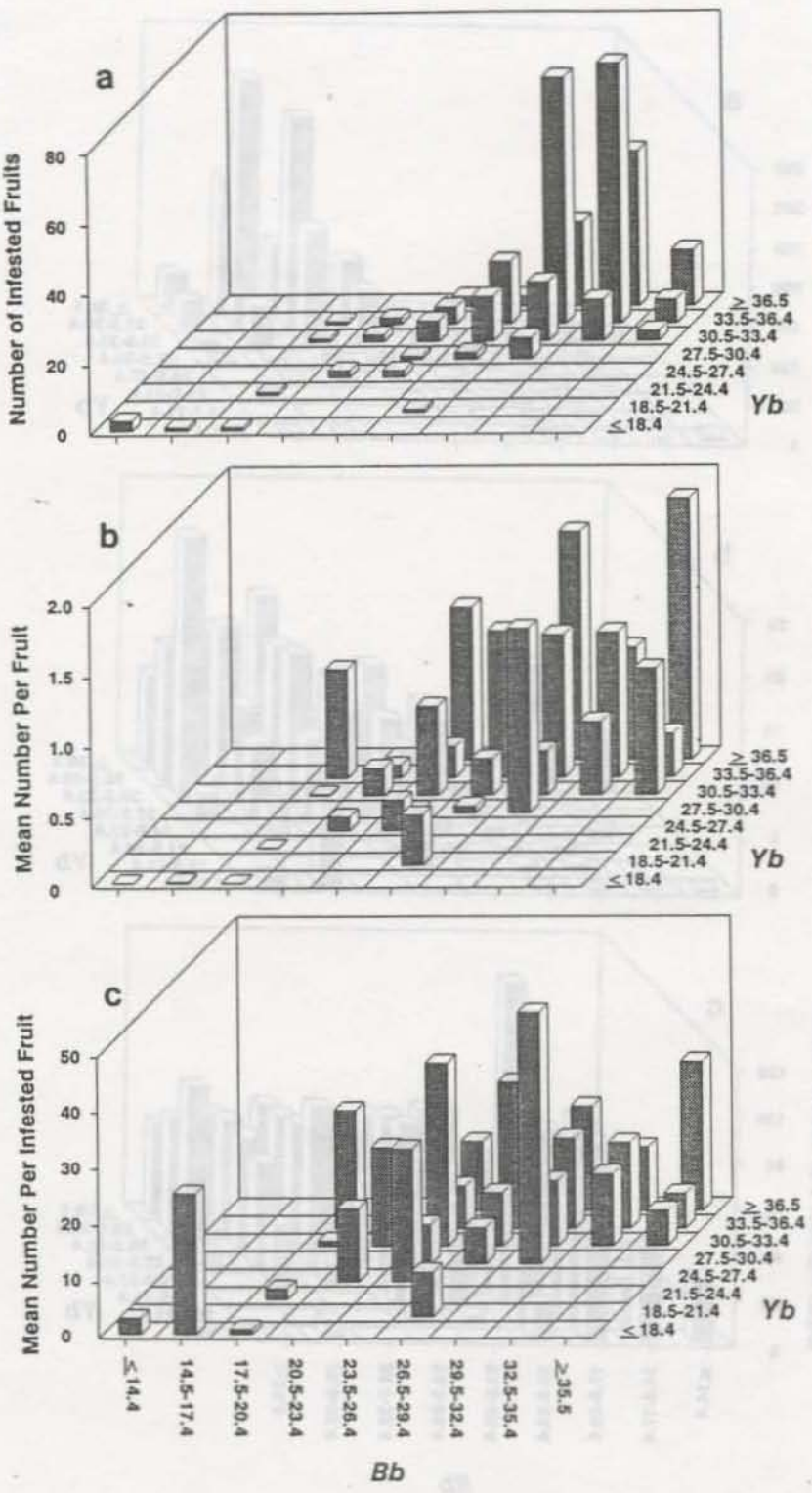

Fig. 2. Infestation rate of papaya fruit by melon fly per blossom end and the most yellow spot b value classes: (a) number of infested fruit; (b) mean number per fruit; and (c) mean number per infested fruit. Reprinted by permission of the Entomological Society of America from the Journal of Economic Entomology 83(2): 480, Fig. 4.

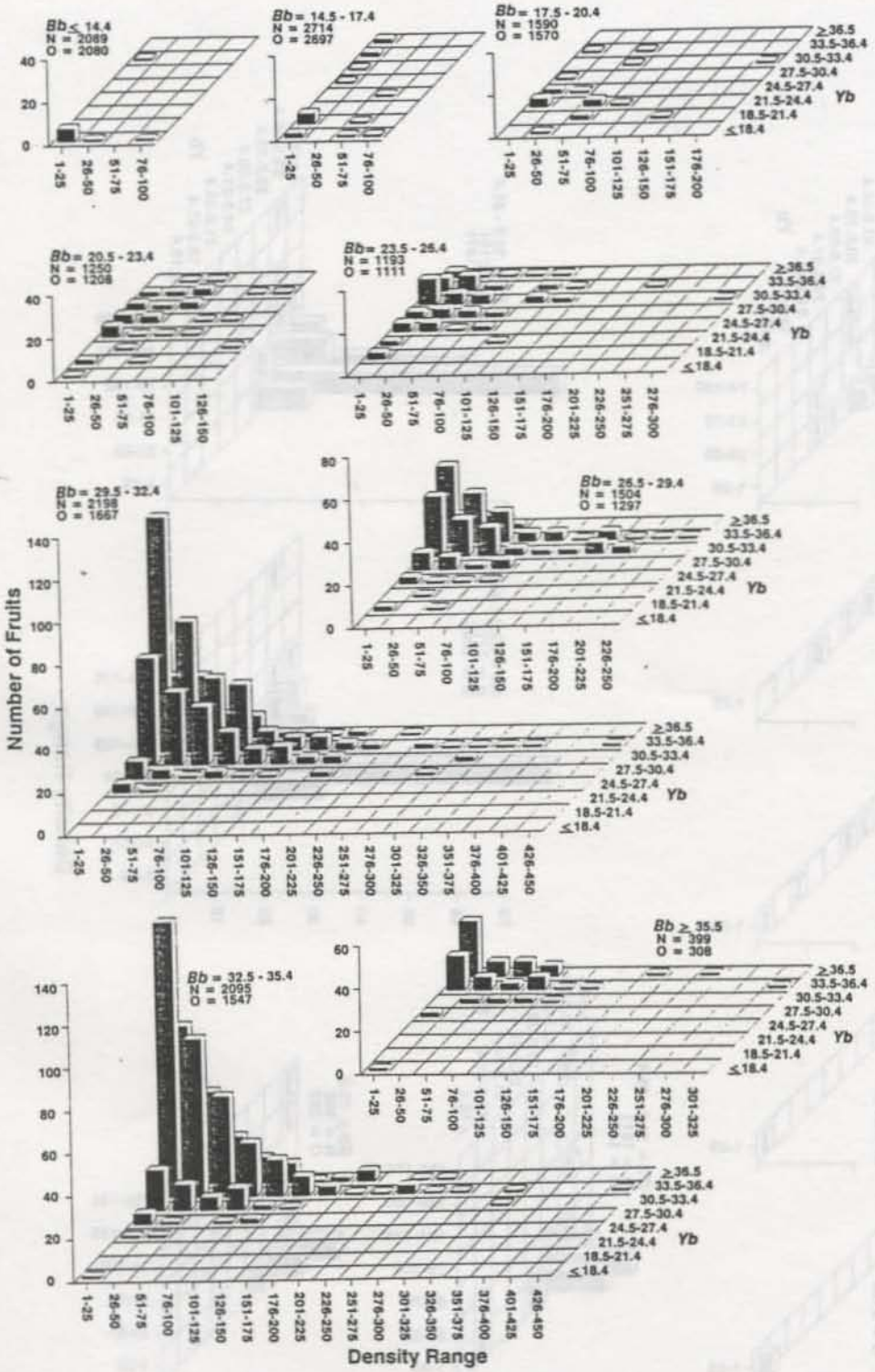

Fig. 3. Frequency distribution of the density of oriental fruit fly in infested fruit per blossom end and the most yellow spot b value classes. N = total number of fruit in a particular blossom end b value class; 0 = number of fruits with no oriental fruit fly. Reprinted by permission of the Entomological Society of America from the Journal of Economic Entomology 83(2): 482, Fig. 5.

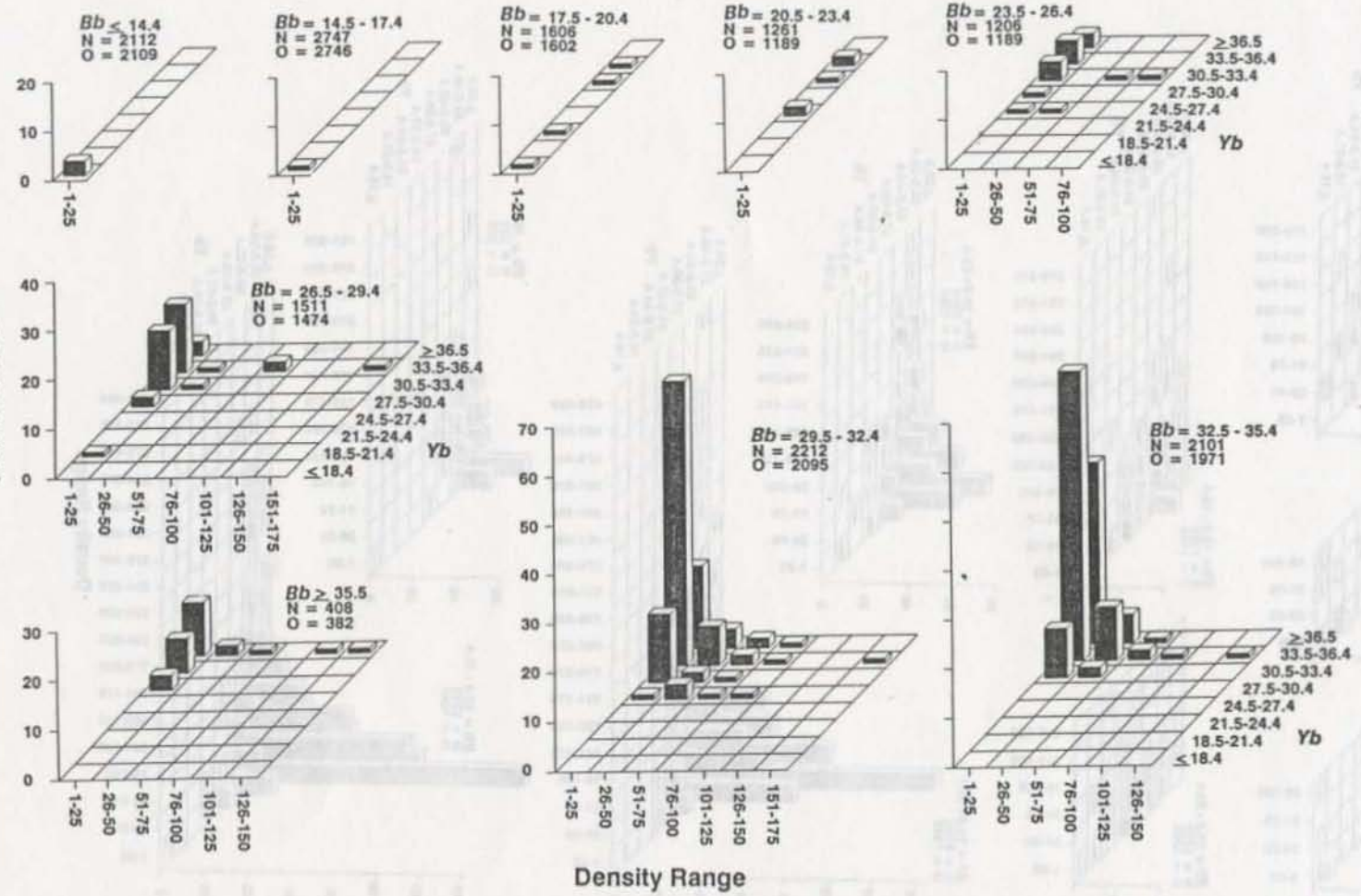

Fig. 4. Frequency distribution of the density of melon fly in infested fruits per blossom end and the most yellow spot b value class. N = total number of fruits in a particular blossom end b value class; 0 = the number of fruits with no melon fly. Reprinted by permission of the Entomological Society of America from the Journal of Economic Entomology 83(2): 483, Fig. 6.

23.4 and Yb ≤ 27.4). The study provides fundamental data on natural infestation rates of oriental fruit fly and melon fly in papaya fruit per quantitative ripeness indices. The efficacy of new quarantine treatments for these fruit flies in papaya should therefore be tested using the data presented in this paper. Because the severity of quarantine treatment is based on the expected intensity of natural infestations, the data can be used in adjusting the severity of any quarantine treatment to the minimum level that provides quarantine security and preserves the quality of the fruits.

Acknowledgment

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HERBIGATION IN AN IRRIGATED MACADAMIA NUT ORCHARD[1]

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ABSTRACT Oryzalin (4-(dipropylamino)-3,5-dinitrobenzenesulfonamide; Surflan® 4AS) and atrazine (6-chloro-N-ethyl-N'-(1-methyl)-1,3, 5-triazine-2,4- diamine; Aatrex® 80W) were applied through an irrigation system in a commercially managed macadamia, *Macadamia integrifolia* Maiden and Betche, orchard in Hawaii. Small amounts of oryzalin and atrazine residues were found in the irrigation water immediately after the herbigation cycle. Negligible amounts were found one, three and six days later. Analyses of oryzalin and atrazine residues in soil showed considerable variability among sampling sites under a single tree. In the control of crabgrass, *Digitaria* spp., and sow thistle, *Sonchus oleraceus* L., there was no difference between herbigation and conventional broadcast application at 6, 12 and 32 weeks. Broadcast application of atrazine + oryzalin controlled crabgrass better than broadcast application of atrazine alone.

Herbigation is the application of herbicides through an irrigation system. Economic advantages of herbigation in irrigated orchards include reductions in fuel, labor, herbicide and equipment. Costs have been reduced by 50 percent or more (Ogg et al. 1983). Herbigation reduces hazards to the operator and the environment because the operator is not in the field and the herbicide mixture being applied is more diluted as compared to conventional applications (Ogg et al. 1983). Herbigation may also increase the effectiveness of herbicides that require soil incorporation (Treadgill 1985). Flexibility in the scheduling of applications is another advantage (e.g., at night when there is no wind).

One disadvantage of herbigation is the risk involved if the system is not designed properly or when a mechanical failure occurs. The major risk is crop injury or death due to overapplication. Another disadvantage is unnecessary irrigation if applying a preemergence herbicide when water is not needed by the crop.

This experiment was the result of a macadamia grower's weed problem in the irrigated area. A possible solution was herbigation. Application of preemergence herbicides only to the irrigated zone compared with a typical strip application would use 67 percent less preemergence herbicide. The objective of this on-farm experiment was to compare the effectiveness of herbicides applied by herbigation verses a conventional spray application.

Materials and Methods

The study orchard was on an 8 percent slope at the southeastern side of the island of Hawaii at an elevation of 354 m. It receives an average annual rainfall of 152 cm. The orchard was divided into three irrigation sections with 170 trees per section. Trees used were seven-year-old 'Kau' (344) and 'Keaau' (660) cultivars planted 7.6 m apart on soil of the Punaluu series, originally an extremely rocky peat soil. During dry periods, each tree was irrigated three times a week for a total of 1.03 ha-cm per week with two microjet emitters placed on opposite sides of the tree trunk (Fig. 1). Each pair of emitters covered a circular area 3.7 m in diameter under the canopy of the tree. To control existing weeds, glyphosate (N-(phosphonomethyl)glycine; Roundup®) was applied at 3.36 kg a.e./ha in the rows two weeks before the experiment began. For all three treatments described below, the total amount of herbicide used over the 48-week period was 6.72 kg per sprayed hectare.

Herbigation Treatment. The first (top) irrigation section was charged with water and a constant pressure achieved at the submain before beginning herbigation. Herbicide amounts equivalent to 2.24 kg per sprayed hectare of oryzalin (Surflan® 4AS) and 2.24 kg per sprayed hectare of atrazine (Aatrex® 80W) was mixed with water to make a 17-liter slurry, then injected into the top section by a differential-pressure bladder system injector at the rate of 21 liters per hr for about 41 min as described by Holman (1985). The herbicide slurry was mechanically agitated during the entire application period. The irrigation system was purged by allowing water to run the entire length of the irrigation section after injection was completed. Lateral lengths ranged from 23 to 84 m. Retreatment was started eight wk after the initial injection at one-fourth the rate and applied in weeks 8, 12, 20, 24, 28, 32, 40 and 44.

A water sample (1 liter) was taken from an emitter for residue analysis immediately following purging of the system. Purging consisted of four minutes of irrigation after the completion of herbigation. Water samples were also taken at the beginning of the second, third and fourth irrigation days which were one, three and six days, respectively, after the initial injection.

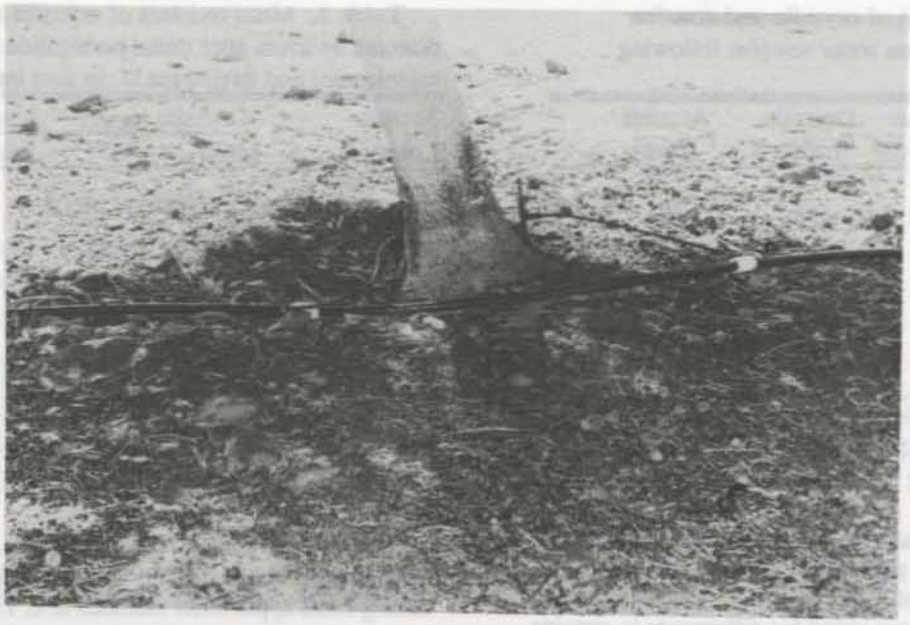

Fig. 1. Two microjet emitters placed on opposite sides of the tree trunk provided irrigation and herbigation within a 3.7 m area.

One kg soil samples for residue analysis were taken 24 hours after herbigation from three sites within the 3.7 m diam. herbigated area of the first, middle and last tree on a lateral. Five cm deep soil samples were taken by a 7.6 cm diam. core until 1 kg of soil was obtained. Sites were designated A, B and C with A being due north and 0.5 m from the tree trunk, B being 120° clockwise from A and 1 m from the tree trunk, and C being 120° from B and 1.5 m from the tree trunk.

Conventional Application, Atrazine Only. In a second section of the orchard, atrazine at 2.24 kg per sprayed ha was applied with a boom sprayer as a band 2 m wide on each side of the tree row. The application was made by a tractor traveling at 4.5 km/h and using 77 liters of water per hectare delivered through 8008 nozzle tips at 67 kg/cm^2.

This application was made on the same date as the first herbigation treatment. Reapplications were made at 16 wk intervals.

Conventional Application, Atrazine plus Oryzalin. Oryzalin and atrazine, both at 2.24 kg per sprayed hectare, were applied to the third section with reapplications made at 16-week intervals.

Analysis of Residues. The method described by Sieck et al. (1976) was used to analyze the soil and water samples for oryzalin residues. Oryzalin was extracted from soil with methanol and the extract was purified with alumina. Methylene chloride was used as the extracting solvent for water samples. Oryzalin was converted to the dimethyl derivative with methyl iodide and analyzed by gas-liquid chromatography using an electron capture detector.

Atrazine in the soil was analyzed by the method of Mattson et al. (1970). Atrazine was extracted from soil with 10 percent water-acetonitrile at reflux temperature and the extract was purified with basic alumina. Methylene chloride was used as the extracting solvent for water samples. Atrazine was determined by gas-liquid chromatography using a nitrogen-phosphorus detector.

Evaluation of Weed Control. Weed control was evaluated by visually determining the percentage of control of crabgrass and sow thistle within the 3.7 m diam. irrigated area of 16 randomly selected trees for each section treated. Evaluations were made at 6, 12 and 32 weeks after initial treatment. The ratings were by percentage control where 100 percent = no weeds and 0 percent = weeds equivalent in population and size to weeds found under three designated untreated irrigated trees.

Because glyphosate was applied to control existing weeds in all the treatment sections and around the designated untreated trees immediately after the 12-week evaluation, the 32-week rating represented an evaluation of a new flush of weeds.

Results and Discussion

At the end of the four-minute purging period following the herbigation cycle, 11 and 4.7 percent of the oryzalin and atrazine concentrations, respectively, used during application were found in the irrigation water (Table 1). At the beginning of the next irrigation cycle, negligible amounts of oryzalin and atrazine were present in the irrigation water. The more rapid decline of atrazine than of oryzalin may be because atrazine is more water soluble (Anon. 1983).

Uneven distribution along the lateral was a concern because wettable powder (atrazine) and flowable formulations (oryzalin) will settle in the tank if not

Table 1. Residues of oryzalin and atrazine detected in the irrigation water samples following herbigation in 1985.

Sample Date	Period after system purge[a]	Oryzalin (ppm)	Atrazine (ppm)
24 July	Control	ND[b]	ND
24 July	4 min	4.10	2.20
25 July	1 d	0.24	0.04
27 July	3 d	0.23	0.07
30 July	6 d	0.08	0.01

[a] With respect to purging irrigation system.
[b] N.D. = none detectable. Limit of detectability = 0.005 ppm oryzalin & 0.01 ppm atrazine.

agitated. There appeared to be no difference in oryzalin concentration in the soil when sampled from the first, middle and last trees along a single 38-meter lateral (Table 2). Data were not tested for differences in atrazine residues because atrazine had been used at this site before the experiment. In a center-pivot sprinkler system, higher amounts of a dry-flowable formulation occurred nearer the injector point of the system (Banks and Dowler 1986). Sedimentation was cited as one of the possible causes of the poor distribution. Presumably there was enough turbulence in the line to agitate the suspension and/or the rate of herbicide movement was sufficiently fast to prevent extensive settling of the herbicides within the lateral.

Oryzalin and atrazine concentrations in soils sampled from different sites within the 3.7 m diam. herbigated zone appeared higher at the B site, but were within one standard deviation of the other sites (Table 2). The B sites, which usually were situated downslope in the herbigated area, appeared to receive more water from the emitters, so that the herbicides may not have been evenly distributed by herbigation.

One problem of using too little water in herbigation is uneven distribution of herbicides (Ogg 1985). The amount of irrigation water used to apply the herbicides in this experiment was 0.31 ha-cm. In herbigation, it is desirable to apply more than the minimum amount of water needed to apply the herbicides. For example, Eisenhauer (1985) suggested that an application of 0.77 ha-cm of water is desirable when applying herbicides. Leaching studies and field observations have shown that approximately 0.52 ha-cm of rainfall or overhead irrigation is needed to activate oryzalin and that excessive rainfall will not leach the compound out of the weed germination zone (Edmondson et al. 1976).

Visual examinations of tree roots and canopies were made at four-week intervals for possible phytotoxic effects on macadamia. No phytotoxic symptoms were observed throughout the duration of the experiment.

Both herbigation and conventional broadcast applications of atrazine + oryzalin provided excellent

Table 2. Mean residues of oryzalin and atrazine detected 24 hours after initial herbigation from three sample sites and three trees in the first lateral.

Sample Location	Oryzalin (ppm)[a] Mean	(SD)[c]	Atrazine (ppm)[b] Mean	(SD)
	Within Lateral			
First tree	1.90	(0.79)	4.03	(1.86)
Middle tree	1.50	(0.35)	3.87	(0.59)
Last tree	1.40	(1.33)	4.53	(2.41)
	Under Tree			
A	1.40	(0.70)	3.47	(0.31)
B	2.33	(0.67)	5.80	(1.61)
C	1.06	(0.71)	3.17	(1.03)

control of sow thistle and crabgrass (Tables 3, 4). Furthermore, there was no difference in weed control among these application methods at 6, 12 and 32 weeks.

Atrazine alone as a broadcast application provided poor control of crabgrass at 6 and 12 weeks after the initial application (Table 3). Nearly complete crabgrass control was obtained when oryzalin was applied in combination with atrazine. The inclusion of oryzalin, whether applied by conventional broadcast or herbigation, was the key factor in the greatly improved weed control.

The lack of weed control outside the irrigated area in the herbigation treatment was a serious disadvantage(Fig. 2). Weeds proliferated outside the irrigated area each time there was sufficient rainfall to permit seed germination. With the conventional broadcast application, oryzalinand atrazine effectively controlled weeds outside the irrigated area. Additional applications of glyphosate were needed to control weeds

Table 3. Percentage control of crabgrass by method of application, atrazine and oryzalin + atrazine, at 6, 12, and 32 weeks after initial applicationa

Treatment	Weeks after initial application: 6 Mean[b]	(SD)[c]	12 Mean	(SD)	32 Mean	(SD)
	Oryzalin + Atrazine					
Herbigation	100	(<1)	100	(<1)	100	(0)
Conventional	100	(<1)	100	(<1)	100	(<1)
	Atrazine					
Conventional	73	(28)	51	(16)	91	(10)

[a] Glyphosate was applied to control existing weeds in all treatment sections and designated untreated trees immediately after the 12-week evaluations.
[b] Mean percentage control of 16 trees.
[c] Standard deviation.

Fig. 2. Excellent weed control was obtained within the herbicated area adjacent to the emitters while weeds grew outside the area.

outside the herbigated area, negating some of the economic benefits of herbigation.

Herbigation can be successful in an orchard, but that success is dependent on the uniform distribution of herbicides which is only as effective as the irrigation system.

Table 4. Percentage control of sow thistle by method of application, atrazine and oryzalin + atrazine, at 6, 12, and 32 weeks after initial application[a].

Treatment	Weeks after initial application					
	6		12		32	
	Mean[b]	(SD)[c]	Mean	(SD)	Mean	(SD)
	Oryzalin + Atrazine					
Herbigation	99	(2)	96	(5)	100	(1)
Conventional	100	(0)	99	(2)	100	(1)
	Atrazine					
Conventional	73	(1)	84	(2)	98	(3)

[a]Glyphosate was applied to control existing weeds in all treatment sections and designated untreated trees immediately after the 12-week evaluations.

[b]Mean percentage control of 16 trees.

[c] Standard deviation.

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[1] **DISCLAIMER:** Reference to a company or product name does not imply approval or recommendations of the product by the College of Tropical Agriculture and Human Resources, University of Hawaii, or the United States Department of Agriculture to the exclusion of others that may be suitable.

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TARO ROOT APHID

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ABSTRACT The taro root aphid, *Patchiella reaumuri* (Kaltenbach), is one of the most destructive insect pests in dryland taro. Crop damage up to 75% has been known to occur with Chinese taro and up to 100% with dasheen taro. The taro root aphid is host specific and apparently infests only taro and closely related plants of the family Araceae. In Hawaii, this species does not produce winged sexual forms, and reproduction occurs without fertilization by males. Taro root aphids have been observed to be associated with numerous attending ants, which probably move the aphids around, enabling them to develop damaging populations.

No effective insecticide is available for use against root aphids on taro. Spread of this insect occurs mainly by planting infested "seed pieces" (hulis).

Description

The taro root aphid, *Patchiella reaumuri* (Kaltenbach), is one of the most destructive insect pests in dryland taro. It greatly reduces plant vigor, yield and quality of dryland taro by sucking sap from taro roots. Crop damage up to 75% has been known with chinese taro and up to 100% with dasheen taro. Extensive aphid damage is usually observed during early plant growth stages under drought conditions .

This aphid is yellow and usually covered with a mass of fine cottony and waxy threads. Signs of infestation appear sporadically as white mold on the fibrous taro roots. When populations are high, colonies are found both on roots and around the basal portions of leaf sheaths.

The taro root aphid is host-specific. Apparently, it infests only taro and closely related plants of the family Araceae. This aphid has been reported on dryland Chinese taro, dasheen and Lehua taro on the island of Hawaii and is not known to occur on the other Hawaiian islands. It has not been reported to be a problem with taro grown under wetland conditions. In Hawaii, this species does not produce winged sexual forms and reproduction occurs without fertilization by males. Taro root aphids have been observed in association with numerous attending ants, which probably move the aphids around, enabling the aphid to develop damaging populations.

Control

No effective insecticide is available for use against root aphids on taro. Spread of this insect occurs mainly by the planting of infested "seed pieces" (hulis). It is very important, therefore, to select clean seed pieces and to plant only in unaffected areas. If the proper moisture requirement is met and taro root aphid population is kept low during the early stages of plant growth, crop damage may be minimized. If a heavy infestation is detected, growers should immediately remove and destroy the crop, including all culls or unharvested cormels, being sure to check around the border areas. The soil bed should be deeply and thoroughly cultivated to drive ants away and promote root degradation. Fallow or rotate with a non-taro type crop for at least one year.

Quarantine regulations in Hawaii prohibit the shipment of taro hulis originating from the Big Island to reduce the risk of pest establishment on the other islands where taro is grown.

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ASSESSMENT OF CROP LOSS DUE TO THE RICE BUG, *LEPTOCORISA ORATORIUS* (F.) (HEMIPTERA: ALYDIDAE), IN THE PHILIPPINES

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ABSTRACT Rice bugs, *Leptocorisa oratorius* (F.), are considered by growers to be one of the most important rice insect pests in the Philippines. A rice bug field population resulting in 11.1 bug-days per panicle caused a mean of 44.9 spikelets per panicle to drop from rice plants which equaled 37 percent of the total spikelets per plant. Nymphs, adult female and male rice bugs fed on 4.6, 6.0, and 3.4 spikelets per day, respectively, in the laboratory. Four bugs caged on individual panicles reduced yield by 22 to 58 percent. Numbers of unfilled spikelets were the most consistent loss factor in a feeding duration trial.

Assessment of crop loss is critically needed before economic injury levels can be established and used in integrated pest management programs (Poston et al. 1983). In the Philippines, significant yield loss in rice results from feeding of the rice bug (also commonly called slender rice bug or rice-earbug), *Leptocorisa oratorius* (F.). Rice bugs enter rice fields as panicles emerge and feed on developing kernels and spikelets resulting in reduced grain quality and quantity (Van Halteren 1979, Dyck et al. 1981). Growers in the Philippines recognize rice bug as one of the three most destructive insect pests (authors, unpublished). Damage has been reported from Australia east into India and north into Japan (Srivastava & Saxena 1967).

Data from field trials using caged rice bugs were used to set an economic injury level at 3 bugs/m^2 (Dyck et al. 1981). One of the goals of this work was to refine the economic injury level by determining the amount of damage produced for each bug-day (Morrill & Wrona 1987). Rice bug field populations were monitored to determine cumulative bug-days and also recorded plant damage. We also evaluated effects of rice bug feeding on individual caged spikelets in the field, and determined damage resulting from bug feeding for various intervals after panicle emergence in the greenhouse. The amount of feeding per day and the resulting effects on spikelets were determined by observing rice bug feeding behavior.

Materials and Methods

Observations of natural rice bug field infestations and plant damage were initiated when panicles began to emerge and were continued at weekly intervals for four weeks until the crop was mature. Rice bug population estimations were made by brushing plants with a one meter-long stick to flush bugs from 10 one m^2 samples. Counts were made within two hours after sunrise because bugs moved to the base of plants as ambient temperatures increased and were difficult to detect. Numbers of spikelets on ten panicles were recorded. Feeding damage, indicated by punctures and brown discoloration, was determined on 10 panicles.

Laboratory feeding observations were conducted on rice var. IR-64 growing in standing water in a greenhouse. Field-collected bugs were sexed and released in individual cages made from mylar sheet cages 1 m high x 30 cm in diameter. Treatments included fifth instar nymphs, female bugs and male bugs. There were six replications with 2 bugs per cage. Panicles were inspected daily and numbers of damaged spikelets were recorded. Means were analyzed with ANOVA and LSD on a computerized statistical program, MSUSTAT (P=0.05).

Rice bug populations in field cages constructed of various materials were evaluated as a means of estimating rice bug survival. Cages were made from 15 cm diameter plastic petri dish tops, a 40 cm high cylinder (made from aluminum wire screen, mylar sheet or nylon cloth) and a bottom closure consisting of nylon cloth sleeve. Cages were placed over newly emerged panicles, and were supported by wooden stakes. Four field-collected adult rice bugs were placed in each cage. Daily bug mortality was recorded and live bugs were added to maintain four bugs per cage. At harvest, numbers of spikelets, numbers of damaged grain, and mean grain weight was determined. Means were analyzed with LSD and MSUSTAT.

The effect of panicle maturity on rice bug feeding damage was estimated by caging field-collected bugs on plants in the greenhouse. Each cage had three panicles with three ricebugs per panicle. Bugs were placed in cages 1, 3, 5, 7 and 9 days after panicle emergence and were permitted to feed until panicles were mature. Grain weight, number of filled spikelets, and number of empty spikelets were determined and means were analyzed using LSD.

Results and Discussion

Observations under natural field conditions indicated that rice bugs began moving into the field prior to

panicle emergence and reached a peak population density of 13.5 bugs per m^2 within two weeks after panicle emergence (Table 1). There was a maximum of 0.7 bugs per panicle. After 21 days, the hard dough stage was reached and the rice bugs left the field. There was an accumulation of 11.1 bug-days based on weekly estimations. Total spikelet numbers per panicle decreased weekly indicating that damaged spikelets dropped from plants. Mean numbers of damaged spikelets actually decreased with time as a result of the dropped spikelets. These data indicate that rice bug loss assessment must include loss of spikelets as well as kernel damage.

Table 1. Rice bug population density and the resulting spikelet damage in rice, Batangas, Philippines.

Parameter	Days after panicle emergence[1] 0	7	14	21
No. Bugs/m	29.1	8.1	13.5	0.0
No. Bugs/panicle	0.5	0.4	0.7	0.0
No. Bug-days/panicle	3.3	2.9	4.9	0.0
Total no. spikelets	120.9	71.4	95.2	76.0
No. Damaged spikelets	13.5	5.4	3.4	3.8
No. Lost spikelets	0.0	48.7	24.9	44.9
No. Damaged + lost	13.5	54.1	28.3	48.7

[1]Numbers are means of 10 counts.

Laboratory feeding observations indicated that rice bug nymphs, adult females and adult males fed on 4.6, 6.0 and 3.4 spikelets per day, respectively. Assuming a 1:1 sex ratio, damage would occur to 4.7 spikelets per bug-day. During the first 7 days in the field, there were 3.3 bug-days X 4.7 spikelets per bug-day expected feeding which equaled 15.5 predicted damaged spikelets, close to the 13.5 damaged spikelets in the field.

Field cage evaluation for rice bug survival and effects on panicle development indicated bug survival was over 90 percent per day with no significant difference among the types of cage material (Table 2). There were no significant differences in panicle weights among cages and uncaged plants. Panicle weights were significantly reduced by 4 rice bugs. Aluminum wire screen cages were used for additional studies with treatments of 0, 1, 2, 4 and 6 bugs feeding for 1, 2, 4 and 6 days, resulting in 0 to 36 bug-days. Trials have not been completed at this time.

The effect of panicle maturity on rice bug feeding damage in the laboratory was based on a total of 11 days of susceptibility. The number of empty spikelets increased with days of feeding (Table 3). Grain weight was significantly reduced after 3 days of feeding and the number of filled spikelets was reduced after 5 days of feeding. This trial simulated the effect of bugs moving into fields at various times after panicle emergence.

Additional trials are underway and data evaluation should indicate if the currently accepted economic injury level of 3 bugs per m^2 is accurate. Based on 100 panicles per m^2 (0.03 bugs per panicle at 3 bugs per m^2) and plant susceptibility of 20 days, this would be 0.6 bug-days, a figure which seems somewhat low at this time.

Table 2. Evaluation of cage material on rice bug survival and panicle weight.

Cage material	% Bug Survival[a]	Panicle weight (grams) 0 Bugs[a]	4 Bugs[a]
Mylar sheet	98.1a	3.1a	1.3a
Nylon cloth	93.5a	3.0a	1.5ab
Aluminum screen	93.5a	2.7a	2.1ab
Uncaged panicles	-	2.6a	-

[a] Numbers within columns followed by the same letter are not significantly different, Least Significantly Different, P=0.05, MSUSTAT.

Table 3. Effect of ricebug feeding on grain weight, filled spikelets, and unfilled spikelets simulating rice bug migration into fields 0-9 days after panicle emergence.

Days after panicle emergence	Days of feeding	Grain wt.[a] (grams)	No. spikelets[a] FFFFilled	Empty
0	0	2.1a	103.8a	61.3a
9	3	1.5b	83.8ab	70.6a
7	5	1.2bc	43.8c	83.6ab
5	7	0.9c	41.5c	85.8ab
3	9	1.5b	65.3bc	105.3b
1	11	1.3bc	71.3b	110.1b

[a] Means within columns followed by the same letter are not significantly different, LSD, P=0.05.

Rice bugs are large, easily seen, and have a characteristic odor. Growers easily detect bugs, either by sight or smell, and insecticide treatments are commonly applied at levels far below the economic injury level. Growers sometimes attempt a nonchemical rice bug control method by suspending a small sack of decaying shrimp (frogs and other rotting material are sometimes substituted) from a stake in the field. Rice bugs are attracted to the sack and are killed by burning. Although the method is ineffective due to the low numbers of bugs killed, it indicates that rice bugs are attracted to certain odors and that growers may be willing to use simple mechanisms for trapping.

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LISTEN AND SPRAY: THE ROLE OF FARMER GROUPS IN THE RICE IPC PROGRAM IN CENTRAL JAVA

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ABSTRACT In Indonesia's massive rice intensification program, farmer groups are frontline practitioners of government-backed extension service policy and "recommended agricultural practice". At the onset of the Rice Intergrated Pest Control Pilot Project (IPC) in 1980, existing farmer groups were assembled into the program as part of the agricultural ecosystem and were treated as such. Their designation as part of the ecosystem was an operational mechanism for relaying information. Although the mechanism appeared highly effective, the real practice was often instructive and provided little room for farmers' opinions.

This paper examines the viewpoints of farmer group members subjected to IPC implementation. As exposure to IPC increased, farmers developed some positive attitudes, although the program itself was not necessarily well-understood.

Rice cultivation in Java is an age-old practice. It dates back as far as the fifth century A.D. For many generations, Javanese farming skills were passed down by one's ancestors. During those times, farmer groups evolved to accomodate farmers' interests such as assuring their irrigation water needs (Van Setten-van der Meer 1979).

Traditional farming practices were gradually replaced by more advanced cultural techniques after Indonesian Independence in 1950. Rice intensification programs launched by the government provided high-yielding rice varieties, fertilizers, pesticides, monetary loans, and new technology to farmers. Rice production increased to more than 2.30 metric tons per hectare in 1976 (Indonesia 1978).

The rice intensification projects had several different programs of which BIMAS (Bimbingan Massal, Mass Guidance) was the most important. This program encouraged the formation of many new farmer groups. Group formation became necessary because few individuals owned radios in the late 1960s (Anon. 1979), and listening to radio- disseminated extension programs was a mandatory requirement of the BIMAS.

In 1974, outbreaks of the rice brown planthopper, *Nilaparvata lugens* Sthl, started in many rice-growing areas in South, South-East, and East Asia, and the Pacific area. Planthopper populations developed and rapidly spread in the 1976/1977 planting season causing great losses in 22 out of 26 Indonesian provinces (146 counties)(Indonesia 1978). Obviously, existing pest control measures did not restrain the pest.

Beginning in 1976, a new control strategy based on integrated pest management was developed. In 1980, the Rice Integrated Pest Control Pilot Project (known as the IPC project) was introduced in five provinces where rice production losses had been greatest. The province of Yogyakarta, located in Southern Central Java (Fig. 1), was one site of the IPC project (Anon. 1983). Soils in the Yogyakarta lowlands are rich and fertile because the lowlands are located on the slope of Mt. Merapi, an active volcano. During the Dutch occupation of Indonesia, this region produced almost one third of Java's cane sugar, an export commodity which at that time made Java a major sugar producer. As a result, the irrigation network in Yogyakarta was well-developed and became an asset for local rice farmers.

Already numerous rice farmer groups in Yogyakarta increased further in number as the efforts of the government Extension Service Agency to disseminate information on its rice intensification programs increased. Regularly scheduled meetings of these groups, a customary practice rather than a organizational requirement, provided the government with a convenient vehicle for convening extension sessions (Indonesia 1971).

The IPC program was implemented by IPC officers contacting participants through farmer group meetings. IPC officers differed from regular extension workers in that they were specially trained in IPM (Anon. 1983). Farmers participating in the IPC Project received extension materials with heavy emphasis on pests and pest control measures. They were also required to treat their rice fields in conjunction with other growers if IPC officers determined that rice pests in their vicinity had surpassed economic thresholds.

Untung (1979) described the action flowchart (Fig. 2) for the IPC project. In the flowchart, farmers were considered as `part of the ecosystem'. This is a common approach in most programs designed to implement Indonesian government policies, where a *patron-client* leadership type is imminent (Prijono & Tjiptoherijanto 1983). Hence, one may question whether the farmers voluntarily accepted concepts implemented by the IPC project or was acceptance mandatory because their fields fell within the jurisdiction of the IPC project management. Understanding farmers' attitudes and

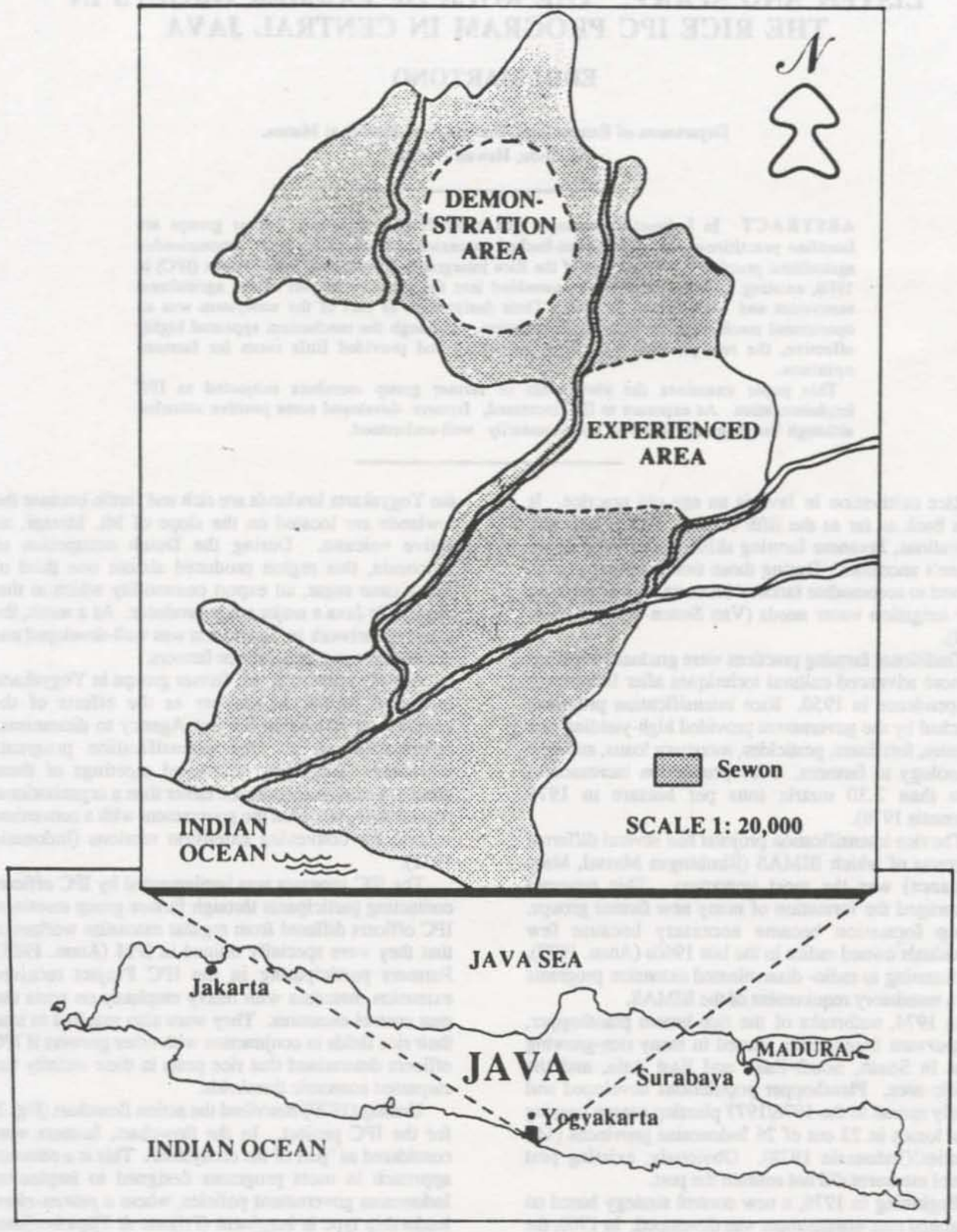

Fig. 1. Location of the observation areas.

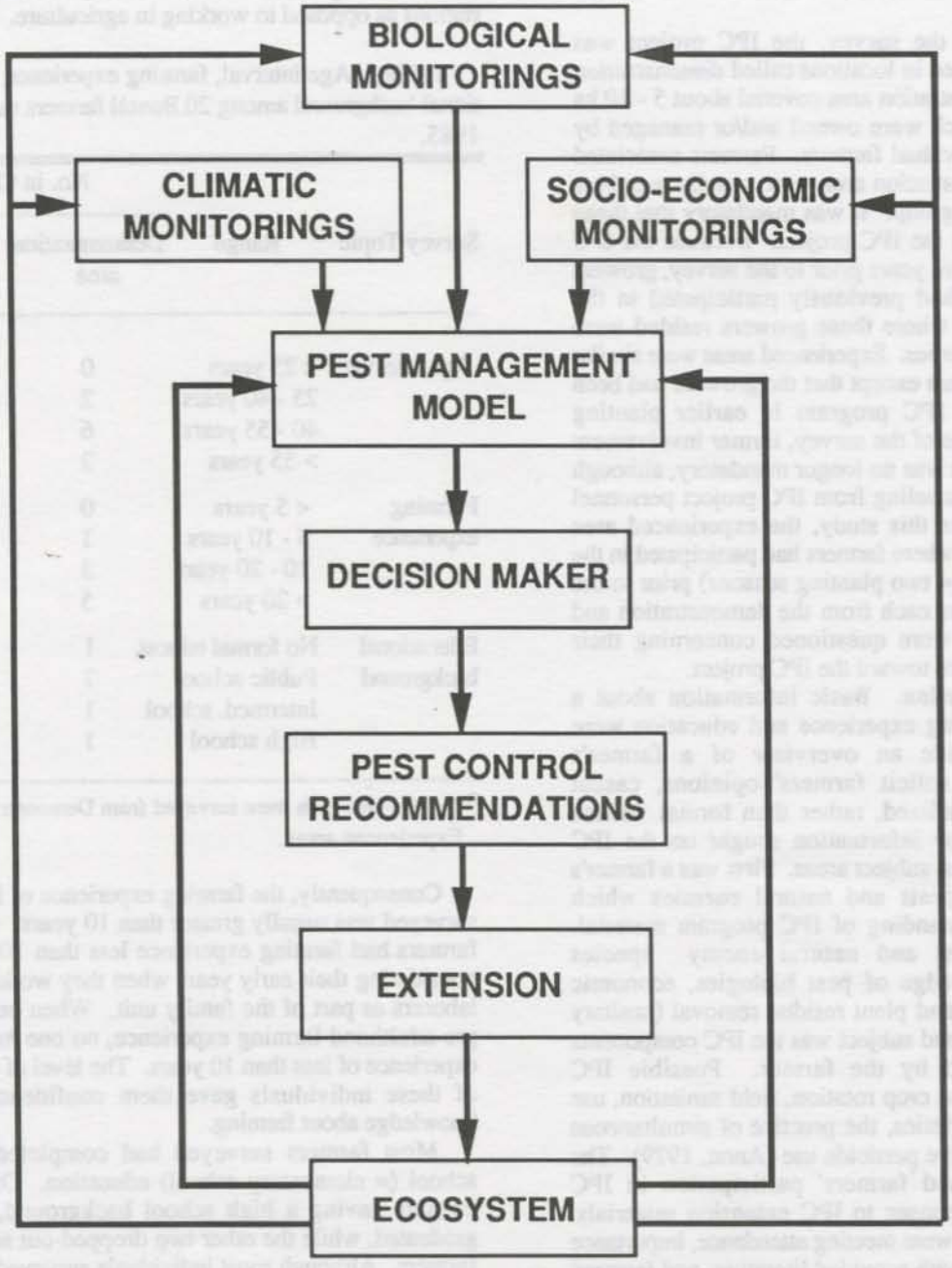

Fig. 2. Program Flowchart of IPC Project (after Untung 1979).

opinions on the IPC programs provides insights into the value of implementation practices as well as establishes evaluation parameters. The objective of this study was to elucidate the views of Indonesian farmers regarding the value of pest control techniques mandated by the IPC project.

Materials and Methods

A farmer survey was conducted in 1985 in an IPC project area at Sewon, Bantul regency, about 20 km south of the city of Yogyakarta, Java, Indonesia (Fig. 1). Selection of farmers for survey purposes was based on land-ownership and farmers' status. Based on these parameters, four farmer categories existed: 1) *owner*; 2) *owner/tenant*; 3) *tenant*; and 4) *farm-laborer*. An *owner* held title to the land but could lease it to others. An *owner/tenant* owned and managed his land. A *tenant* leased the land he managed, either on a yield-sharing or currency basis. A *farm-laborer* worked for individuals in the three previous categories with a yield-sharing arrangement for compensation. Only owner/tenant farmers were surveyed based on the assumption that their

income was predominantly derived from farming their own land.

At the time of the survey, the IPC project was currently implemented in locations called *demonstration areas*. Each demonstration area covered about 5 - 10 ha of rice paddies which were owned and/or managed by about 70 - 100 individual farmers. Farmers associated with a given demonstration area were usually members of the same farmer group. It was mandatory that these farmers take part in the IPC project. Because the IPC project had begun five years prior to the survey, growers in some localities had previously participated in the project. Localities where these growers resided were termed *experienced areas*. Experienced areas were similar to demonstration areas except that the growers had been involved with the IPC program in earlier planting seasons. At the time of the survey, farmer involvement in experienced areas was no longer mandatory, although supervision and counseling from IPC project personnel still continued. For this study, the experienced area consisted of an area where farmers had participated in the IPC project a year (= two planting seasons) prior to the survey. Ten farmers each from the demonstration and experienced areas were questioned concerning their opinions and attitudes toward the IPC project.

Survey Information. Basic information about a farmer's age, farming experience and education were recorded to provide an overview of a farmer's background. To solicit farmers' opinions, casual discussions were utilized, rather than formal written questionnaires. The information sought on the IPC project included three subject areas. First was a farmer's knowledge about pests and natural enemies which reflected an understanding of IPC program material. This included pest and natural enemy species recognition, knowledge of pest biologies, economic threshold concepts and plant residue removal (sanitary practices). The second subject was the IPC components currently practiced by the farmer. Possible IPC components included crop rotation, field sanitation, use of resistant rice varieties, the practice of simultaneous planting, and selective pesticide use (Anon. 1979). The third area concerned farmers' participation in IPC gatherings and responses to IPC extension materials. Responses recorded were meeting attendance, importance of and satisfaction with provided literature, and farmers' actions after acquiring the IPC information.

No attempt was made to quantitatively analyze the data because too many factors would have to be either eliminated or included. Interpretation was done by comparing the opinions between farmers from different areas.

Results and Discussion

Farmers' background. Most farmers surveyed in the demonstration and experienced areas were 40 or more years old (Table 1). Of the total 20 individuals surveyed, only five were less than 40 years old. This was typical for the current Indonesian farm labor force (Woelke 1978) because the better-educated young people from rural regions desire to make their living in urban regions as opposed to working in agriculture.

Table 1. Age interval, farming experience and educational background among 20 Bantul farmers surveyed in 1985.

Survey Topic	Range	No. in Category[a]	
		Demonstration area	Experienced area
Age interval	< 25 years	0	1
	25 - 40 years	2	2
	40 - 55 years	6	4
	> 55 years	2	3
Farming experience	< 5 years	0	1
	5 - 10 years	1	1
	10 - 20 years	3	3
	> 20 years	5	5
Educational background	No formal educat.	1	1
	Public school	7	5
	Intermed. school	1	2
	High school	1	2

[a] Ten farmers each were surveyed from Demonstration and Experienced areas.

Consequently, the farming experience of individuals surveyed was usually greater than 10 years. Only three farmers had farming experience less than 10 years, not considering their early years when they worked as farm laborers as part of the family unit. When one includes pre-adulthood farming experience, no one had farming experience of less than 10 years. The level of experience of these individuals gave them confidence in their knowledge about farming.

Most farmers surveyed had completed a public school (= elementary school) education. Of the three farmers having a high school background, only one graduated, while the other two dropped-out and became farmers. Although most individuals surveyed were able to read and write, their skills were infrequently used. Therefore leaflets, bulletins and written guidelines did not influence them greatly.

This background information, which was similar in both areas, reflected the general situation for Javanese farmers who are older people, with limited education, that have traditionally farmed. Given these traits, it is hard to introduce new farming practices. Because of their conservative nature, they are not readily convinced of the benefits of adopting new ideas. New concepts are voluntarily accepted only when endorsed by local community leaders (Prijono & Tjiptoherijanto 1983). The alternative to voluntary acceptance is to introduce programs as mandatory practices giving farmers no options except to comply.

Knowledge of Pest Management. Farmers' knowledge about pests and natural enemies was good (Table 2). Most understood concepts of pest biologies (life-cycles, oviposition habits, pests' alternate hosts), plant residue removal (benefits of burning compared to burying, why fields become infestation sources), pest species recognition (signs and symptoms of pest attack, seasonal differences between pests) and natural enemies (importance of spiders and mantids, existence of fungi pathogenic to pests). A slightly higher number of farmers in the demonstration area correctly answered questions on this subject topic. They attributed correct answers to a "recent speech at the meeting". This was confirmed by some farmers in the experienced area who said they had forgotten IPC information received several months earlier.

Table 2. Bantul farmers' replies to questions concerning knowledge of rice pest management and IPC components practiced in 1985.

Survey Topic	No. in Category[a]	
	Demonstration area	Experienced area
Areas of Knowledge		
Pests biology	9	8
Plant residual removal	8	7
Pest species recognition	9	8
Economic threshold	7	3
Natural enemies	8	6
IPC Components Practiced		
Crop rotation	6	5
Field sanitation	6	2
Resistant varieties	10	10
Simultaneous planting	9	7
Selective pesticide use	8	5

[a] Ten farmers each were surveyed from Demonstration and Experienced areas.

Farmers were surveyed on their knowledge of the concept of the economic threshold which endorses the idea of applying pest control measures only after economically significant numbers of individual pests are found in contrast to using "preventive" chemical applications. This concept was not easily understood by the farmers. Most were confused by questions on this topic. Only three farmers from the experienced area could explain the concept. Because scouting and monitoring were done by IPC officers, farmers had little hands-on experience with this concept. They preferred to depend on the IPC officers for control decisions because the officers had professional training.

IPC Components. Use of resistant plant varieties, a required practice under regional decree, was practiced by all farmers surveyed (Table 2). Some individuals complained about the loss of local varieties which were susceptible to pests, but produced tastier, higher priced rice. However, given the harsh sanctions potentially imposed on growers planting non-resistant varieties, these growers did not wish to violate the law. Other farmers wisely responded by saying that planting resistant varieties was better than planting food for the pests.

Other IPC components were not practiced by all farmers, but more respondants in the demonstration area followed recommendations as compared to the experienced area. This does not mean that farmers in the experienced area rejected the components because they did not practice them. Some farmers explained that after one or two "trials", the components were not practical for them to continue because they were too time consuming or required continous attention. This statement confirms the idea of Waibel (1986) that farmers tend to develop their own "technology". Hence, measuring a program's success by the extent to which recommendations are practiced will produce frustration among the extension officers managing the program.

Responses to extension activities. Information collected on extension activities consisted of farmer attendance at extension meetings, the importance and quality of extension programs, and actions taken after receving extension information (Table 3). Both in the demonstration and experienced areas, the traditional custom of compliance was followed by most farmers. The ability of IPC extension officers to emphatically convince the farmers of the importance of the IPC guidelines played a major role. Farmers also recognized if IPC officers understood the materials they presented or if they were just "doing their job". With a poorly trained staff, dynamic and effective leadership can have only limited success in policy implementation. Timmer (1988) observed this in a similar case involving Indonesia's farm-product policy.

Farmers' opinions on practicing the concepts, outlined in extension literature, emphasized the need for a period to assimilate information provided in the extension materials. While Prabowo & Sayogyo (1975) report that Javanese farmers may demand more agrochemical supplies as their knowledge increases concerning the benefits of insecticides in negating insect-induced crop losses, new information on the adverse effects of agrochemicals will not be readily accepted without strong, undeniable proof.

Conclusions

The bottom line is that it is not a simple task to implement and evaluate the success of an IPC program. Because farmers also have their own parameters to measure success, it is important to consider their point of view in measuring a program's outcome. The complete success of an implementation program, therefore, cannot be judged on increased yields and pest suppression alone, but must also consider farmers' roles

and place their contributions in a more proper perspective.

Table 3. Bantul farmers' responses to extension activities in 1985.

Survey Topic	No. in Category[a] Demonstration area	Experienced area
Meeting participation/attendance		
One time	3	6
> One time	7	4
Importance of Extension		
Worthy	9	8
Unimportant	1	2
Satisfaction with Extension		
Satisfied	9	8
Not Satisfied	1	2
Practice of Recommendations		
Always	3	3
Sometimes	7	7
Never	0	0

[a] Ten farmers each were surveyed from Demonstration and Experienced areas.

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PROCONTARINIA SP. N.: A MANGO PEST LONG MIS-DIAGNOSED AS ANTHRACNOSE

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ABSTRACT For many years on Guam, mango trees were observed to have holes in the leaves with fungus symptoms. Isolation of the fungi showed the presence of anthracnose, and the holes were attributed to this common disease of mango. Recently, it was observed that the young leaves are attacked by a cecidomyiid midge, which is a previously undescribed species of *Procontarinia*. These insects lay their eggs in leaves 5 - 10 cm in length and develop as blotch miners. After five days they exit the leaf and pupate in the soil. The 1.5 - 3 mm circular mine is then invaded by fungi, primarily anthracnose, which cause the mine to fall out of the leaf, leaving only holes surrounded by fungal spores. A three year survey of population levels showed that the number of blotch miners were generally low, but occasionally could reach as high as 200 per leaf. No correlation of blotch miners with rainfall was observed, but two peaks in the miner population seemed to follow months when a large proportion of the mangos on the island flushed simultaneously.

On Guam in the Marianas Islands, anthracnose on mangos can be a serious problem. For many years shot hole damage has been observed on the leaves and attributed to this disease. It has recently been realized on Guam that often the primary cause of the damage is feeding by an insect with the disease being secondary.

Procontarinia sp. n. is a cecydomyiid fly which develops in mango foliage. Unlike other *Procontarinia* species it does not make a gall, but only a small blotch mine in the leaf. The flies attack mango leaves when the leaves are recently emerged and are between 5 and 10 cm in length. The leaves are about 5 - 10 days old at this time. The larvae develop as miners within the leaf, excavating a circular mine 1.5 - 3 mm in diameter. As the leaf grows, the mines cause the leaves to crinkle to some degree, depending on the severity of the attack. The larvae complete their egg eclosion and feeding period in five days and emerge from the leaf, leaving a characteristic hole. The mature larvae hop or fall from the leaf, and are thought to pupate in humus or soil beneath the tree. In the laboratory, mature larvae were placed in containers with damp peat moss and were observed to emerge as adults 5-6 days later.

Once the leaf has been opened, the mines provide a site where infection from fungal diseases may occur. *Colletotrichum gloeosporioides*, the fungus which causes anthracnose, is the pathogenic organism most commonly recovered from older mines. If conditions are suitable, or mines very numerous, the disease may infect the entire leaf, which then usually falls off. In less severe cases, leaves remain on the trees for many months, presumably providing a reservoir of inoculum which may then infect the flowers, fruits, and new buds. The mine drops out of the leaf after infection occurs, leaving only a small hole ringed with fungus by the time the leaves harden, resulting in a shot-hole appearance of the leaves.

Although the flies have only been reared on Guam, fresh damage which appears to be caused by the same species has also been observed in Saipan in the Marianas Islands, and Palau in the Caroline Islands. In Yap, Caroline Islands, freshly damaged leaves were not observed during brief visits, but older leaves with damage resembling that left by the midges on Guam were seen. Damage similar to that caused by blotch miners can also be found on mangos on Truk (Hermis Refit personal communication). Because miners leave the leaf at such an early stage it is easy to overlook their presence and attribute shot hole damage to disease. It is probable that this insect is more widespread than just Western Micronesia.

Insecticidal control

This insect causes visible damage to the leaves creating a desire on the part of mango tree owners to suppress the damage. One experiment was conducted to assess the efficacy of a pesticide treatment. Eight trees were treated weekly with carbaryl any time that new leaves were observed on the trees. Twenty full-sized young leaves were sampled on a weekly basis when possible to estimate the number of blotch mines. The eight treated trees were compared with eight untreated trees nearby. Over a four month period, blotch mines averaged 6.1 ± 3.3 per leaf on the treated trees and 6.0 ± 3.0 on the untreated trees. This difference was not significant ($t = 0.093$). To have an impact on the blotch miners, one would apparently have to spray more frequently than once a week during the time the trees are in flush to provide coverage of all new and rapidly expanding leaves. It is important to note that pesticide treatment for the level of damage recorded in this trial is probably unnecessary as this population level would not

likely have any measurable impact on the number of fruit produced by the trees.

Long Term Monitoring

Because it was clear that the level of damage was variable, and pesticides would have to be used before any damage was visible to be effective, we began some long term monitoring programs to determine whether there were any factors which would enable one to predict when heavy damage might occur.

To estimate populations trends, trees were sampled once a month for a three year period. For this sample, four trees in full flush were selected in each of four villages and 20 leaves sampled on each tree. Monitoring is still in progress at this time. Examination of collected data shows that the mean number of mines per leaf was quite low, averaging less than 10 per leaf every month except for two months (Fig. 1). Two population peaks, where the number of mines per leaf exceeded 15, occurred in November 1986 and August 1987. Both peaks occurred one month after a relatively large proportion of mango trees produced new flush. This high level of flushing was associated with high rainfall during the month. Months with high rainfall during which flushing was minimal were not followed by a rise in the number of *Procontarinia*. Casual observations suggest a reduction in blotch miner populations during dry weather. The data showed that populations of the blotch miners were low during the 1988 dry season, but not during the 1987 dry season.

A set of 16 trees at various locations were monitored for 3 years and whenever they flushed the number of mines per leaf was estimated (Table 1). There were significant differences among trees ($F=2.552$, d.f.=15,320, $P<0.001$). Some trees averaged as few as 1.5 mines per leaf during that period, whereas one tree averaged more than 15 mines per leaf. The peak mean count for a sample was 9 mines per leaf on some of the trees with low overall means, but reached 167 mines per leaf in the most susceptible tree. I also examined the number of dates on which the trees flushed but no blotch miners were present. The tree with the highest peak counts also had the lowest percentage of flushes when no blotch miners were present, but there was only a weak correlation between these two parameters for the

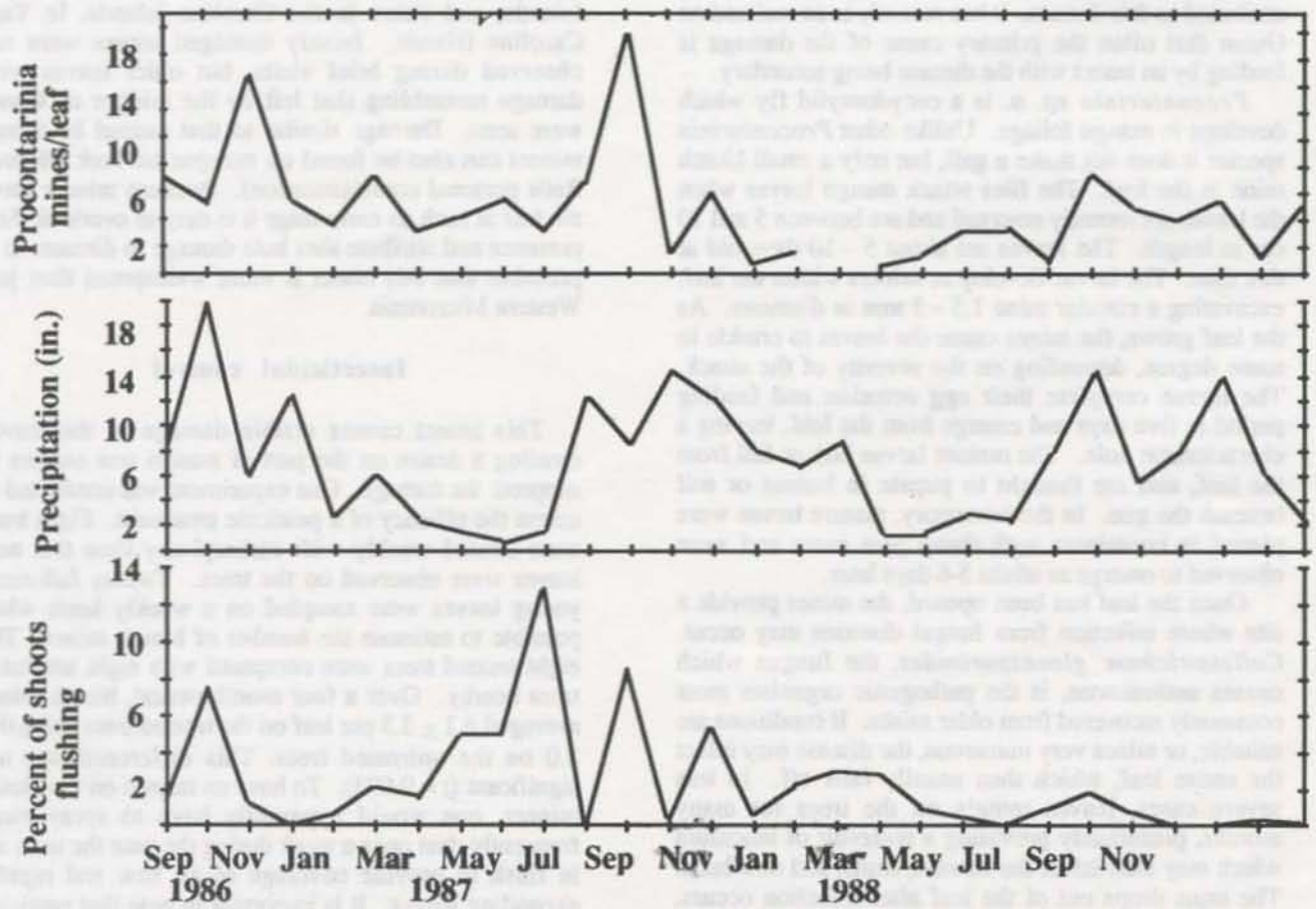

Fig. 1. Average number of *Procontarinia* mines per leaf between 1986 and 1988 in relation to monthly precipiation and proportion of mango branch ups with new leaves.

data set as a whole. Because all the trees were seed grown, we cannot be certain if the differences are due to genetic differences between trees or to differences between sites. A study in India showed that there were significant differences among varieties in their susceptibility to *P. matteiana* (Jhala et al. 1987) and it is probable that this is also true for this new species of *Procontarinia.*

Table 1. Populations of blotch miners on sixteen trees sampled for a three year period. Only dates when young leaves were present on the trees were used to calculate figures below.

Location	Tree ID	No. Blotch miners per Leaf		Percent sample dates with no miners
		Mean	Peak	
Agat	1	1.6	11	67
Agat	2	1.5	13	60
Agat	3	2.3	6	33
Agat	4	3.3	9	26
Agat	5	1.8	9	38
Agat	6	3.1	14	37
Agat	7	3.3	15	38
Agat	8	3.7	21	43
Barrigada	1	2.6	12	33
Barrigada	2	2.8	10	32
Barrigada	3	5.8	33	27
Barrigada	4	3.7	27	30
Barrigada	5	7.6	29	19
Barrigada	6	4.6	33	41
Barrigada	7	7.3	28	16
Barrigada	8	33.6	167	17

These data show that in most cases blotch miner populations are low on mango. Many trees never experience high populations, but some trees do. For the majority of trees, it is unlikely that the blotch miners ever reach levels that cause a reduction in the amount of fruit the tree is capable of producing. Individual trees may be highly susceptible, and for these few trees an effective spray treatment might be of value in increasing fruit production. At this point, however, prediction of serious blotch miner outbreaks is not possible, and effective treatments for such an outbreak are unknown. Even in trees where the population of miners is low, the presence of the old mines serves as a reservoir of anthracnose inoculum, and this may have an impact on the severity of this disease on the flowers and fruit. Further study is required to clarify this relationship.

Acknowledgment

K. Harris identified the blotch miner as a new species. N. Dumaliang handled the long term collection of data with the assistance of J. Paulino, V. Kamiaz , J. Borja and others. This project was funded by USDA Special grants in Tropical and Subtropical Agriculture 86-CRSR-2-2840. This is paper number 80 of the Guam Agricultural Experiment Station.

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH (DSIR), NEW ZEALAND: PARTICIPATION IN AGRICULTURAL RESEARCH IN THE PACIFIC REGION

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ABSTRACT The Department of Scientific and Industrial Research (DSIR), Mt Albert Research Centre Auckland comprises Entomology, Plant Diseases, and Horticulture and Processing Divisions. As a Centre it is responsible for crop protection studies in New Zealand. New Zealand's involvement in agricultural science in the Pacific started almost 100 years ago with the publication of the flora of Rarotonga, Cook Islands, and a viability study of a Cook Islands based citrus industry. Since 1918, when New Zealand took over the trusteeship of Western Samoa, cooperation was particularly close, and DSIR operated the Geophysical Observatory. With the various island countries regaining their independence during the 1960s, New Zealand's political influence dwindled, but DSIR's scientific links remained and were considerably strengthened with the establishment of the Totokoitu Research Station in the Cook Islands in 1973. At this permanent base, Pacific Island requirements in agriculture were studied. Advice and technical assistance on agricultural production and crop protection were disseminated from the Totokoitu Research Station as well as training of island personnel. Surveys of plant diseases, entomological and nematological problems were conducted.

From DSIR's long involvement in the Pacific, we have acquired a range of talents which can benefit the island countries.

The New Zealand Department of Scientific and Industrial Research (DSIR) is a large multidisciplinary scientific organisation consisting of twenty-two Divisions where various aspects of scientific research are conducted. Typical examples are nuclear physics, geophysics, oceanography, botany, soils, plant disease, virology, molecular biology, entomology, ecology, crop, horticulture, applied mathematics, and food and fish processing.

Based on these disciplines DSIR's current roles in Pacific science are to 1) respond to requests for assistance from Pacific countries on a range of topics; 2) initiate projects to determine or extend basic information related to the Pacific Region; 3) operate research stations, observatories and projects for the benefit of Pacific countries and New Zealand; 4) supervise technical activities; 5) motivate Pacific countries by personnel training; 6) provide advice to Pacific countries, organisations based on experience in New Zealand and overseas; 7) participate in forums and meetings and through various media to assist and guide scientific knowledge about the Pacific countries; and 8) provide information in response to requests.

Unfortunately there appears to be a magic line, the Equator, which separates knowledge transfer from south to north and vice versa in the Pacific. All would benefit from two-way communication regarding scientific endeavors on either side of the equator. Thus the history, current assistance and interest of DSIR in the Pacific might be useful to all Pacific Basin countries.

Early History

New Zealand's involvement in Pacific science started about 100 years ago with the publication of the 'Flora of Rarotonga' and the investigation of the viability of a Cook Islands based citrus industry. Since 1918, when New Zealand took over the trusteeship of Western Samoa, co-operation has been very close and DSIR has operated the Geophysical Observatory. Gradually, as the various Island countries regained their independence during the 1960's, New Zealand's political influence waned but the scientific links remained and have been improved. This was particularly true with DSIR establishment of the Totokoitu Research Station in the Cook Islands in 1973. At this permanent base Pacific island requirements in agriculture are studied and advice and technical assistance on agricultural production and crop protection is disseminated. The training of island personnel is of particular importance.

Also, in 1985 a consultant scientist position was established in Singapore to co-ordinate research requests from South East Asia and related regions.

DSIR Facilities and Capabilities

I should like to review in some detail, what facilities are available at DSIR, what DSIR has done in the Pacific Region and how DSIR may be able to further assist the island countries of the Pacific. A description of the roles of the various Divisions of DSIR follows.

DSIR Divisions. The Physics and Engineering Division has amongst many things been involved in the development of a Brugger fore-furnace stove to run at low cost on wood and coconut husks for the drying of copra, cocoa and the cooking of family meals. The Auckland Industrial Development Division developed a banana drying plant and an osmo-solar drier for other fruits. The Chemistry Division and Division of Horticulture and Processing established a successful lime-oil still on Niue Island. The Soil Bureau has carried out extensive soil surveys, advised on fertilizer requirements and made detailed soil maps of most South Pacific island countries. The Geophysics and Geological Survey Divisions have assessed and carried out water supply drilling and water quality testing for island nations. The Ecology Division has investigated rodent control in coconut plantations, kumara and food storage areas. The Oceanography Division (now Division of Water Sciences) has made detailed marine charts of the Pacific Island areas. The Botany Division has published check lists of floras of many of the South Pacific islands.

Totokoitu Research Station. Subsistence level agriculture is the preoccupation of most of the Pacific Basin's population who still work and live on atolls or in small traditional villages located in rural areas. In recent years, very high rates of population growth have not been equally matched by agricultural production. With these facts in mind, DSIR gave consideration to establishing a Pacific region research station.

Until the beginning of the 1970's, most requests to DSIR for assistance in the agricultural area resulted in short-term investigations, usually undertaken by one scientist. These investigations generally provided a practical solution to immediate problems, but the lack of adequate dissemination of results and solutions, or any consistent follow-up to projects, proved discouraging. Thus, DSIR decided to establish a permanent research base to service those countries which did not have research facilities (i.e. Cook Islands, Niue, Tonga).

The Cook Islands were chosen as the site and in 1973 the Totokoitu Research Station on Rarotonga was established. A New Zealand manager was appointed together with local staff. The Station is the responsibility of the Plant Diseases Division which provides a *Scientist in Charge* although several other DSIR Divisions (Botany, Horticulture and Processing, Entomology, Soils) utilize the facilities. At Totokoitu Research Station a wide range of crops have been studied with respect to all aspects of horticulture and crop development. Particular emphasis has been placed on plant variety testing for climatic stability and tolerance to major diseases and pests (nematodes and insects). Plant nutrition and management practices of bananas and vegetables, and especially citrus, have been researched, the results of which have been applied in Fiji and Bhutan. All aspects of vegetable crop production have been studied (weed control, disease and pest control, by chemical and biological methods) as well as the screening of potato varieties for tropical conditions in co-operation with the International Potato Centre, Peru. Postharvest packaging and transport of bananas, papaya, vegetables and taro for internal or overseas markets, and breeding of higher yielding self-compatible, insect pollinated yellow passionfruit for Niue have been successfully researched.

The research programme for Totokoitu Station is reviewed annually. Budget and work programmes are determined with local advisory officers contributing an important role in establishing research programme directions. An annual report is published and circulated to most Departments of Agriculture in the Pacific region. Practical knowledge gained from the Station is disseminated to any Island country requesting information.

Mt. Albert Research Centre. The Divisions (Entomology, Plant Diseases, Horticulture and Processing) based at Mt. Albert Research Centre, Auckland, are particularly suited to assist Pacific Basin countries' agricultural/economic problems. Within this Centre, we can offer a comprehensive recommendation for a particular situation based on a wide range of experienced skills developed from current research programmes.

During 1975, the Plant Diseases and Entomology Divisions were involved in the "UNDP/FAO-SPEC Survey of Agricultural Pests, Diseases and Viruses in the South Pacific" for the Pacific countries of Cook Islands, Fiji Islands, Kiribati, Niue, Tonga, Tuvalu and Western Samoa. Subsequently, plant disease surveys have been carried out for American Samoa, Federated States of Micronesia, Marshall Islands, Palau (Belau), Solomon Islands, and Vanuatu. Also insect pest surveys have been carried out for American Samoa and Vanuatu. The 'Survey of Nematode Pests of Agricultural Importance' was made of the Cook Islands, and recently, 1989, of American Samoa. Nematode surveys of the other mentioned islands were conducted by the Commonwealth Institute of Helminthology.

From these surveys, Mt. Albert Research Centre, DSIR, now has the most extensive and properly maintained insect and nematode collection and herbarium of plant diseases of the South Pacific which is an invaluable resource for future studies. This data is being entered into the Plant Protection Data Base for the Pacific, making it readily available to individual countries. This gave the Centre both the continuity and essential data base which had been previously lacking.

Since the surveys were completed, resources have been continually increased with material collected made during frequent visits to the islands and from samples submitted for identification and control of plant diseases and insect and nematode pests.

Divisions of Entomology and Plant Diseases contributed to the 'Plant Quarantine Guidelines Within the Pacific Region' compiled by O. O. Stout in 1982 (UNDP/FAO-SPEC). The basis of this publication was to enhance trade by removing restrictions based on unnecessary quarantine barriers.

Entomology Division. Entomology Division's involvement in the Pacific started in 1949 when L. J. Dumbleton was "released to work for the South Pacific Commission". He investigated entomological problems in Western Samoa, Cook Islands and French Polynesia and contributed several useful papers on the distribution of agricultural pests, parasites and potential predators for biological control of pests. Apart from this work, entomological involvement in the Pacific was sporadic prior to 1974 and provided no opportunity for collating a planned information and collection base. After the establishment of the Totokoitu Research Station, a more concerted and planned programme of entomological involvement in Pacific Islands agricultural problems was initiated.

The Entomology Division is able to handle entomological problems in temperate, subtropical and tropical climates because of its own domestic based research programmes and its long and continued involvement with the Pacific Islands. Members of this division have specialized knowledge covering most areas of basic and applied entomology. In particular, these include systematics, taxonomy, integrated pest management (IPM), biological control of arthropods and weeds, pheromones and sex attractants, mass rearing of insects, insect pathology, plant parasitic nematodes and their control, bee diseases and biology, pollination studies both in agriculture and horticulture, and wasp biology and control.

Considerable effort has been put into research on IPM of insects with respect to using biological control agents in coordination with timely chemical applications in New Zealand. Knowledge and technology gained from this research has been applied to solve insect problems on Pacific islands. Recent research in New Zealand on biological control techniques included the use of phytophagous arthropods to control troublesome weeds (e.g., weevils against thistles; mites against gorse; and Chrysomelid beetles against alligator weed).

Staff continually look for naturally associated parasites of insect pests which may have potential use as biological controls. Recently in the Cook Islands, one was found attacking a bean infesting leafminer. Recent introductions of biological control agents into the Cook Islands include a parasitic wasp for control of Diamondback moth on cabbage and a parasitic fly for control of the cushiony scale, *Iceryae seychellarum* (Westwood), on maile (maire) plant, *Alyxia elliptica* Cheeseman. In Hawaii, the fragrantly scented maile stems are greatly esteemed for use as leis.

Insect pheromone research in New Zealand has been directed towards the use of pheromones and sex attractants as baits in traps to determine the optimum time for spray application. Use of pheromones for mating disruption is being investigated. These results may eventually be of use to Pacific countries.

Studies on the use of *Bacillus thuringiensis* as a specific biological control agent have resulted in an improved formulation which maximizes the potency of the preparation over a longer time period. Noteworthy are studies on the coconut Rhinoceros beetle which have resulted in a semi-commercial technique of producing *Oryctes* virus strain 'X' which is useful for more than 8 weeks at room temperature and at least a year under refrigeration. This virus strain has been utilized in the Maldives Islands, Indonesia, Tonga and Western Samoa.

A very effective chemical control of coconut termites in the Northern Cook Islands has been devised.

Research on entomophagous nematodes suggests that they could have application as biological control agents of tropical pests. A successful commercial method has been developed which improves nematode viability and considerably reduces production costs.

Extensive studies on plant parasitic nematode control were conducted on banana, citrus and a wide range of vegetables. Results have markedly improved yields. Of special interest was the recent isolation of a nematode disorder of giant swamp taro in Palau (Belau).

Successful techniques have been developed for postharvest insect disinfestation of exportable fresh vegetables. These techniques could be highly applicable to Pacific countries wishing to export fresh produce.

Plant Disease Division. Plant Diseases Division's (PDD) involvement in the Pacific Region became particularly effective after establishment of the Totokoitu Research Station. Prior to this, visits were made to the Pacific in the 1960's to study mealy bug wilt of pineapples and black rot of kumara. PDD assists island countries in the storage and transport of their produce to either internal or external markets. Noteworthy was the redesigning and upgrading of banana harvesting, packaging and transport of bananas from the Cook Islands and Western Samoa to the New Zealand markets. Similar research on postharvest treatment and transport conditions has resulted in improved export methods for produce such as papaya, mango, vegetables (bell pepper, bean, courgette, tomato, watermelon). With the large Polynesian population now in New Zealand, the supply of taro from the Pacific islands is of particular importance. Successful studies on taro transport techniques have resulted in a high quality product being available to overseas markets. Additionally, detailed studies on quarantine procedures in compliance with overseas markets requirements have been conducted.

Extensive long term field trials were conducted on control of Sigatoka disease of bananas. To complement field trials, the cooperative (Australia/New Zealand) "Banana Improvement Project" was developed in New Zealand with the aim of offering improved cultivars to growers in Australia and the Pacific Basin. This project, affiliated with the International Network for Improvement of Bananas and Plantains, involves screening of banana breeding lines for resistance to Yellow Sigatoka, *Mycospherella musicola*, Leach ex Mulder, and Black Sigatoka, *M. fijiensis* Morelet and the determination of the pathogenic variability in the pathogen on a global basis. This screening can only be carried out in a non-banana producing area (e.g., New Zealand).

A biological control study with potential relevance to Pacific Basin countries is the development of a

technique using the fungus *Trichoderma* as a seed coating on vegetable seeds to successfully prevent seedling 'damping-off'. Similarly, the use of *Trichoderma* as a wound cover after tree pruning may be applicable to tropical situations.

Use of the fungus *Metarhizium anisopliae* (Metschnikoff) Sorokin as a biological control agent of the coconut Rhinoceros beetle has not proved as successful as was first hoped.

Particular attention is being paid to the screening of fungi for resistance to commonly used fungicidal sprays.

Division of Horticulture and Processing. Division of Horticulture and Processing (DHP) research programmes are directly relevant to food harvesting, storage and transport problems of the Pacific Basin. DHP has been involved in the development of small industries suitable to local people needs. However, the philosophy has always been to identify the needs of the island countries, rather than to introduce sophisticated overseas ideas which are completely inapplicable to island conditions. Assistance in food processing techniques related to island requests have always been considered as an overall plan. There is no point in having fruit juice factories if the supply of quality fruit is insufficient. DHP assistance always involves the cooperation of staff from other DSIR Divisions whose knowledge is complementary. Thus, the upgrading of the Rarotonga citrus juice factory also involved Plant Diseases and Entomology staff in improving the production and supply of fruit for the factory. Similarly, the pineapple juice factory on Atiu Island was not viable until major overseas funding was continuously available. Other projects have improved production and quality of lime juice on Niue Island, and the establishment of a small industry in Western Samoa based on extraction of a marketable natural red food colouring, derived from the seeds of the Annatto, *Bixa orellana* L. By the addition of an emulsifying agent during the processing of coconut cream, an improvement in texture, shelf-life, and flavour produced a marketable product for the Solomon Islands and Western Samoa.

Assistance and guidance was provided to local people of the 'highlands' of Papua New Guinea for crop production and transportation to coastal town markets. Presently, assistance is being given to the highlands people of the Chiang Mai region of Thailand, in production, storage and transport of their temperate produce down to the densely populated city of Bangkok in the tropics.

The fish technology section of DHP has specific expertise directly applicable to the Pacific Region. This section investigates all problems related to postharvest and processing of fish, shell fish and their by-products. DHP studies result in improved handling, quality and shelf-life of these products. Knowledge on wet-fish processing, storage, drying, freezing and smoking is available for island countries. Major research was directed towards insect disinfestation of stored fish, a major problem in the Pacific Region. Experience in maintaining ice for chilling and other basic technologies is available utilizing inexpensive equipment. A simple technique for depuration (removal of biological impurities) of shell fish could be applicable to Pacific Region countries. The section has an ongoing programme for training island personnel in fish technology. An extensive data base on fish technology which can assist in answering technological problems is also available.

Summary

The basic philosophy of the Department of Scientific and Industrial Research is that we have the appropriate expertise to assist tropical countries with numerous problems and that expertise is provided at a level appropriate to the farmer. We investigate the local problems (e.g. sociological etc.), then we assist with an overall policy.

DSIR maintains a very close liaison with the various agricultural departments of the island countries and also with other Regional and International Agencies operating in the Pacific (e.g., SPC, EEC, UNDP, FAO, ACIAR, British ODA, Asian Development Bank and the World Bank). DSIR is an integral part of the Pacific Region with a strong focus on Pacific problems.

DSIR and, in particular, the Mt. Albert Research Centre, is a professional group of experienced scientists who have a tremendous body of knowledge and wide experience in the Pacific Region. With this expertise available on one campus, we can provide an overall assessment of Pacific island food production problems. We are able to communicate in local terms with farmers and provide simple explanations. We realise that farmers do not want and cannot afford expensive equipment or high technology solutions. DSIR's role in the Pacific Basin is to provide programmes that are operative at the local level and meet the needs of this unique tropical region.

DEVELOPING PEST MANAGEMENT STRATEGIES FOR CUCUMBERS IN MICRONESIA

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ABSTRACT Development of a pest management system for cucumber was identified as a pest control priority in the American Pacific region. Common pests of this crop have been identified in Guam, and their importance is being evaluated as the first step towards developing rational control techniques. As a result of various experiments, information on the effects of populations of the melonworm, *Diaphania indica* Saunders, and the melon thrips, *Thrips palmi* Karny, on cucumber yield were obtained on Guam. Three trials where melonworm, *D. indica*, was present were evaluated. Regression analysis of melonworm populations per leaf versus yield of cucumbers showed that yield loss was approximately 10 percent when *D. indica* populations reached one per leaf. Yield loss could not be detected below this level. Yield loss increased linearly as populations increased above 1 per leaf and reached 30 percent when there were 4.5 larvae per leaf. Moderate populations of melon thrips, *T. palmi* (up to 80 thrips per leaf), experienced in one trial, had no significant effect on yield. Several pest species, including *Liriomyza trifolii* Burgess and *Leptoglossus australis* (F.) were identified as being rare on cucumber on Guam, probably because of effective parasites which may not be present elsewhere in Micronesia.

Cucumbers are one of the most widely grown European vegetable crops on islands in the Micronesian region. As with other European vegetables, cucumbers receive much of the insecticides used on agricultural crops on these islands, as native crops are hardly ever sprayed, except perhaps in the Marianas. Cucumber is the second most important cash crop on Guam following watermelon, and the two crops share many pest species.

The first step in developing a pest management plan is to determine economic injury levels for pest species. Many Micronesian pests are primarily Asian in distribution, and little published material is available about these insects, particularly with regard to their economic impact. To date I have only been able to develop economic information for one pest with preliminary information for one more pest, but other biological information which should be more widely known in the region is also available. All cucumber pests present in the Micronesian region are present on Guam, thus, if a management program was developed for use in Guam, most of the control tactics should be applicable to the whole Micronesian region.

Important pests of cucumbers in the Micronesian region include orange pumpkin beetle, *Aulacophora similis* (Olivier); melon fly, *Dacus cucurbitae* Coquillett; melon thrips, *Thrips palmi* Karny; two agromyzid leafminer species, *Liriomyza trifolii* Burgess and *L. sativae* Blanchard; the Asian melonworm *Diaphania indica* Saunders; the pentatomid stink bug, *Nezara viridula* (L.); the coreid stink bug, *Leptoglossus australis* (F.); the melon aphid, *Aphis gossypii* Glover; and the mirid *Halticus tibialis* Reuter. In addition, a variety of diseases exist which will not be considered here. Fungal diseases are especially important in the wetter islands of Micronesia, and information about their control will be an important part of an ultimate pest management system for the region.

Asian Melonworms

D. indica larvae feed on cucumber leaves, almost defoliating plants when populations are high. I have not observed them feeding on cucumber fruit, but in melons they may feed on the rind when their populations are high (Ba-Angood 1978,1979). This pyralid is present in the Marianas Islands, Palau, and possibly Truk within the Micronesian region. Using insecticide treatments, population levels of larvae were manipulated in cucumber plantings on Guam. Carbaryl, dimethoate and also *Bacillus thuringiensis* were effective in reducing larval populations, but oxamyl had no effect (Schreiner 1989a). Regression analysis of *D. indica* larval populations per leaf versus yield of cucumbers showed that yield loss was approximately 10 percent when *D. indica* populations reached one larva per leaf (Schreiner 1989b). Yield loss could not be detected below this level due to other sources of variance among plots. Yield loss increased linearly as larval populations increased above 1 individual per leaf. When larval populations reached 4.5 individuals per leaf, yield was reduced by one-third. In all three trials, *D. indica* populations were low in the early part of the crop cycle and only reached high levels after the harvest had begun.

Melon Thrips

The melon thrips is a new pest in the Micronesian region, first found in Guam in 1983 and several years later in Palau and the larger islands of the Northern Marianas. Efficacy of mulches for *T. palmi* control was evaluated. At the time there was no natural thrips infestation so thrips were introduced to the field edges. They became numerous on the plants after the cucumbers began to produce fruit. There was a significant difference in the number of thrips present among the replicates probably due to initial differences in the number of thrips successfully introduced to the field. Populations in some plots were as high as 85 thrips per leaf. The number of melon thrips per leaf was not affected by mulch or insecticide treatments. A slight reduction, about 4 percent, in the number of fruit set was observed in the plots with the highest thrips infestation, but the trend was not significant (Schreiner 1989b). Melon thrips also feed on developing cucumber fruit causing scarring, yet no significant correlation between thrips numbers and numbers of scarred fruit could be detected. A trend of increased fruit scarring (14% greater) was observed in the plots with high thrips numbers. Natural melon thrips infestations in Guam may be twice the number found in this trial, and may infest the field at an earlier stage. It is probable that more damage would be observed in these circumstances. The results found in this experiment contrast with those of Kawai (1986) who found a relatively consistent and strong correlation between numbers of melon thrips and both yield and percent injured cucumber fruit. It should be noted that fruit scarring resulting from *T. palmi* populations can vary and cucumber can tolerate substantial feeding injury without concomitant yield loss (Rosenheim et al., these Proceedings).

In several experiments on Guam, it has been found that melon thrips numbers increase as a result of insecticide use on cucurbits (Nafus et al. 1986, Schreiner 1986). I have observed nymphs of the anthocorid bug *Orius niobe* Herring, phytoseiid mites and predatory thrips feeding on the melon thrips. The numbers of predators are significantly reduced as a result of insecticide treatments. Numbers of predatory mites in plots treated with dimethoate, fenvalerate, and malathion averaged between 0.3 and 1.5 mites per 20 leaves compared to 16.9 predators in untreated plots. Naled had less effect, reducing the number of predatory mites by only 35 percent (Nafus et al. 1986). No insecticides which are legal for use on cucumbers under U. S. A. Environmental Protection Agency rules are known to control the melon thrips in Guam.

Aphids and Fleahoppers

A. gossypii and *H. tibialis* are the most widespread pests, occurring on all the larger Micronesian islands. The melon aphid can reach high levels of abundance if not treated. Although a number of parasites and predators are known from the region, they often do not reduce aphid numbers until the aphids have far surpassed the level at which plant injury is caused. On Guam the principal predators are the syrphid *Ischiodon scutellaris* (F.) and several ladybeetle species of which *Menochilus sexmaculatus* (F.) is the most common. Aphid parasitization is rare on Guam (Yudin et al., these Proceedings). Availability of parasite species elsewhere should be investigated and promising parasite species possibly introduced to keep the populations at lower levels. When viruses are present, other management strategies will be necessary to prevent significant yield losses (Yudin et al; Ullman et al., these Proceedings).

H. tibialis sucks on the leaves, creating white spots wherever it feeds. It has many hosts including a number of crop plants and common weeds. As shown by Nafus & Schreiner (these Proceedings), this insect seems to favor low growing plants, and becomes much less abundant when cucumbers are grown on a trellis. We have not made any assessment of how much damage these insects cause to the cucumber plant.

Stink Bugs

N. viridula and *L. australis* are also widespread, being present on all the larger Micronesian islands except Kosrae. I have observed large numbers of *N. viridula* in Palau and Pohnpei. *L. australis* was abundant on Pohnpei and probably also on other islands. Both of these insects are fruit and seed feeders. Their feeding causes spotting and distortion of cucumber fruits and many immature fruits may fall off prematurely. *L. australis* also feeds on the terminal shoots, which may cause them to wither and die beyond the point of attack. On Guam both species are relatively rare, and only a few individuals of each species are likely to be found even in an unsprayed cucumber planting. I have begun to examine some of the reasons why these insects are rare on Guam. *Trissolcus basalis* Wollaston was introduced to Guam to control *N. viridula* but no evaluation was conducted to determine if it established (Nafus & Schreiner 1989). In Guam cucumber plantings, I have collected a species of *Telenomus* (*podisi* group) from the eggs of *N. viridula* and *Gryon pennsylvanicum* (Ashmead) from the eggs of *L. australis*. *G. pennsylvanicum* is a scelionid wasp with widespread distribution, known to attack the eggs of several species of Coreidae and other Hemiptera with similarly shaped eggs. In most of Micronesia, there are few other hosts which would be suitable, so that its lack of specificity should not be a problem. It may be desirable to introduce this species to other Micronesian islands where *L. australis* is a pest. Several parasites are known which might be used to control *N. viridula*. (Davis 1967).

Leafminers

Leafminers are present on several islands. *L. sativae* is present only on Guam whereas *L. trifolii* is present on Guam, Saipan, Pohnpei and Yap. On Guam neither species is a common problem in cucumber plantings, although *L. trifolii* may occasionally become a serious pest in other crops. Usually only 2 - 3 mines per leaf

are observed on cucumber. A complex of six parasite species attack leafminers on Guam. The most common species on cucumber was *Ganaspidium utilis* Beardsley (D. Nafus, unpublished data). On other Micronesian islands, the parasite fauna may not be as rich. D. Nafus and I sampled mines on a variety of vegetable crops in Pohnpei for several days in 1984, and found only two species of parasites: *Hemiptarsenus semialbiclavus* Girault and *Gronotoma adachiae* Beardsley.

Other Insects

Melon fly, *D. cucurbitae*, a serious pest of cucumbers throughout the Marianas Islands, oviposits in the fruit and thereby causes it to drop prematurely, or at least permanently marks it. I have not studied their impact on yield on Guam , except to observe that during the wet season weekly foliar sprays may be insufficient to prevent complete loss of the cucumber crop.

Orange pumpkin beetles, *A. similis*, attack cucumbers in both the adult and larval stage. Adults feed on leaves, and a heavy attack at the seedling stage may destroy part of a planting. The larvae feed on the roots. I have not evaluated their impact on cucumber yield. These beetles are present in the Marianas Islands and in Yap and Palau.

Conclusions

Development of a pest management system for cucumbers is especially important for islands where the melon thrips is present. This insect is resistant to most insecticides, and insecticide use greatly reduces the number of predators which may feed on it. Careless use of insecticides may result in outbreaks of this species. Many farmers in the Marianas apply more insecticide than is necessary or otherwise use insecticides inappropriately. More rational use of insecticides will improve their crops and incomes. In the Caroline islands, very little insecticide is used at the current time, and most used is applied to various European vegetable crops including cucumbers. Although complex pest management systems are unlikely to be practical in these locations, even these farmers need an increased awareness of what and when to use materials. In several islands of Micronesia, a first step in managing their cucumber pest fauna may be to introduce biological control organisms against stink bugs and possibly leafminers.

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THE RIPENING OF WATERMELON IPM IN GUAM

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ABSTRACT The development of an integrated pest management (IPM) program for watermelon in Guam was intiated in January 1989. To initiate the program, arthropod pests and potential biological control agents were identified; and infestation levels of aphid species transmitting cucurbit mosaic viruses in watermelon were determined. Results from five commercial plantings indicated that the melon thrips, *Thrips palmi* Karny; the melon aphid, *Aphis gossypii* Glover; and the orange cucumber beetle, *Aulacophora similis* (Oliver), were the predominant pest species. *Liriomyza* leafminers and the melon fly, *Dacus cucurbitae* Coquillett were found in moderate numbers. Other foliar pests included the cowpea aphid, *A. craccivora* Koch; the melonworm, *Diaphania indica* Saunders; and the cluster caterpillar, *Spodoptera litura* (F.). *Ganaspidium utilis* Beardsley and *Grotonoma micromorpha* (Perkins) were the most predominant leafminer parasites collected from both pan traps and leaf samples.

Papaya ringspot virus - watermelon infecting isolate (PRSV-W) and zucchini yellow mosaic virus (ZYMV) were the predominant cucurbit viruses isolated from the five commerical watermelon fields. Six of the seven aphid species identified are known to transmit these cucurbit viruses in a non-persistent fashion.

Integrated pest management (IPM) is very important in the tropical and subtropical regions of the world. Indeed, IPM programs may provide the primary hope for future continuation of practical crop production in these agricultural areas. There is a vital need to create an awareness among all in agriculture of the diverse pest problems present, arthropod impact on crop yields, and alternative control methods. IPM is one of the imperative tools farmers need to manage the complex of arthropods, diseases, and other pest problems they face in producing crops.

In 1983, a multidisciplinary team of University of Hawaii - Manoa research and extension personnel initiated development of methods for the implementation of a watermelon IPM program in the Kahuku area of Oahu, Hawaii (Johnson 1986b). The objectives of their study were to quantify population levels of foliar pests, and, based on these findings, suggest management guidelines for pesticide application in watermelon (Johnson et al. 1989). Implementation of the suggested management guidelines reduced pesticide usage by 90 percent in some watermelon production areas in Hawaii. The success of their watermelon IPM project in Hawaii inspired the transfer to and implementation of this program in Guam.

Watermelon is the major agricultural commodity grown on Guam. According to the Guam Annual Economic Review (1987), there were approximately 68.4 ha of watermelon in production which in 1986 grossed $1,338,900 out of a total of $4,293,772 for all fruit and vegetable production on Guam. Because farming practices and pest diversity vary from one agricultural community to another, our first year's objectives were to (1) identify insect pests and potential biological control agents, and (2) quantify aphid vectors in relationship to cucurbit mosaic diseases associated with watermelon production in Guam. Once these objectives were achieved, implementation of the Hawaiian watermelon IPM program (Johnson et al. 1989) could begin with modifications appropriate to farming conditions in Guam.

Materials and Methods

From January to May 1989, five commercial watermelon farms were surveyed weekly in Guam to identify direct and indirect arthropod pests and plant viral pathogens. Farms were located in four separate villages: Barrigada, Dandan, Radio Barrigada, and two sites in Merizo. At each farm site, five sampling stations, 3 m square, were set up 8 -12 days after seed germination and remained in the field until first harvest. A modified horizontal pan trap (Irwin & Ruesink 1986) was used to mark the center point of each sampling station. The trap consisted of a 12 cm x 12 cm square ceramic tile fitted into a slightly larger plastic sandwich box (12.2 cm x 12.2 cm x 5 cm in depth). The trap was then mounted on a piece of PVC pipe (35 cm long, 2.5 cm dia.) which was driven into the ground at a height equal to the top of the watermelon canopy. Based on data from reflectance spectrophotometery, the color of ceramic tile used in our traps resembled that of a mature watermelon leaf (Moore, Ullman & Cho, unpublished data). The trap was filled with a 25 percent solution of ethylene glycol in water. Ethylene glycol was added to the traps to reduce the water evaporation rate. Traps

were initially set out to estimate the number of alate (winged) aphids landing in the field, however, other aerial insects (i.e., thrips, leafminers, and parasites) were also collected and recorded. Traps were replaced weekly and the mean number of insects were recorded each week.

Using techniques similar to those described by Johnson et al. (1989), foliar insect population densities were assessed weekly. At each sample station, ten leaves (uniform in size) were randomly removed from the middle sections of vines for a total of 50 leaves per farm site. Leaves were placed in labeled (i.e., farm site, date, sampling station) plastic bags, stored in an ice chest, and taken to the laboratory where they were examined under a dissecting microscope. The mean number of foliar insects was recorded. In addition, melon vine tips were monitored for thrips. At each sampling station, 10 vine tips were randomly selected; 50 vine tips per field site. Thrips densities were expressed as a percentage of infected tips per field (Johnson 1986b).

Due to the frequent flight activity of the orange cucumber beetle, *Aulocophora similis* (Oliver), only the number of adult beetles observed feeding within the boundries of each sampling station were counted. The mean observed number of beetles was recorded each week.

At three farm sites, two USDA melon fly (*Dacus cucurbitae* (Coquillett)) traps, baited with cue-lure to attract male melon flies, were placed at opposite ends of the field to monitor melon fly. The total number of melon flies collected from these traps were recorded each week.

Detection of infected plants from within each sampling station was determined by an *enzyme-linked immunosorbent assay* (ELISA). Antisera to four viruses [Papaya ringspot virus - watermelon infecting isolate (PRSV-W); watermelon mosaic virus 2 (WMV-2); cucumber mosaic virus (CMV); and zucchini yellow mosaic virus (ZYMV)] were used to identify the virus or viruses present in plants sampled. At each sampling station, ten newly formed leaves were randomly removed giving a total of 50 leaves per farm. Leaves were placed in labeled (farm site, date & sampling station) plastic bags, stored in an ice chest, and taken to the laboratory where samples were stored at -5°C prior to ELISA testing. ELISA results were used to determine percent virus incidence on a weekly basis.

Results

Fourteen insect pests and three biological control agents were identified from the five watermelon surveys conducted in Guam from January to May 1989 (Table 1). Out of the 14 insect pests found inhabiting watermelon plantings, the melon thrips, *Thrips palmi* Karny, the melon aphid, *Aphis gossypii* Glover, and the cucumber beetle were the most abundant insects recorded at all farm sites surveyed during the five month period. Beneficial insects identified from our surveys included two *Liriomyza* parasites, *Ganaspidium utilis* Beardsley and *Grotonoma micromorpha* (Perkins); and the aphid preditor, *Iscihiodon scutellaris* (F.).

The number of insects collected from the leaf samples revealed an abundance of thrips, aphids, and cucumber beetles (Table 2). Ninety-five percent of the thrips species identified were *T. palmi*. Four species of aphids were identified from the leaf samples (Table 1).

Table 1. Phytophagous species and biological control agents collected from watermelon IPM surveys in Guam, from January - May 1989

Scientific Name	Family	Common Name	Collected from	
			Foliage/Fruit	Pan Trap
Aphis citricola van der Goot	Aphididae	Green citrus aphid		X
Aphis craccivora Koch	Aphididae	Cowpea aphid	X	X
Aphis gossypii Glover	Aphididae	Melon aphid	X	X
Aulacophora similis (Oliver)	Chrysomelidae	Orange cucumber beetle	X	
Brachycaudus helichrysi (Kaltenbach)	Aphididae	Leaf-curling aphid		X
Dacus cucurbitae Coquillett	Tephritidae	Melon fly	X	
Diaphania indica Saunders	Pyralidae	Melonworm	X	
Ganaspidium utilis Beardsley[a]	Eucoilidae			X
Grotonoma micromorpha (Perkins)[a]	Eucoilidae			X
Hysteroneura setariae (Thomas)	Aphididae	Rusty plum aphid	X	X
Iscihiodon scutellaris (F.)[b]	Syrphidae			X
Liriomyza sativae Blanchard	Agromyzidae	Vegetable leafminer	X	X
Liriomyza trifolii (Burgess)	Agromyzidae		X	X
Rhopalosiphum maidis (Fitch)	Aphididae	Corn leaf aphid		X
Spodoptera litura (F.)	Noctuidae	Cluster caterpillar	X	
Tetraneura nigriabdominalis (Sasaki)	Aphididae	Grass aphid	X	X
Thrips palmi Karny	Thripidae	Melon thrips	X	X

[a] Parasitoids of *Liriomyza* spp.
[b] Aphid predator.

Table 2. Foliar densities of pests and incidence of mosaic viruses recorded from five watermelon farms in Guam from January to May 1989.

	Individuals per Leaf						Percent	Percent Incidence
	Orange Cucumber	Aphids	*Liriomyza* spp.		Lepidoptera	*T. palmi*	*T. palmi* Infested	of Mosaic Virus
Survey Date	Beetle		Live	Parasitized	Larvae		Vine Tips	Infected Plants
				Merizo Site I				
30 January	0.0	0.00	0.20	0.04	0.60	0.16	2	0
6 February	0.0	0.0 0	0.04	0.00	0.20	0.04	2	10
13 February	3.2	0.00	0.00	0.00	0.30	0.00	0	10
20 February	0.3	0.00	0.50	0.04	0.40	0.04	0	20
27 February	0.0	0.00	1.20	0.0 0	0.20	4.20	40	50
6 March	0.1	0.00	0.20	0.00	0.04	4.00	74	70
13 March	0.0	0.00	0.60	0.20	0.00	0.80	56	90
20 March	0.0	0.00	1.30	0.20	0.08	6.30	48	90
27 March	0.0	0.00	3.80	0.00	0.00	3.20	64	90
				Merizo Site II				
10 April	0.0	0.00	0.00	0.00	0.00	0.00	0	0
17 April	0.1	0.00	0.00	0.00	0.00	0.84	0	0
1 May	0.1	0.00	0.00	0.00	0.00	0.00	0	10
8 May	2.3	0.00	0.00	0.00	0.00	0.00	4	50
15 May	0.5	0.00	0.00	0.00	0.00	0.04	0	30
22 May	0.0	0.00	0.00	0.00	0.00	0.12	24	40
30 May	0.5	0.00	0.04	0.00	0.04	0.88	68	40
				Radio Barrigada Site				
6 February	0.6	0.04	0.08	0.00	0.16	0.00	2	0
13 February	3.2	0.76	0.28	0.00	0.12	0.00	0	0
20 February	0.8	0.68	0.10	0.04	0.04	0.10	0	0
27 February	0.1	0.08	0.10	0.00	0.00	0.04	0	0
6 March	0.0	108.90	0.00	0.00	0.04	0.04	8	10
13 March	0.0	116.70	0.44	0.04	0.00	0.08	0	40
20 March	0.3	81.00	0.12	0.00	0.08	0.00	10	60
27 March	1.4	90.20	0.00	0.00	0.00	0.00	12	80
				Barrigada Site				
10 April	0.0	0.00	0.00	0.00	0.00	0.00	0	0
17 April	0.2	0.00	0.00	0.00	0.00	0.00	0	0
24 April	0.2	0.00	0.00	0.00	0.04	0.08	0	20
1 May	0.1	0.00	0.00	0.00	0.00	0.28	0	20
8 May	1.3	0.00	0.04	0.00	0.04	0.08	0	20
15 May	0.0	0.04	0.16	0.00	0.00	0.56	8	50
22 May	1.4	0.00	0.28	0.00	0.04	3.20	22	40
29 May	1.6	0.08	1.40	0.00	0.24	1.60	48	50
				Dandan Site[a]				
30 January	0.0	0.00	0.00	0.00	0.00	45.70	8	0
6 February	0.0	0.08	5.50	0.00	0.00	11.80	2	0
27 March	0.0	2.40	0.28	0.16	0.08	2.90	0	0
10 April	0.0	0.02	0.24	0.20	0.00	0.50	0	50
17 April	0.0	0.00	0.00	0.00	0.00	0.12	0	40
24 April	4.7	5.80	0.00	0.00	0.20	0.12	14	50
1 May	2.0	2.50	0.00	0.00	0.00	0.24	0	60

[a] Field was destroyed by typhoon in February and was replanted in mid-March 1989.

A. gossypii was the most common species collected from the leaf samples representing 85 percent of all aphids recorded (Table 4). *A. craccivora* Koch, *Hysteroneura setariae* (Thomas), and *Tetraneura nigriabdominalis* (Sasaki) accounted for the remaining 15 percent of total aphids collected from the leaf samples (Table 4). The cucumber beetle was found to inhabit all five field sites. Other foliar pests included two lepidopterous species *Diaphania indica* Saunders and *Spodoptera litura* (Fabricius), and two agromyzid leafminers, *Liriomyza sativae* Blanchard and *Liriomyza trifolii* (Burgess) (Table 1). High populations of *D. cucurbitae* were collected in the two Merizo sites and in Radio Barrigada (Table 2). Watermelon growers on Guam may suffer losses up to 35 percent due to melon fly damage (F. J. Cruz, personal communication).

Aphids, thrips, leafminers and biological control agents were collected in the water pan traps (Table 3). Seven aphid species were identified from pan traps (Table 4). *A. gossyppi* was the most abundant aphid species collected from pan traps and represented 78 percent of the total aphids recorded. Nine percent of the aphids identified were *A. craccivora* whereas *H. setariae* represented 7 percent of total aphids. The other four aphid species accounted for the remaining 6 percent of aphids collected in the pan traps (Table 4). In addition to the number of alate aphids collected from pan traps, *T. palmi*, *L. sativae*, *L. trifolii*, *G. utilis* and *G. micromorpha* were also identified (Table 1).

There was a significant correlation between the percentage of watermelon tips infested with thrips and number of thrips collected from the leaf samples ($r = 0.68$, $P = 0.05$).

PRSV-W and ZYMV were the two most predominant cucurbit viruses found (Table 5). CMV was found only on a native amarath species, *Achyranthes canescens*. WMV-2 was never isolated from any sample. Nine cucurbit hosts of these viruses were identified of which six had mixed infections with PRSV-W and ZYMV (Table 5). Disease incidence was high at all farm sites reaching up to 90 percent at the Merizo site (30 January - 27 March) (Table 2). PRSV-W was the predominant virus found in the two southern farm sites (Merizo). ZYMV cucurbit virus epidemics were predominant at the central (Dandan) and northern farm sites (Radio Barrigada & Barrigada).

Discussion

Results of this survey provide a foundation for the transfer of the Hawaiian watermelon IPM to Guam. The major and minor insect pests and biological control agents in watermelon were successfully identified. In addition, three cucurbit viruses were isolated and six potential aphid vectors known to transmit cucurbit viruses were identified (Blackman & Eastop 1985). Of the 14 insect pests associated with watermelon in our surveys, five were listed as watermelon pests in Hawaii (Johnson et al. 1989). *A. gossypii* and *T. palmi* are major watermelon pests in Guam and in Hawaii. Only *A. similis*, *D. indica* and *S. litura* have not been

Table 3. Trap counts for watermelon pests recorded from five watermelon farms in Guam from January to May 1989.

Survey Date	Total Individuals per Water Trap			Melon[a] Fly
	Aphids	*Liriomyza* spp.	*T. palmi*	
Merizo Site I				
30 January	0.4	0.40	0.0	0
6 February	0.8	0.30	1.5	0
13 February	0.3	0.00	0.4	0
20 February	0.2	0.30	1.2	0
27 February	0.0	0.00	24.0	10
6 March	0.2	1.10	76.4	21
13 March	1.2	1.00	67.2	25
20 March	1.8	0.20	123.9	14
27 March	0.9	2.50	39.1	28
Merizo Site II				
10 April	0.0	0.00	0.0	0
17 April	0.0	0.00	0.0	0
1 May	0.8	0.00	0.8	0
8 May	0.0	0.00	0.0	0
15 May	0.0	0.00	0.0	4
22 May	0.0	0.00	0.0	1
30 May	0.0	0.00	3.2	13
Radio Barrigada Site				
6 February	1.0	0.00	0.2	0
13 February	0.3	0.00	0.1	0
20 February	0.7	0.12	0.1	0
27 February	0.4	0.00	0.0	4
6 March	5.9	0.00	4.1	10
13 March	4.6	0.10	3.0	1
20 March	15.0	0.00	1.6	7
27 March	6.2	0.04	3.0	28
Barrigada Site				
10 April	0.0	0.00	0.4	—
17 April	0.0	0.00	0.0	—
24 April	0.0	0.00	0.1	—
1 May	0.1	0.10	0.7	—
8 May	0.0	0.10	0.0	—
15 May	0.4	0.70	0.0	—
22 May	0.4	0.50	3.8	—
29 May	0.4	1.10	3.1	—
Dandan Site				
30 January	0.0	0.00	—	—
6 February	1.4	7.30	13.1	—
27 March	0.7	0.00	3.7	—
10 April	0.4	0.00	0.4	—
17 April	0.0	0.20	0.4	—
24 April	0.0	0.30	0.2	—
1 May	0.0	0.00	0.2	—

[a] USDA melon fly traps baited with cue-lure.

Table 4. Total species and numbers of alate aphids collected from leaf samples and water pan traps from watermelon fields in Guam in 1989.

Species	Total aphids collected from		
	Leaf samples	Water pan traps	Known cucurbit vector
Aphis citricola	0	1	yes
Aphis craccivora	0	24	yes
Aphis gossypii	96	199	yes
Brachycaudus helichrysi	0	1	yes
Hysteroneura setariae	4	17	yes
Rhopalosiphum maidis	0	4	yes
Tetraneura nigriabdominalis	4	10	no

recorded in Hawaii. The greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), and the carmine mite, *Tetranychus cinnabarinus* (Boisduval), are minor watermelon pests in Hawaii (Johnson et al. 1989), but were not found on watermelon in Guam. However, unlike the foliar watermelon pests in Hawaii (Johnson et al. 1989), where the primary pests were the *Liriomyza* leafminers, leafminers in Guam's watermelon plantings were considered minor pests. One possible explanation may lie in the lower frequency of pesticide sprays applied to watermelon in Guam compared to the number applied to suppress leafminer pests in Hawaiian watermelon fields (Johnson et al. 1989).

In Guam, the two predominant cucurbit viruses (PRSV-W & ZYMV) that attributed to disease incidence in watermelon are also the predominant cucurbit viruses affecting watermelon production in Hawaii (Cho et al., these Proceedings). Disease incidence at harvest ranged from 40 to 90 percent (Table 2). When one closely examines the data from both the Merizo and Barrigada sites, there were few or no aphids collected from leaf samples (Table 2). However, aphids were collected in the water pan traps (Table 3). This phenomenon suggests that the primary source of field inoculum was by infected aphids flying into the field. This is not surprising considering the large reservoir of cucurbit virus hosts (ie., bittermelon, luffa, wild pumpkin) that surround these farms (Table 5). One may assume that these infected aphids primarily feed and establish their colonies on the reservoir cucurbit virus hosts which surround these fields, and they occasionally feed on watermelon as they migrate from one host to another. Non-persistant transmission of viruses is characterized by extremely short inoculation times (i.e., seconds up to minutes). Hence, managing spread of these viruses requires a completely different approach than can be achieved with traditional insecticide applications to reduce aphid vectors. New control strategies, such as trap crops, reflective mulches, stylet oils, or biological repellence are needed to minimize the numbers of infected aphids landing in watermelon fields.

Conclusions

The transfer of Hawaii's watermelon IPM program to Guam is apparently quite feasible under the conditions and farming practices present in Guam. Many of the same foliar pests and cucurbit pathogens were found in both watermelon systems. Data collected from our five month survey will enable us to modify and adopt the Hawaii watermelon IPM program to fit Guam's conditions. Several modifications will be required including a monitoring program for cucumber beetle, a major watermelon pest in Guam, but not Hawaii, and adjustment for lack of greenhouse whitefly and spider mites present in Hawaii, but not Guam. Watermelon is one of the most important agricultural commodities grown in Guam. Its preservation in future years will depend on utilizing all suitable methods of control as found in an IPM system. However, watermelon growers in Guam are still conditioned to weekly spray programs. If an IPM program is to be established in Guam, growers must be convinced that the benefits of an IPM program are greater than their current practices.

Table 5. Common plant species in the watermelon production areas of Guam which were infected with one or more of three cucurbit viruses as determined with ELISA[a].

Plant species	Common name	Cucurbit virus[b]
Achyranthes canescens	amaranth	CMV
Citrullus lanatus Schrad.	watermelon	PRSV-W, ZYMV
Cucumis sativus L.	cucumber	PRSV-W
Cucumis staivus var. *cantalupensis* L.	cantaloupe	PRSV-W, ZYMV
Cucurbita moschata L.	wild pumpkin	PRSV-W, ZYMV
Cucurbita pepo L.	zucchini	PRSV-W, ZYMV
Carica papaya L.	papaya	PRSV-W
Luffa acutangula (L.)	gourd, luffa	PRSV-W, ZYMV
Mormordica charantia L.	bittermelon	PRSV-W, ZYMV

[a] Enzyme-linked immunosorbent assay.

[b] CMV = Cucumber mosaic virus; PRSV-W = Papaya ringspot virus - watermelon infecting isolate; ZYMV = Zucchini yellows mosaic virus.

Acknowledgment

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PRESENCE/ABSENCE SAMPLING FOR GREENHOUSE WHITEFLY ON TOMATOES

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ABSTRACT Greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), is a serious pest of field and greenhouse produced fresh market tomatoes in Hawaii. Whitefly densities greater than ca. 0.7 immature per cm^2 area of tomato leaflet can reduice yield by more than 5 percent. Weekly counting of immature whiteflies on leaflet samples can be time-consuming and requires equipment usually not available to Hawaii's tomato growers.

To reduce sampling time and difficulty, two presence/absence sampling techniques were examined using 1) whole tomato leaflets and 2) 4 cm^2 squares randomly placed on the leaflet as the sample units. For both sample units, there was a significant regression between the log mean and log variance of the whitefly counts. Slope and intercept values from these regressions were used to estimate the population densities based on the proportion of infested leaflets.The results demonstrated that whole leaflet samples were unreliable in a presence/absence sampling scheme when infestation rates surpassed 80 percent of the sample units examined. In contrast, presence/absence sampling was reliable in detecting the specified density treatment level when four cm^2 squares were used as a sampling unit.

Reduction of pesticide use in agroecosystems through the use of economic thresholds (ET's) or density treatment levels (DTL's) requires knowledge of a pest's impact on crop yields; establishment of management strategies which prevent pest-induced injury from reaching economically significant levels; and a method to monitor pest densities so that management strategies can be employed in a timely manner. On the U.S. Mainland, growers of various commodities (vegetables, citrus, deciduous fruit, ornamentals, field & row crops) have access to affordable pest management scouting and consulting services. These mangement services assist growers in their decision-making process by routinely providing information on pest levels in crops and the probable outcomes if pest densities are not suppressed. To date, such services are unavailable for most of Hawaii's vegetable growers.

During the last few years, the concepts of rountinely monitoring crops to determine density levels of pest and beneficial species; and applying pesticides only when pest densities surpass DTL's have gained acceptance among Hawaii's vegetable growers (Johnson et al. 1989). Currently, a pest management program is being developed for fresh market tomatoes in Hawaii. A major objective of the program is to reduce pesticide applications on tomatoes by limiting insecticide treatments through the use of DTL's. Studies in Hawaii have shown that yield reductions due to greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), are correlated with the number of "immature whitefly days" accumulated during the crop cycle on a given tomato planting (Johnson et al., these Proceedings). Data indicate that greater than 5 percent yield loss may occur when immature whitefly densities surpass ca. 0.7 immature whitefly per cm^2 tomato leaflet area. On an average tomato leaflet, this is ca. 36 immature whiteflies per leaflet. Accurate monitoring of immature whitefly densities on leaflets requires a quality dissecting microscope and varying amounts of time dependent on the densities of individuals encountered on each leaflet. In Hawaii and the Pacific Basin, few growers have access to the equipment needed for counting whiteflies. Even fewer growers have time enough to perform counts when numbers approach the DTL of 36 immatures per leaflet which would require that an individual count a minimum of 3,600 whitefly immatures for a 100 leaflet sample. Thus, the use of DTL's for timing control actions for greenhouse whitefly may be minimal or zero unless Hawaii's growers are provided simple and easy survey techniques for this pest.

Many IPM sampling programs determine the mean number of individuals present for a given pest stage(s) based on the total count of pest individuals on a fixed number of sample units (e.g., leaves, plants, traps). Depending on the pest species and sample unit, these samples may require significant processing time. Shortcuts to reduce counting time include the use of sequential sampling and presence/absence sampling regimes. These sampling programs are intimately linked to the statistical distribution of the species being sampled.

Researchers have found that for many arthropod species there is a linear relationship between the log of the mean densities and the log of the corresponding variances. This relationship is referred to as *Taylor's Power Law* (Taylor 1961). If a linear regression

equation is determined for log mean and log variance data pairs, then a line can be drawn which has a slope (β) and intercept on the Y axis (log α). It has been theorized that the β value is a characteristic of the arthropod species with respect to the habitat sampled and the α value is characteristic of the sampling method. Values of β not significantly different from 1.0 indicate that the organism has a random distribution, while values less than 1.0 indicate that the organism has a uniform distribution. Most arthropod species exhibit β values significantly greater than 1.0 which indicates that their distribution is clumped. This means that if one individual is found in a sample, there is a high probability that a second individual will occur in the same sample. When pest densities are low (< 10 individuals per leaflet), usually most of the pests in a 100 leaflet sample will be confined to very few leaves. As the mean pest density increases, the proportion of leaves infested [P(I)] increases. This pattern can be mathematically represented using the equation below:

$$P(I) = 1 - e^{-m[\ln(\alpha x^{\beta-1})][(\alpha x^{\beta-1}-1)^{-1}]} \qquad (1)$$

where $e = 2.7182$; α = antilog(Y intercept); β = slope of the log mean/log variance regression line; and m = organism's population density (Wilson & Room 1983). If the pattern generated by graphing the mean pest density (*on the X axis*) vs. the proportion infested leaflets (*on the Y axis*) in the field does not deviate significantly from the curve generated by Equation 1, then it may be possible to accurately estimate pest densities by determining the proportion of leaflets which are infested. This sampling method is referred to as "presence/absence" or "binomial" sampling. This sort of sampling is only applicable when the proportion of leaves infested is less than 0.8.

The objective of this study was to develop presence/absence sampling programs for greenhouse whitefly using sample units consisting of 1) whole leaflets and 2) four 1 cm^2 squares placed on leaflets which would be appropriate for DTL's of 36 immature whiteflies/leaflet and 3 immature whiteflies/4 cm^2 tomato leaflet area, respectively.

Materials and Methods

Field studies to determine greenhouse whitefly mean densities and associated variances were conducted at the University of Hawaii Experiment Station at Poamoho, Oahu, during 1987 and 1988. For each planting, sixteen plots, each consisting of three tomato rows 6 m long with 2.3 m between rows were established. Plots were treated with various pesticides to manipulate the whitefly densities among plots. In April - June 1987, samples consisting of 20 leaflet each were taken weekly from each plot. The entire undersurface of each leaflet was examined under a dissecting microscope and all greenhouse whitefly nymphal stages (1st - 3rd instars) were recorded. The proportion of infested leaflets was determined for each sample set. In August 1987, 30 leaflet samples were taken weekly from each plot. A clear acetate sheet printed with outlines of randomly placed 1 cm^2 squares (non-overlapping) was placed over inverted leaflets. Leaflet undersurfaces were examined under a dissecting microscope and numbers of whitefly immatures were recorded from four individual 1 cm^2 squares. Numbers of immature whiteflies recorded were totalled for the 4 squares counted per leaflet. The proportion of leaflets having 1 or more immatures in the 4 cm^2 leaflet area sampled was determined for each sample set.

For each sampling regime, weekly means and variances were calculated for each plot during the survey period.

Development of Presence/Absence Sampling Progam. For data sets generated using each sample unit, log means and associated log variances were regressed and slopes (β) and intercept values (log α) were determined. Appropriate values were used in Equation 1 to quantify the relationship between the mean density of immature whiteflies per sample unit and the proportion infested units in a sample set. Comparisons were made between the model estimates and the field data used to generate the models for the whole leaflet and 4 cm^2 sample units. For the 4 cm^2 sample unit, a separate set of data collected in April and May 1988 was used to test the model. All comparisons between model estimates and field data were tested using χ^2 analysis.

Development of Presence/Absence Sampling Progam. For data sets generated using each sample unit, log means and associated log variances were regressed and slopes (β) and intercept values (log α) were determined. Appropriate values were used in Equation 1 to quantify the relationship between the mean density of immature whiteflies per sample unit and the proportion infested units in a sample set. Comparisons were made between the model estimates and the field data used to generate the models for the whole leaflet and 4 cm^2 sample units. For the 4 cm^2 sample unit, data collected in April and May 1988 was used to validate the model. All comparisons between model estimates and field data were tested using χ^2 analysis.

Results and Discussion

Means determined for the data sets generated using the two sample units ranged from 0.0 to 375.7 immatures per tomato leaflet and 0.0 to 40.4 immatures per 4 cm^2 tomato leaflet area for the whole leaflet and 4 cm^2 sample units, respectively.

Whole leaflet samples. Using whole leaflet data from 1987, log transformations of mean immature whitefly densities per tomato leaflet were regressed against log tranformations of the corresponding variances (Fig. 1). Regressions were significant ($P < 0.0001$). Values of α (5.43) and β (1.783) obtained from field data were used in Equation 1 to estimate the

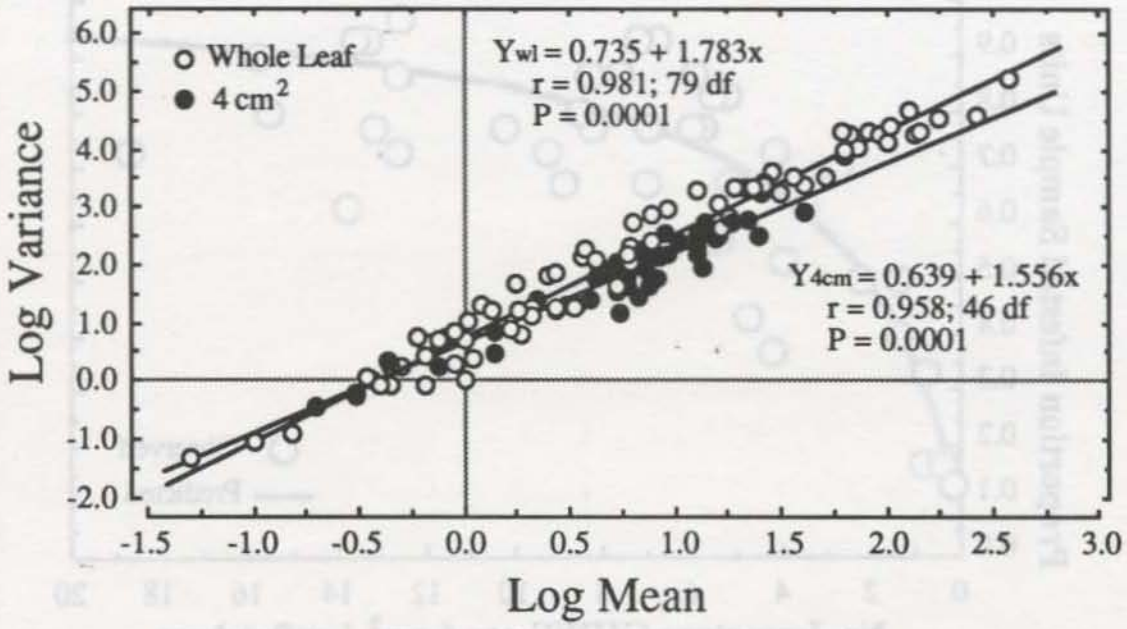

Fig. 1. Regression of log means and associated log variances for whole tomato leaflet and 4 cm^2 sample units.

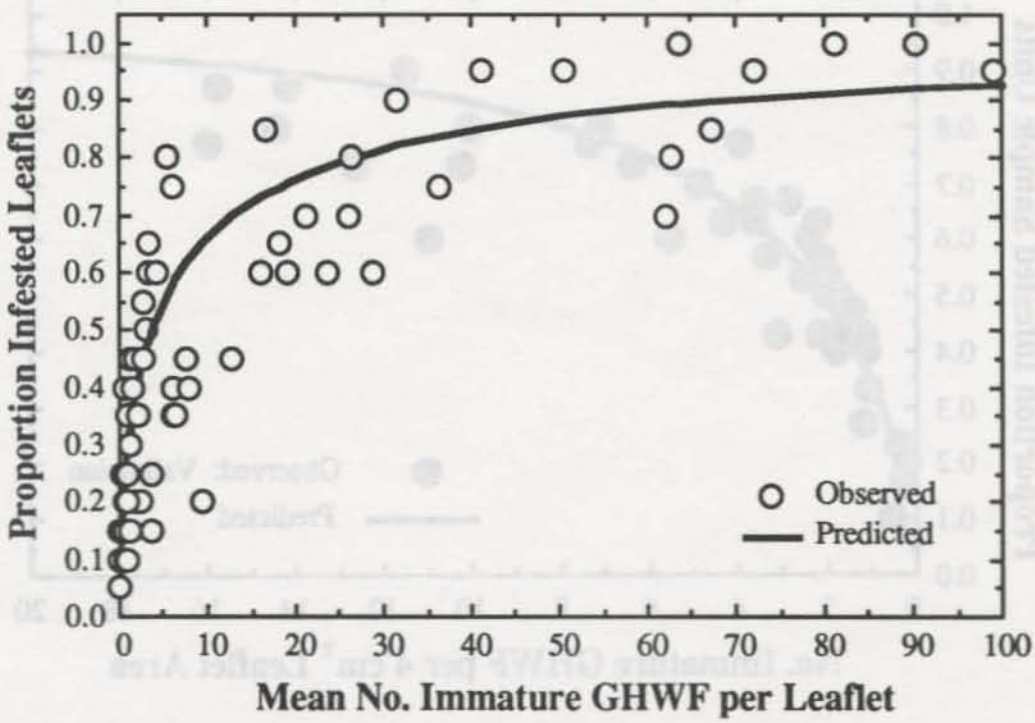

Fig. 2. Observed and predicted proportions of whole tomato leaflets infested with immature whitefly stages as a function of mean immature whitefly densities.

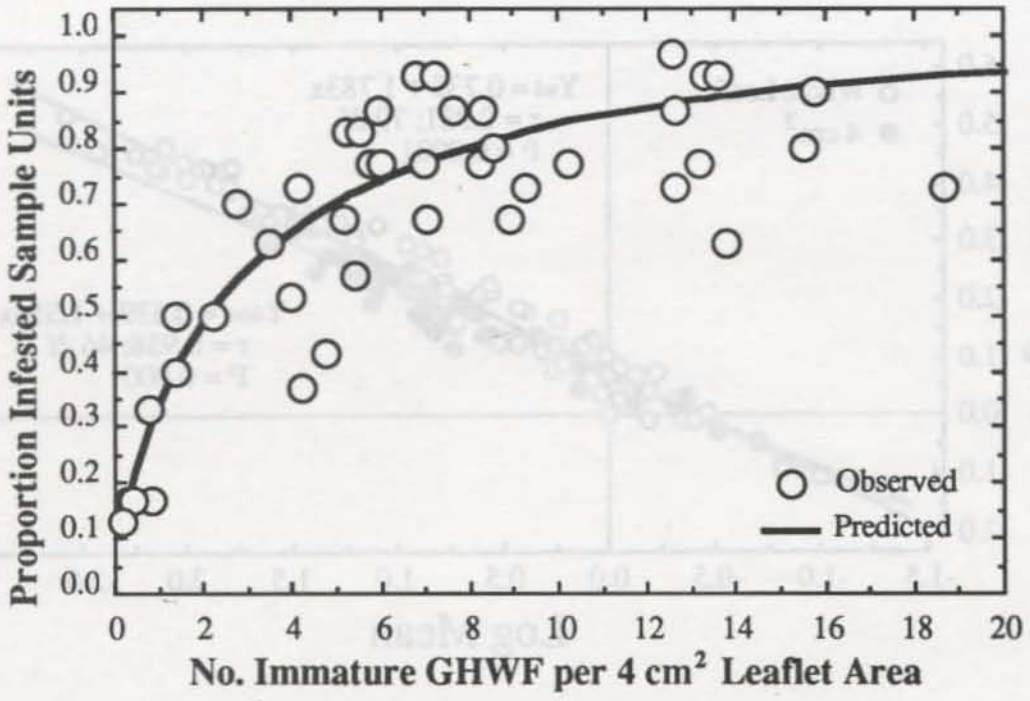

Fig. 3. Observed and predicted proportions of 4 cm^2 sample units infested with immature whitefly stages as a function of mean immature whitefly densities using data collected in 1987.

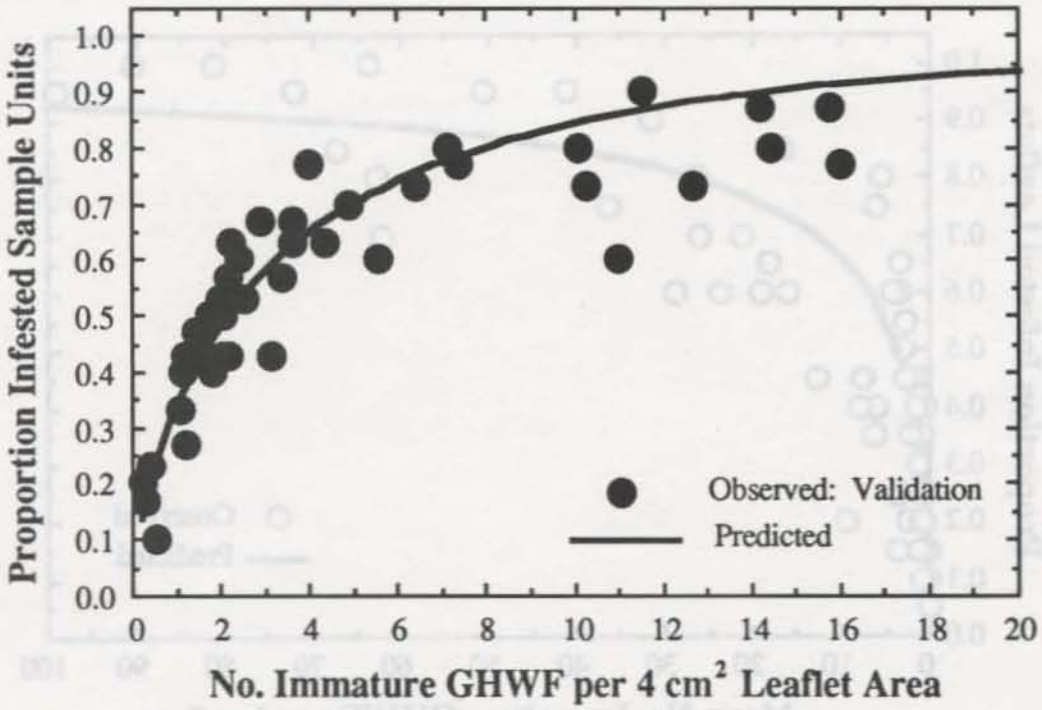

Fig. 4. Validation of presence/absence sampling regime using data collected in 1988; observed and predicted proportions of 4 cm^2 sample units infested with immature whitefly stages as a function of mean immature whitefly densities.

proportion of infested leaflets with respect to mean whitefly density per leaflet (Fig. 2). There were no significant differences between the observed and predicted values ($\chi^2 = 44.1$ w/ 54 df; $P > 0.5$).

Four cm² leaflet samples. Regression of the log means and log variances was significant for the 4 cm^2 leaflet samples ($P < 0.0001$) (Fig. 1). The values of α (4.35) and β (1.556) were used in Equation 1 to estimate the proportion of infested leaflets with respect to mean whitefly density per 4 cm^2 leaflet area (Fig. 3). Again, field data did not differ significantly from predicted values ($\chi^2 = 31.24$ w/ 46 df; $P > 0.5$) (Fig. 3). Using this sample unit, mean whitefly densities ≤ 8 individuals/ 4 cm^2 units are found when the proportion infested 4 cm^2 units is < 0.8. This results in estimates that accurately reflect the range of densities which need to be estimated for the DTL. Predicted proportion infested leaflets vs. mean whitefly densities were validated by comparing predictions with additional field data from 1988 ($\chi^2 = 16.23$ w/ 46 df; $P > 0.5$) (Fig. 4). This indicates that growers would be able to use presence/absence sampling to estimate whitefly densities for management purposes, thereby saving sampling costs and reducing unnecessary pesticide use.

As previously stated, significant yield losses (5 pecent) may occur when immature whitefly densities surpass 36 individuals per leaflet. Examination of Fig. 2 shows that when mean immature whitefly densities are greater than 30 individuals per leaflet, proportion infested leaves is greater than 0.8. Estimates of mean densities from proportions greater than 0.8 are unreliable because a small change in the proportion infested sample units makes an extremely large change in the estimated mean population density. Thus, the use of presence/absence sampling would not be appropriate if whole leaflet samples were used with a density treatment level of 30 to 100 individuals per leaflet as the threshold. However, by changing the sample unit from whole tomato leaflets (ca. 52 cm^2) to samples of 4 cm^2 leaflet area the problem was alleviated. This meant that the white density level at which significant yield loss occurred (1 immature per 1 cm^2 leaflet area) changed from 36 whiteflies per leaflet to 4 whiteflies per 4 cm^2.

Simple and accurate grower-usable monitoring techniques are a prerequisite for implementing current and future IPM programs in Hawaii and many Pacific Basin areas where consultant services are unaffordable or non-existent. Without these survey tools, many DTL's developed for tropical crops will not be utilized. This can result in yield losses due to ineffective timing of control actions and the development of pesticide resistance in pest species in those areas where preventative treatments are applied. In addition, growers will not be able to take full advantage of biological control agents present in their plantings as a result of applying pesticides at inopportune times. Our future research efforts are aimed at developing grower-usable sampling techniques for the *Liriomyza* leafminers on tomatoes.

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CUCUMBER FRUIT SCARRING BY *THRIPS PALMI* AND *FRANKLINIELLA OCCIDENTALIS* (THYSANOPTERA: THRIPIDAE)

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ABSTRACT Within-plant variation in density and sex ratio of *Thrips palmi* Karny and *Frankliniella occidentalis* (Pergande) and the relative contribution of each species to fruit scarring were studied in field plantings of cucumber, *Cucumis sativus* (L.), on Oahu, Hawaii. Densities of *T. palmi* were greatest on foliage, intermediate on flowers, and lowest on fruits. In contrast, *F. occidentalis* aggregated in flowers; densities were low on foliage and lower still on fruit. Sex ratios for *T. palmi* were female biased and independent of the plant substrate sampled. Sex ratios for *F. occidentalis* were also female biased, but the proportion of males increased in flowers. Temporal (within and between field plantings) and spatial (within field) variation in the incidence of fruit scarring was generated primarily by variation in the density of *F. occidentalis* rather than *T. palmi*. These data combined with the recent finding that cucumber tolerates substantial indirect feeding damage from thrips without a concomitant yield loss (Welter et al. 1990) suggest that *F. occidentalis* may be the more severe pest in mixed-species infestations of cucumber.

Thrips palmi Karny has recently expanded its range across the Pacific and emerged as a key pest of a broad array of crop plants (Waterhouse 1987, Hamasaki 1987). On Oahu, Hawaii, *T. palmi* is a major pest of cucumber, *Cucumis sativus* (L.), commonly existing in mixed-species infestations with another thrips pest species, *Frankliniella occidentalis* Pergande (Rosenheim et al. 1990). Thrips feeding on immature fruits generate silver, web-like scar tissue that may be accompanied by fruit deformation. Scarred or deformed fruit may be downgraded at harvest, resulting in economic losses to growers. As an initial step towards the development of a pest management program for *T. palmi* and *F. occidentalis* on cucumber, we analyze here their within-plant distributions and relative contributions to fruit scarring.

Materials and Methods

Two experiments were conducted at the University of Hawaii Poamoho Agricultural Experiment Station on Oahu, Hawaii. Protocols described below are common to both experiments except as noted. For additional methodological details see Rosenheim et al. (1990).

Experimental Design. Twenty-four plots, each with ca. 75 cucumber vines (cv. 'Sweet Slice') arranged in three 8 m rows, were planted on 21 January 1988 (= day 0, Experiment I) and 22 August 1988 (= day 0, Experiment II). Four treatments, control (lowest thrips density), low, medium, and high thrips densities, were replicated six times in a randomized block design. Thrips densities were manipulated with approximately weekly applications of avermectin (0.15 EC [emulsifiable concentrate]; 0.024 g [AI]/liter) made with a sprayer mounted to a cart pulled by an all-terrain vehicle. Spray volumes of 1.6 - 5.2 liters per plot were adjusted to maintain coverage of growing plants. In Experiment I, avermectin sprays were begun on days 28, 61, and 71 for the control, low and medium density treatments, respectively, and continued until the final harvest; corresponding dates for Experiment II were days 25, 46, and 66. High density treatments were never sprayed with avermectin. Other arthropod pests and pathogens were suppressed as needed with pesticides demonstrating no impact on either thrips species.

Thrips densities were monitored with weekly foliage samples. The fifth leaf from the vine tip (the first leaf defined as one with a width $\geq$ 2.5 cm) was cut along the midrib and the half with the midrib sampled. Ten half-leaves were sampled per plot. Samples were rinsed sequentially with ethanol and water and the thrips recovered for counting with a sieve (79 meshes/cm). Species and sex determinations were made for adults only. The area of sampled leaves was measured with a LI-COR® portable area meter (model LI-3000); thrips densities are reported as numbers per 200 cm^2 of leaf surface. This area is equal to the upper and lower surface area of an average sized half-leaf (Welter et al. 1990). Foliar samples were accompanied on days 60 and 95 (Experiment I) and days 35,56, and 77 (Experiment II) by samples of young fruit (length 5 - 8 cm; ten sampled per plot), male flowers (ten sampled per plot), and female flowers (two sampled per plot). Surface area of flowers sampled on day 86 of Experiment II were also measured with the portable area meter. The surface areas of young cucumbers sampled on day 77 of Experiment II were approximated as 2π width length.

Fruit were harvested twice a week, and fruit from the center row of each plot (Experiment I) or all fruit (Experiment II) were scored for scarring. Fruit were considered scarred if scar tissue covered >1 cm^2, as estimated by visual inspection.

Statistical Analysis. Means are presented ± one standard error. Analyses of within-plant variation in species composition and sex ratio included data from all 24 plots only if there was no significant difference between plots sprayed with avemectin and those not so sprayed, as measured by analysis of variance (ANOVA). Sprayed plots were excluded if the ANOVA revealed a significant difference. Stepwise multiple regression was used to determine which of two independent variables, the densities of *T. palmi* and *F. occidentalis*, was making a significant contribution to fruit scarring, the dependent variable.

Results

Within-Plant Distributions. The relative preferences of *T. palmi* and *F. occidentalis* for leaf, fruit, and male and female flower substrates are presented (Fig.1). *T. palmi* was consistently more common on leaves than on flowers, where *F. occidentalis* tended to predominate. *T. palmi* was also generally the dominant species on sampled fruit.

The absolute preference of each thrips species for different plant parts can be investigated by comparing the densities per unit area substrate. Data from the high density treatments (unsprayed plots) only are presented. Figures are presented as a fraction of the foliar densities and are averaged over the five sampling dates (Experiments I & II combined). Densities of *T. palmi* on young fruits, male flowers, and female flowers were 0.19 ± 0.09 (range 0.00-0.51), 0.55 ± 0.40 (range 0.00-2.16), and 0.57 ± 0.38 (range 0.00-2.08), respectively. Corresponding figures for *F. occidentalis* were 0.17 ± 0.06 (range 0.00-0.34), 29.2 ± 11.8 (range 2.91-69.9), and 50.1 ± 36.2 (range 2.99-193.1). Thus, *T. palmi* shows a modest preference for leaves while *F. occidentalis* shows a strong preference for flowers. Fruit is the least preferred substrate for both species.

Sex Ratio. The sex ratio of *T. palmi* was consistently female biased ($t = 16.16$, $P < 0.001$) and did not vary across plant substrates (Fig. 2A, 2B). Although *F. occidentalis* sex ratios were also female biased (on flowers, $t = 4.92$, $P < 0.001$; on leaves and

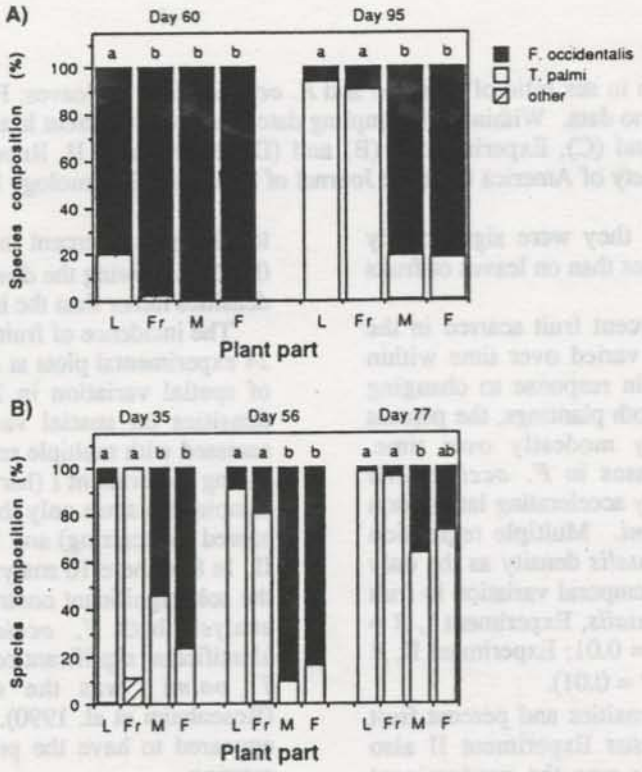

Fig. 1. Thrips species composition on cucumber leaves (L), fruits (Fr), male flowers (M), and female flowers (F). Within each sampling date, bars with different letters are significantly different ($P < 0.05$). (A) Experiment I, (B) Experiment II. Reprinted by permission of the Entomological Society of America from the Journal of Economic Entomology 83(4):1521, Fig. 1.

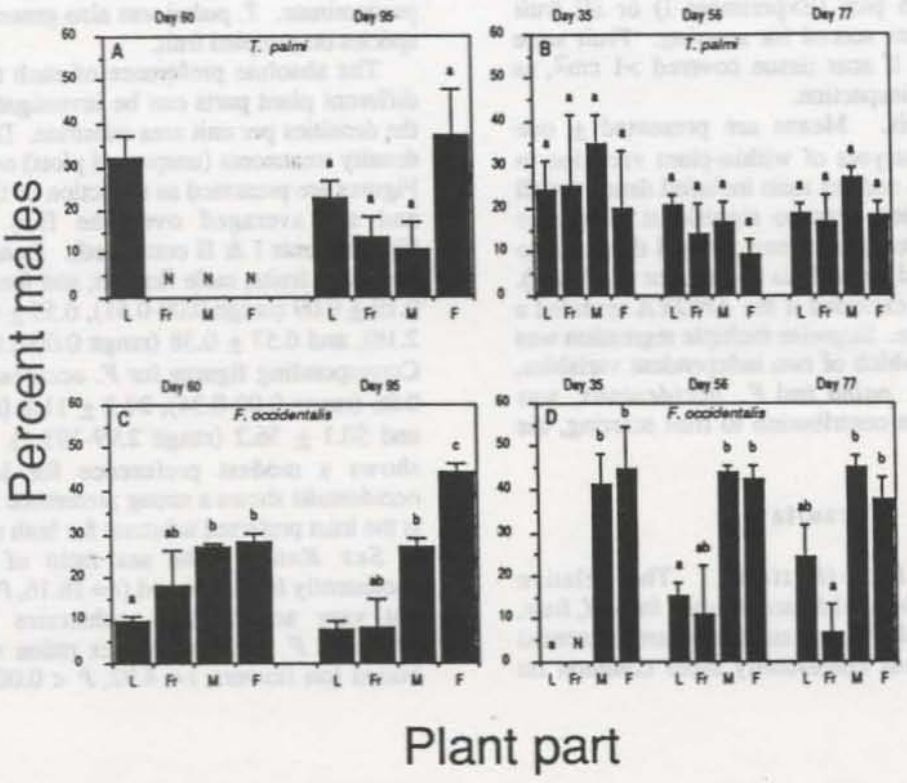

Fig. 2. Within-plant variation in sex ratio of *T. palmi* and *F. occidentalis*. L, leaves; Fr, fruit; M, male flowers; F, female flowers; N, no data. Within each sampling date, bars with different letters are significantly different ($P < 0.05$). (A) and (C), Experiment I; (B) and (D), Experiment II. Reprinted by permission of the Entomological Society of America from the Journal of Economic Entomology 83(4):1522, Fig. 2.

fruits, $t = 16.13$, $P < 0.001$), they were significantly less skewed on flower substrates than on leaves or fruits (Fig. 2C, 2D).

Fruit Scarring. The percent fruit scarred in the high density treatment plots varied over time within both experimental plantings in response to changing thrips densities (Fig. 3). In both plantings, the percent fruit scarred increased only modestly over time, reflecting the gradual increases in *F. occidentalis* densities rather than the rapidly accelerating late-season population growth of *T. palmi*. Multiple regression analysis identified *F. occidentalis* density as the only significant contributor to the temporal variation in fruit scarring observed (*F. occidentalis*, Experiment I, $B = 0.0049 \pm 0.0015$, $r = 0.68$, $P = 0.01$; Experiment II, $B = 0.0130 \pm 0.0041$, $r = 0.73$, $P = 0.01$).

A comparison of thrips densities and percent fruit scarred in Experiment I versus Experiment II also suggests that *F. occidentalis* was the predominant influence on fruit scarring. Densities of *F. occidentalis* decreased from Experiment I (mean = 21.98 ± 6.11) to Experiment II (mean = 4.00 ± 1.74), while *T. palmi* densities increased (Experiment I, mean = 38.40 ± 21.40; Experiment II, mean = 62.62 ± 39.25). Percent fruit scarred decreased from $45.5 \pm 3.0\%$ in Experiment I to 17.3 ± 2.2 percent in Experiment II ($t = 7.58$, $P < 0.001$), following the downward trend of *F. occidentalis* densities rather than the increasing densities of *T. palmi*.

The incidence of fruit scarring also varied across the 24 experimental plots at a given harvest. The influence of spatial variation in *T. palmi* and *F. occidentalis* densities on spatial variation in fruit scarring was assessed with multiple regression for five harvest series during Experiment I (harvests were grouped to increase sample size since only the middle row of each plot was scored for scarring) and 11 harvests during Experiment II. In 8 of these 16 analyses *F. occidentalis* density was the sole significant contributor to fruit scarring; in one analysis both *F. occidentalis* and *T. palmi* were identified as significant contributors, and in two analyses *T. palmi* was the sole significant contributor (Rosenheim et al. 1990). Thus, *F. occidentalis* again appeared to have the predominant influence on fruit scarring.

Discussion

The within-plant distribution observed for *F. occidentalis* may be related to this species' strong influence on fruit scarring. Female and especially male

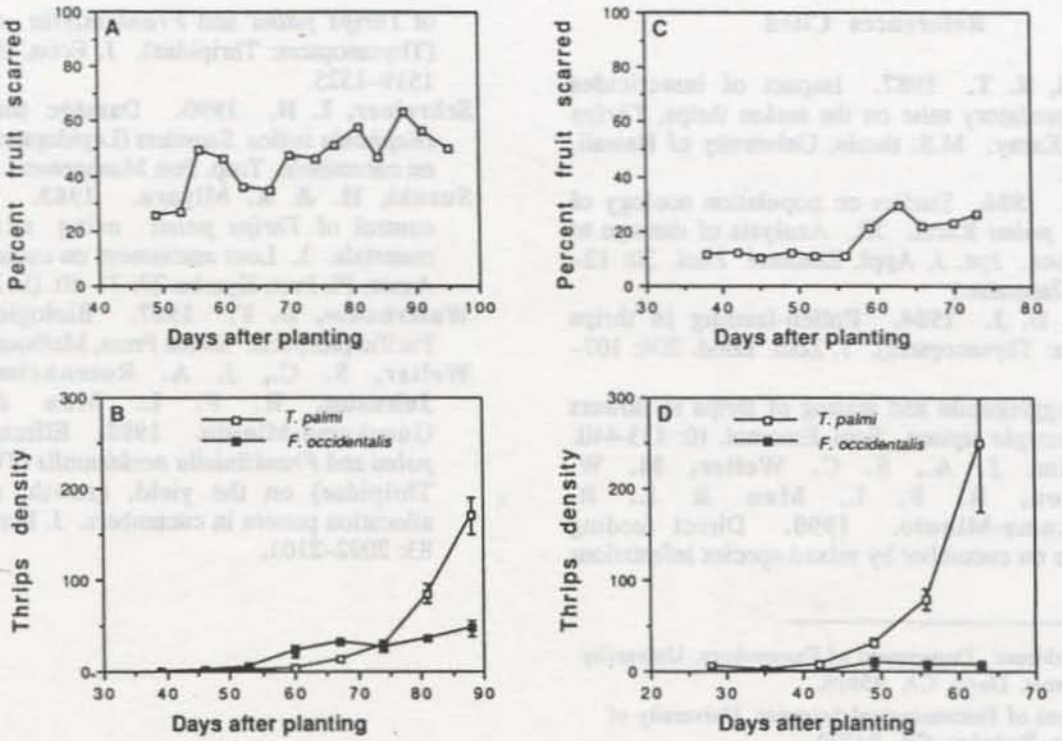

Fig. 3. Temporal trends in *T. palmi* and *F. occidentalis* foliar densities on cucumber and corresponding trends in percent fruit scarred. (A) and (B), Experiment I; (C) and (D), Experiment II. Reprinted by permission of the Entomological Society of America from the Journal of Economic Entomology 83(4):1523, Fig. 3.

F. occidentalis congregated in flowers, the females probably in search of pollen (Kirk 1984) and the males probably in search of mating opportunities (Kirk 1985). Because female flowers are physically supported by developing fruits, which are susceptible to scarring, the aggregation of *F. occidentalis* in flowers may provide opportunities for them to incidentally feed upon and damage young fruit.

Our conclusion that *T. palmi* had a minor influence on fruit scarring is in accord with that of Schreiner (1990), who found no relationship between *T. palmi* densities and the incidence of fruit scarring, but conflicts with those of Suzuki & Miyara (1983) and Kawai (1986), who found positive linear relationships between *T. palmi* densities and percent fruit scarred. The basis for these contradictory results is not known. One possibility is that different cucumber cultivars may show different degrees of susceptibility to scarring; both our study and that of Schreiner (1990) employed western cucumber cultivars, whereas Suzuki & Miyara (1983) and Kawai (1986) used Japanese cultivars, which differ markedly in growth form.

Our results have immediate implications for thrips management on cucumber. First, because *T. palmi* and *F. occidentalis* appear to have qualitatively different impacts on cucumber, it will be necessary to distinguish these species during field population monitoring. Second, the economic injury level (EIL) for *T. palmi* will be dictated by its propensity to impact cucumber yield indirectly via foliage feeding. Welter et al. (1990) have shown that cucumber can sustain substantial foliar damage from thrips feeding with no detectable decrease in yield, and suggested a conservative EIL for *T. palmi* of 95 thrips per leaf. Third, the EIL for *F. occidentalis* will be dictated by its propensity to generate direct damage to cucumber fruit; data in Figure 3C, D suggest that *F. occidentalis* densities as low as 16 per leaf are sufficient to increase fruit scarring by 10 percent. Thus, in mixed-species infestations of cucumber, *F. occidentalis* may be the more acute pest, requiring an EIL that is substantially lower than that observed for *T. palmi*.

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CONCEPTS AND ADVANCES IN ECONOMIC THRESHOLDS FOR IPM

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ABSTRACT Population assessment and decision making are key elements in integrated pest management. Among the approaches used in decision making, none has been more prevalent than the economic-injury level concept of V. M. Stern and coworkers. This concept has been refined since its inception, but its basic elements remain unchanged. Current research in this area emphasizes understanding multipest interactions and developing thresholds for pest complexes. However, probably the greatest need on a worldwide basis is the development of practical sampling programs and establishment of valid economic thresholds for major pests. Approaches to development of economic thresholds for integrated pest management have included both subjective and objective methods. A new application of time-sequential sampling is proposed as an alternative means of developing objective and practical economic thresholds. An example of this new approach is presented for larvae of the soybean defoliator, *Plathypena scabra* (F.), (Lepidoptera: Noctuidae). Additionally, limitations to economic thresholds and directions for future development are discussed.

Without question, pest population assessment and decision making are among the most basic elements in any integrated pest management (IPM) program. In fact, these activities characterize state-of-the-art approaches to pest control and differentiate IPM from previous strategies.

Forming the basis of assessment and decision making is bioeconomics, the study of the relationships between pest numbers, host responses to injury, and resultant economic losses (Chant 1966). The relationship of bioeconomics to other elements of an IPM system is shown (Fig. 1). Here, it can be seen that bioeconomics is a keystone element, connecting basic biology and ecology on the one hand with sampling and identification on the other. It is an element that involves both biology and economics.

An important outcome of bioeconomics is the formation of decision rules that are used with management options. Of decision rules that have been suggested, none has met with more success than those involved in the economic-injury level (EIL) concept of Stern et al. (1959). In fact, this concept, with only minor changes, still forms the basis of most IPM programs in use today.

Because of the substantial following of the economic-injury level concept, this paper will review some of the basic elements of the EIL theory, consider the current status of bioeconomics research, and explore some of the traditional, as well as advanced, modes of economic threshold development. Additionally, some of the limitations involved in threshold development will be discussed as well as areas for future improvement.

Theoretical Aspects of the Economic Injury Level

The elements Stern et al. proposed formally in 1959 are essentially the same as those used today. They are economic damage, economic-injury level, and economic threshold. Collectively, these elements form the EIL concept.

Economic damage. Economic damage is the most elementary of the EIL elements, being defined by Stern et al. as "the amount of injury which will justify the cost of artificial control measures." This definition has been criticized by several workers because a quantitative expression of economic justification was not given.

However, Southwood and Norton (1973) presented a practical mathematical expression that has been used widely. That expression is:

$$C(a) = Y[s(a)] \times P[s(a)] - Y(s) \times P(s)$$

where: Y = yield; P = price per unit of yield; s = level of pest injury; a = control action [s(a) is level of injury as modified by the control action]; and C = cost of the control action. This equation simply states that cost of the control tactic equals yield times price when the tactic is applied minus yield times price without the tactic. Consequently, economic damage begins at this point (i.e., when the cost of damage equals the cost of suppression).

Although not recognized by Stern et al. (1959), another useful damage level to consider is the damage

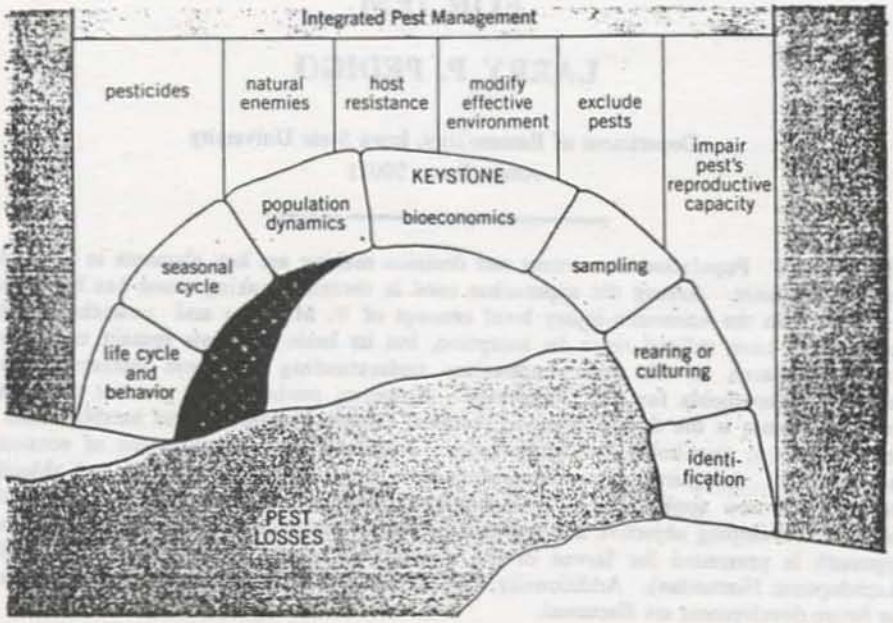

Fig. 1. Diagram of IPM components showing the central importance of bioeconomics to system development. Reprinted by permission of McGraw-Hill, Inc., from L. P. Pedigo, Integrated Pest Management in *Yearbook of Science and Technology* . Copyright© 1985 by McGraw-Hill, Inc.

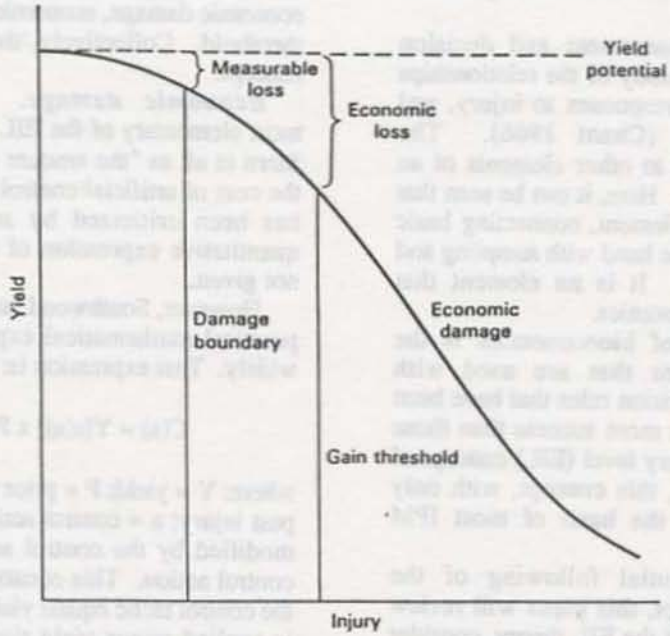

Fig. 2. Diagram showing relationship of the damage boundary to economic loss and the gain threshold. Reprinted by permission of Macmillan Publishing Company from *Entomology and Pest Management* by L. P. Pedigo. Copyright© 1988 by Macmillan Publishing Company.

boundary, also called the damage threshold by Norgaard (1976). The damage boundary is the lowest level of injury at which damage can be measured (Fig. 2). This level of injury occurs before economic loss. Expressed in terms of yield, economic loss is reached at the gain threshold, and the gain threshold is beyond the damage boundary. For high-value commodities, the damage boundary may be very close to the gain threshold. A basic IPM principle ensues from the damage boundary - economic damage relationship: *no injury level below the damage boundary merits suppression, but injury predicted to result in economic damage does.*

Economic-Injury Level. Another of the basic elements, the economic-injury level, was defined by Stern et al. as the lowest population density that will cause economic damage. The EIL is the most basic of the decision rules. It is a theoretical value that, if attained by a pest population, economic damage will result. Therefore, the EIL is a measure against which we evaluate the destructive status and potential of a pest population.

Although the EIL is expressed as a pest density, it is actually a level of injury that is indexed by pest numbers. We use insect numbers for practicality because it is usually easier to count pests rather than to quantify and project future injury. The relationship of the EIL to the damage boundary is shown (Fig. 3).

Because the EIL is actually a degree of injury, it is sometimes useful to think of it in terms of injury equivalents (Pedigo et al. 1986). An injury equivalent is the total injury produced by a single pest over an average lifetime. It is a potential value because a pest dying prematurely will obtain only a partial equivalent. The concept of using injury equivalents is particularly appropriate when working with populations having discrete generations and when trying to account for mortality and its effect on total injury. If numbers alone are used, the economic threshold may need to be positioned above the EIL early in a generation to account for subsequent mortality (Andow & Kiritani 1983, Chiang 1979). When using injury equivalents, the economic threshold is always below the EIL, as presented in the Stern et al. model.

Whether expressed as numbers or injury equivalents, the EIL is based on five major variables: cost of the management tactic per production unit (C); market value per production unit (V); injury units per insect (I); damage per injury unit (D); and proportionate reduction of the insect population caused by the tactic (K). If the relationships of these variables to their independent units is linear or roughly so, the EIL can be represented according to the equation:

$$EIL = C/VIDK$$

In several situations, the D variable is not linear and, if so, would need to be replaced by a complex function.

Economic threshold. The economic threshold (ET) differs from the EIL in that it is a practical or operational rule, rather than a theoretical one. Stern et al. defined the ET as "the population density at which control action should be determined (initiated) to prevent an increasing pest population (injury) from reaching the economic-injury level." Although measured in insect density, the ET is actually a time to take action (i.e., numbers are simply an index of that time). Some workers refer to the ET as the **action threshold** to emphasize the true meaning of the ET. The relationship of the ET to the EIL and action times is illustrated (Fig. 4).

The ET is a complex value that depends on estimating and predicting several difficult parameters. The most significant of these include 1) the EIL variables (this is because the ET is based on the EIL); 2) pest and host phenology; 3) population growth and injury rates; and 4) time delays associated with the IPM tactics utilized. Because of the uncertainties involved, particularly in pest population growth rates, most ETs are relatively crude; they do not carry the same quantitative resolution as do EILs.

Modes of Economic Threshold Development

The ET of Stern et al. has been referred to as an operational, if not an ideal, decision rule (Mumford & Norton 1984), and it is the ultimate level that must be developed in any given situation. Yet, the ET is the most problematic because of considerable uncertainty.

Currently, a major research thrust is taking place in IPM toward understanding multipest interactions and, subsequently, developing ETs for pest complexes. Such research is truly integrative and farsighted. Although this research direction is appropriate, there is still a critical need on a worldwide basis for accurate single-species loss functions and ETs. These ETs provide 1) first approximations in managing complexes; 2) final guidelines where pest interactions do not exist; and 3) the basis for research into multipest ETs.

In developing single-species ETs, several approaches, representing different levels of sophistication, have been devised. The level of sophistication has been determined largely by existing data and needs of the particular management program. Most of these approaches can be grouped into two broad classes, subjective determinations and objective determinations.

Subjective vs. objective ET determinations. Subjective determinations are the crudest approach to ET development. They are not based on a calculated EIL; rather, they are based on a practitioner's experience. These have been called **nominal thresholds** by Poston et al. (1983) and are not formulated from objective criteria. Nominal thresholds probably represent the majority of ETs found in extension publications and verbal recommendations. Although static and possibly inaccurate, these still are more progressive than using no ET at all because they require pest population assessment. Therefore, their use can often result in reduced pesticide applications.

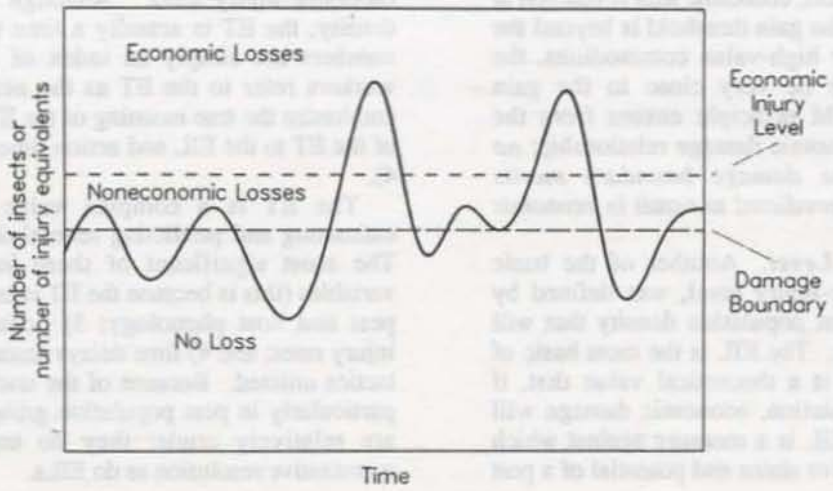

Fig. 3. Diagram showing relationship of the damage boundary to the economic-injury level. Reprinted by permission of Macmillan Publishing Company from *Entomology and Pest Management* by L. P. Pedigo. Copyright© 1988 by Macmillan Publishing Company.

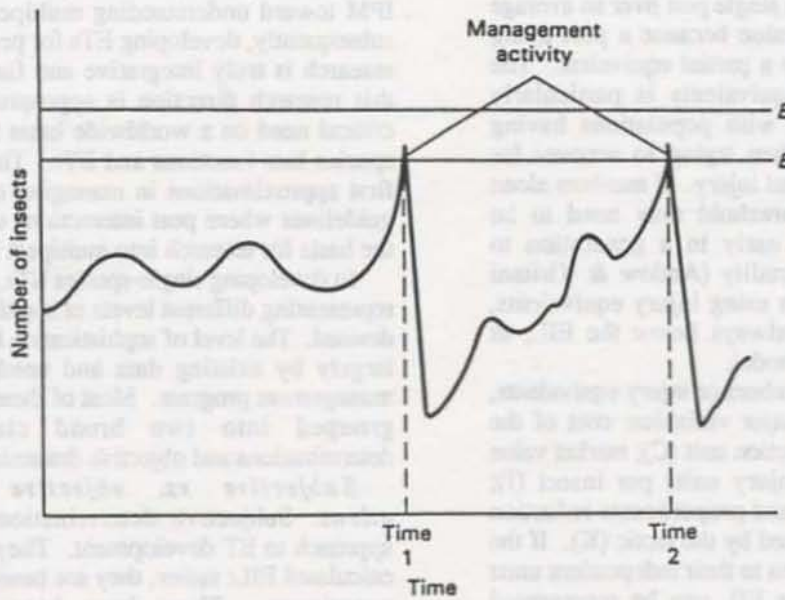

Fig. 4. Diagram showing relationship of the economic threshold to the economic-injury level and time of taking action. Reprinted by permission of Macmillan Publishing Company from *Entomology and Pest Management* by L. P. Pedigo. Copyright© 1988 by Macmillan Publishing Company.

Objective ETs, on the other hand, are based on calculated EILs, and they change with changes in the primary variables of the EILs (e.g., market values and management costs). With objective ETs, a current EIL is calculated, and estimates are made regarding potential of the pest population to exceed the EIL. The final decision on action to be taken and timing is based on expected increases in injury and logistical delays, as well as activity rates of the tactics used. Considering the various types of objective ETs, at least three can be described. These types can be termed 1) fixed ETs; 2) descriptive ETs; and 3) dichotomous ETs.

Fixed ET Category. The fixed ET is the most common type of objective ET. With this type, the ET is set at a fixed percentage of the EIL (e.g., 50% or 75%). Use of the term "fixed" does not mean that these are unchanging; it means only that the percentage of the EIL is fixed. Therefore, these change constantly with changes in the EIL. The fixed ET ignores differences in population growth and injury rates; however, the percentages are usually set conservatively low (i.e., when they err, they err on the side of taking action when it is not necessary). Fixed ETs are crude, but they may be the highest level that can be developed when pest population dynamics is poorly understood. There are many examples of fixed ETs for crops, including those for pests on grapes, beans, soybean, sorghum, rice, and apples (Pedigo et al. 1986).

Descriptive ET Category. Descriptive ETs are more sophisticated than fixed ETs. With descriptive ETs, a description of population growth is made, and need for, as well as timing of, action is based on expected future growth in injury rates. Growth-rate estimates have been derived either by stochastic or deterministic means.

With stochastic derivations, action decisions and timing are derived by understanding previous pest population growth rates and basing future rates on these. As an example, the green cloverworm, *Plathypena scabra* (F.), can be sampled in soybean beginning in late June and an early growth curve established (Fig. 5). When larval numbers cause injury to reach the damage boundary, a statistical model based on sampling data can be applied to project future population growth. If these projections indicate that numbers will exceed the EIL during the susceptible period, then action is taken; if not, incremental sampling usually would be continued to detect any unexpected population changes until the crop is no longer susceptible. The stochastic approach has the advantage of using current sampling data to keep track of the injuriousness of the pest population. Its weakness is in making projections from earlier injury rates (i.e., future rates may not show a strong relationship to past rates, giving errors in decision making).

With deterministic derivations, estimates of future

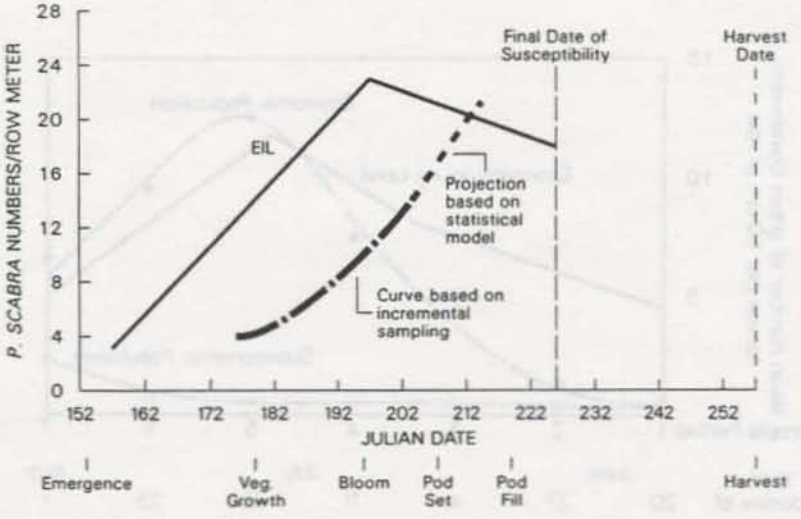

Fig. 5. Growth of a green cloverworm, *Plathypena scabra*, population on soybean as indicated by incremental sampling, and projection of future growth based on a statistical model.

pest-population growth and injury rates are derived from age-specific parameters or processes. These growth estimates may be based on the probability of age-specific survival from life tables or on mechanistic models of a population process (e.g., a predator-prey model). An example of the deterministic type can be seen in the work of Ostlie & Pedigo (1987) with the green cloverworm in soybean. In this work, stage-specific survival probabilities from life tables were used to compute mortality-adjusted injury equivalents (IEQs). An IEQ is the proportion of potential injury obtained by a damaging stage when premature mortality occurs. A different IEQ is specified for each larval stage, and it quantifies amount of food consumed to date plus expected consumption based on the probability of survival. The calculated IEQs can be used by multiplying them by numbers in each stage obtained in field samples. By tallying the results, realized and future injuriousness of a pest population can be estimated, and decisions based on this estimated status. Furthermore, these look-ahead values can be used with conventional sequential sampling plans to determine whether or not to take action.

Dichotomous ET Category. Dichotomous ETs can be developed by using a statistical procedure for classifying a pest population as economic or noneconomic from samples taken over time. The statistical procedure has been termed time-sequential sampling and has been used to classify adult populations of the green cloverworm into outbreak or endemic classes (Pedigo & van Schaik 1984). The procedure is based on the sequential probability ratio test of Wald (1947) as is conventional or spatial sequential sampling. However, time-sequential sampling differs in that a time perspective, rather than a space perspective, is used to make decisions.

Time-sequential sampling can be used with the damaging stage of a pest to objectively determine its ET. To develop this approach, weekly larval counts of the green cloverworm from 1977 through 1980 near Ames, Iowa, were compiled. Those counts in 1977 and 1980 exceeded the calculated EIL, and those of 1978 and 1979 did not (Fig. 6). The calculated EIL was based on a gain threshold (cost/market value) of 28 kg/ha (0.5 bu/acre). Class limits or critical densities for describing noneconomic (m_0) and economic (m_1) types (Table 1) where chosen from the population configurations shown (Fig.6). Furthermore, several dispersion models were

Table 1. Critical green cloverworm densities (mean no. larvae/60 cm of soybean row, m_0 = noneconomic and m_1 = economic levels)

Sample period	Critical density	
	m_0	m_1
1	0.1	1.0
2	0.6	2.0
3	1.5	4.5
4	2.0	9.0
5	2.2	12.5
6	2.3	10.0
7	2.5	5.5

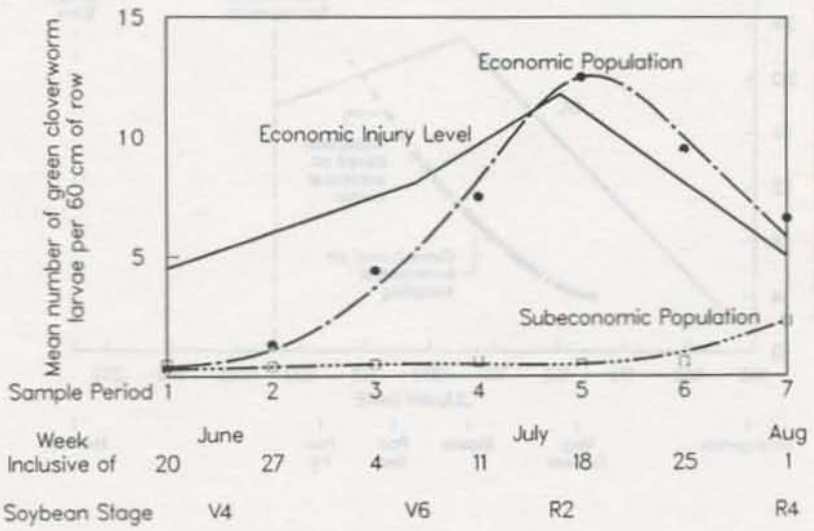

Fig. 6. Economic (1977 and 1980) and subeconomic (1978 and 1979) populations of the green cloverworm, *Plathypena scabra*, in central Iowa. Data points represent mean number of larvae from six fields (three fields each in two different years).

Table 2. Time-sequential sampling plan for green cloverworm larvae in soybean (cumulative mean number per 60 cm of row for a weekly date are multiplied by the weighting factor and compared with the lower limit and upper limit values; sampling is begun week of June 20; decision on low population should not be made until larvae are found in field).

Sample period	Weighting factor		Equal to or less than weighted value		Equal to or less than weighted value	
1	1.7649		0.00		2.82	
2	0.6197		0.00		3.50	
3	0.3443	LOW	0.00	CONTINUE	4.38	HIGH
4	0.3371	POPULATION:	1.35		5.74	POPULATION:
5	0.3356	DON'T TREAT	2.98	SAMPLING	7.37	TREAT
6	0.2994		4.34		8.73	
7	0.1903		5.04		9.43	

fitted to the sample data, with the negative binomial being the best fit ($X^2 = 12.9$, $P>0.05$, $k = 1.164$). By using the m_0 and m_1 values, k from the negative binomial analysis, and alpha and beta error values of 0.1, a time-sequential sampling plan was calculated.

This sampling plan (Table 2) can be used by taking five 60-cm of row samples in a field to calculate the mean, starting the week of June 20 in Iowa. The mean count for a field then is multiplied by the weighting factor for the time period, and this value is compared to the upper and lower limits for making a decision. If a decision cannot be made on a date, the weighted value is accumulated over the next date. This accumulated value is compared on each date until a decision can be made or until seven sample periods have been attained.

This program was tested by using random samples from 12 computer simulation runs, four each of low-, medium-, and high-density populations. The sampling plan gave correct decisions in all instances of high- and low-density populations. No decisions could be made in two instances of medium-density populations; these populations would have been sampled for a full seven weeks, and no management would have been undertaken. Overall, the program gave about a 25% savings over a fixed number of sampling periods and provided an objective basis for determining the ET.

Advantages of the time-sequential sampling program are that it is easy to calculate and simple to use. Its drawbacks are that several years of population data are required for development, and some pests may not show distinct and repeatable population configurations.

Limitations of the EIL Concept and Future Outlook

Many factors have limited both the design of new economic thresholds and the development of existing ones. Some of the major limitations are:

1. Lack of a thorough mathematical definition of the ET;
2. Lack of valid EILs;
3. Inability to make precise population estimates;
4. Inability to predict critical ET variables such as market values and population trends; and
5. Lack of a simple means to incorporate externalities such as environmental costs into EILs.

Future development and improvement of economic thresholds in IPM requires that these existing limitations be addressed and overcome where possible. To advance, the limitations should be addressed across all areas, including theoretical work, research, and implementation. In particular, research is needed to achieve improved thresholds. Here, knowledge of pest population dynamics and a better capability to predict pest population trends is needed. Additionally, more research should be directed toward improving knowledge of pest injury and host responses to injury; an understanding of this important area is still quite inadequate. Indeed, knowledge gained about host responses to injury will greatly improve ETs, and improved ETs can produce practical management solutions at a time when agriculture is seeking increased production efficiencies and sustainable yields.

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ASSESSING PEST IMPACT ON CROP YIELDS AT THE MICRO AND MACRO-LEVELS

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ABSTRACT Pest impact is commonly assessed at different levels of complexity - single plant, crop, farm and region - all of which require quantification of the pest-loss relationship. This quantification is done using experiments with single plants and field plots, or through on-farm sampling. *A priori* postulation of the pest-loss relationship is a major determinant of experimental approach. Any one of nine possible functional relationships may exist to characterize pest impact on yield loss at specific phenological stages. Statistical designs emphasizing treatment levels rather than replications have resulted in accurate and precise pest-loss relationships for developing pest management economic decision-aids such as BEANRUST and RUSTMAN programs. Other considerations in empirical determination of the pest-loss relationship are assessment technique, sampling procedure, and knowledge of yield physiology. At the macro-level, crop loss profiles and pest zoning are two techniques of pest impact assessment to guide resource allocation decisions; both are based on synoptic methodology.

The impact of pests on crop yields has commonly been studied in a plant protection specialism called *crop loss assessment*. This specialism has aimed at studies on crop losses incurred at the micro (farm) level and the macro (regional, large-area). At the micro-level, crop loss assessment is particularly relevant for pest management decision making. Pest management may be considered the economical management of crop losses using socially-acceptable and environmentally-sound techniques. Pest control by applying management concepts implies that economic criteria are available to estimate the benefits from known costs of control. Management implies that the farmer does not aim at total eradication of his pest problem, but rather that the individual is concerned with keeping it below some economically unacceptable level of infestation. The above scenario is a simplistic view of pest management from an economics viewpoint, since it does not recognize that pest management also depends on managing the delicate balance between pests and their predators/parasites in a total ecosystem. However, it does underscore the point that pest management depends, *inter alia*, on an ability to estimate potential losses caused by a pest and from it, the potential gains derived from applying corrective action.

At the macro-level, losses are known to be substantial in many cropping systems of the tropics: in coconuts due to Cadang-Cadang disease; in corn due to the Asian cornborer; in rice due to Rice Tungro Virus; in cruciferous vegetables due to the diamondback moth and soft rot bacteria; in papaya due to viral diseases. Quantitative data on the magnitude of the losses in farmers' fields are often difficult to obtain, not because the methodology does not exist, but commonly due to the difficulty of conducting sample surveys in the affected areas. There is much evidence to show that, on the average, crop losses have not decreased in the major food and fiber crops in the tropics (Teng 1986). Furthermore, losses are being detected in crops which previously were thought to have reached their yield potentials in farmers' fields. For example, in irrigated rice, Litsinger et al. (1988) have detected losses ranging from 5 to 37 percent in central Luzon, the Phillipines, in spite of the area being known to have relatively high average rice yields. In the same study, it was found that although losses caused by individual pests were not significant, they collectively could be measured. Crop loss assessment techniques, such as those used by the above authors, can lead to an improvement in pest management by redefining control thresholds for a particular pest when it occurs in the presence of other pests.

Crop loss assessment is a scientific activity aimed at understanding and predicting the effects of pest infestations on crop yield, at different levels of biological organization. It has techniques unique to it and it utilizes techniques common to other scientific disciplines. In this presentation,, I will discuss some aspects of the techniques associated with pest assessment, sampling, derivation of damage functions, and the spatial estimation of losses. I will also discuss some applications of crop loss assessment to pest management, notably the derivation of thresholds, strategic uses for resource allocation, and on-farm aids.

Crop Loss Assessment Techniques

Pest Assessment. This includes all techniques leading to a quantitative estimate of the pest itself or the injury caused by the pest. For insects, Walker (1987) distinguished direct methods such as number of pests per unit area or plant, and indirect methods such as tunnel length in corn stems due to corn-borer injury or percent defoliation from Colorado potato beetle feeding. For diseases, Gaunt (1987) considered standard area diagrams, image analysis, keys, remote sensing and indirect methods such as spore counting, as the main techniques for quantifying diseases. It is important to make a distinction between the direct methods for insects (such as counting actual numbers of insects or percent leaf area showing lesions for diseases). For diseases, symptom assessment is commonly done, rather than actual counting of pathogen structures or propagules. In fact, the most common field method of assessing disease is to use a set of standard area diagrams, where each diagram represents a grade of disease such as a percent leaf area infected. These diagrams have been packaged into small, portable, ring-bound and laminated sheets for field use and have proven very popular in disease resistance screening and management research. Most field methods rely on the human eye to estimate level of injury, and with improvements in electronic and and computer technology, attempts have been made to use image analysis for quantifying infected leaf area. Equipment is available, ranging from very sophisticated and expensive, to very simple and low-cost, for measuring diseased area of leaves. However, most of these are still not suitable for rapid assessment of many samples, nor can they be used to any extent in the field. It may be a reality, in the near future, to have a portable scanner that scientists or technicians can take to the field for measuring percent defoliation or leaf area showing certain symptoms.

Conceptually, it is necessary to distinguish between assessing incidence of infected/infested plants versus severity of the injury on plants. Incidence is the proportion of plant units showing injury, damage or symptoms of disease. Severity is the proportion of affected plant tissue (Teng 1987). Another term, prevalence, is used to describe the frequency of occurrence of pests, for example the proportion of fields in a region estimated to suffer losses. It is important to accurately define terms and to use them accordingly, as inconsistency has resulted in making comparisons of losses between countries difficult. In this regard, James & Teng (1979), have proposed that the percent scale be used for denoting incidence, severity and prevalence.

Sampling. Pest assessment techniques are commonly applied on a specified plant part or a predetermined cropping area. For example, with rice, it is common to assess the percent leaf area infected with blast lesions. However, in order to apply the assessment method to give an estimate of the mean pest population or the mean injury level in a field or plot, it is necessary to know how to sample. Pertinent questions are usually how many plant units to include in the sample; how to take the sample and from what sized area; and whether to do destructive or non-destructive sampling. Shepard & Ferrer (1990) and Teng (1983) have provided some useful guidelines for sampling, depending on the distribution pattern of the pest-infested units. With pests that show an aggregated or random pattern in the field, samples should be taken from a big "X" to ensure precision, while with a regular pattern a small "x" would suffice. Furthermore, the number of plant units to take for a required level of precision can be determined empirically. Enhancements to sampling procedures have been introduced in pest management; a notable example being the sequential sampling scheme for rice insects of Shepard & Ferrer (1987). In general, more knowledge is available on insect sampling than for diseases and much research is still required to elucidate the statistics of distribution patterns for diseases. Modern, portable computer technology has also enabled an improvement in sampling for pest populations in the field. For example, the FIELDRUNNER program of Stowell et al (1984) allows a researcher to use a hand-held computer to determine what the best sampling procedure is by making observations of infected plants in the field itself.

Derivation of Damage Functions. A cornerstone of crop loss assessment methodology is the damage function, which relates yield loss to the magnitude of pest infestation. Damage functions in the literature range from simple linear regression equations to multiple regression equations to non-linear models (Teng 1985). Most damage functions have been empirically determined, are location as well as cultivar specific, and have mainly been developed for one pest. An example is the damage function for rice blast in Japan (Katsube & Koshimizu 1970):

$$Y = 0.57\ X$$

in which Y is percent yield loss and X is percent blasted nodes 30 days after heading. The coefficient, 0.57, has also been referred to as a damage or loss coefficient (Waibel 1986).

Damage functions, after validation, have been used to estimate thresholds in pest management (Walker 1987). The empirical derivation of the damage functions or loss coefficients is commonly done using experimental units such as field plots, microplots or single plants. The aim in the experimentation is to generate many treatments with varying levels of pest infestation. With diseases, it is common to use fungicides, time of sowing and cultivar resistance, to manipulate epidemics, resulting in many progress curves from which multivariate analyses can be done. Much of the detailed methodology for experimentation may be found in texts such as those of the Food and Agriculture Organization, U.N. (Chiarappa 1971) and Teng (1987). Recently, there has been increased appreciation for using response surface, non-replicated designs to collect data for determining damage functions. Crop loss experiments do not aim to prove significant differences between the effects of two levels of pest infestation on yield; rather

they aim to prove that there is a response relationship between increasing levels of pest infestation and yield. Hence, it is more important to have more treatment points on the pest-yield curve, rather than have more replications of a single point on the curve. The "ideal" empirical damage function is one that explains a high proportion of the variability on yield and loss, has precision in predicting loss, and can account for the differential effects of different pest levels at different stages of crop phenology.

A problem that has hindered loss assessment is the inability to make loss estimates environment neutral. This has now been overcome by the availability of crop models which require site soil and weather data to run, and which predict healthy crop yield. Thus, when pest effects are coupled to the "healthy" crop simulations, loss from the pest infestation may be predicted (Rouse 1988, Teng 1988). Much progress has been made in using these crop models in conjunction with pest models, especially under the auspices of transnational projects such as the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) project based in Hawaii and the Pest and Pesticide Management (PPM) project of the Consortium for International Crop Protection based in Maryland.

Spatial Estimates of Losses. A separate phase in many crop loss programs is to use the models or damage functions developed from experiments to estimate losses over a large area. This is done through sample surveys, in which representative farmers' fields are visited several times during a cropping season, and data on levels of pest infestation collected. Surveys provide useful information on the distribution of different pest types, on the levels of attack under different farming conditions, and if used with damage functions, an estimate of actual losses in farmers' fields. All the above types of information are useful to decision makers, especially those who set plant protection policy. In many countries in the Asia-Pacific region, surveillance and early warning systems have been implemented with varying success (Heong 1988). None of these have resulted in any regular assessment of losses and feedback on the economics of pest management programs. Indeed it may be this lack of feedback that is hampering the development of and support for, plant protection in many countries. Time and again, one is reminded of G. Lyman's comments, made in 1918 : "How can we expect practical men to be properly impressed by the importance of our work and to vote large sums of money for its support when in place of facts we have only vague guesses to give them, and we do not take the trouble to make careful estimates?".

With an additional investment in effort, much of the data on prevalence and intensity of pest attacks that is currently collected may be converted into data of economic and political value. Survey methodology for pests is now well documented, and IRRI has also embarked on a project to test integrated methods for pest surveys in rice fields (Elazegui et al. 1990).

Applications of Crop Loss Assessment to Pest Management

Thresholds. The concept and practice of thresholds in insect and disease management have been reviewed recently by Pedigo et al (1986) and Zadoks (1985). A basic idea is to use some estimate of expected loss and expected costs of reducing that loss, and to determine a level of pest infestation at which action is required. Thresholds are therefore able to provide an evaluation of the costs versus benefits to be derived from a control input, and theoretically, can result in reducing the number of pesticide applications. There have been problems in using economic or action thresholds in farmers' fields, one of which is that few thresholds have good biological reason and appear to be "rules of thumb" derived form experience. Damage functions and models potentially can generate location specific thresholds which take into account varying weather and crop phenology, and some effort has been made with wheat, potato and rice to produce these "sliding thresholds" (Zadoks 1985). I therefore argue that thresholds should be based on a sound understanding of the basic pest intensity - yield loss relationship, and how this is affected by soil, weather, crop genotype and cropping practice. An example of how this can be done using coupled crop and pest models was recently presented (Teng 1988). Action thresholds for major rice pests, developed from understanding pest-loss relationships, have also been reported by Bandong & Litsinger (1988).

Strategic Uses for Resource Allocation. The role of crop loss assessment in resource allocation may be exemplified by the "crop loss profile" of Pinstrup-Andersen et al. (1976). Using an on-farm sampling procedure, the authors partitioned the difference between actual yield and attainable yield into production constraints. The contribution of each constraint to the yield difference was thus quantified, from which it could be determined which was more amenable to resolution, and the cost of resolving the constraint. The concept of production constraints has also been investigated by some international agricultural research centers such as IRRI. This application of crop loss assessment allows for strategy development with respect to research or extension. The survey procedure, together with knowledge on soil types and weather patterns, can also allow for pest ecosystem characterization (i.e., the delineation of "pest zones" or "epidemiologic zones"). These zones indicate the likelihood of certain levels of pest attack and may be regarded as empirical "hotspots". Characterization of these zones will add greatly to efforts at screening for resistance and development of widely applicable pest management technology.

On-Farm Decision Aids. Ultimately, crop loss assessment should provide practical tools that extension personnel or farmers can use to make decisions in the field, when a pest is observed. On-farm decision aids are one way in which research information can be simplified for practical use. Examples were the "IRRI Sequential Sampling Peg Board" (Shepard & Ferrer 1987) and the "RUSTMAN" programs on small, hand-held computers

(Teng & Montgomery 1982). In both of these, loss expectations or equations are either implicitly or explicitly used to provide decision rules on whether or not a certain pest level has exceeded a threshold. They represent a very active technique for transferring technology. With rapid developments in microprocessor technology, and decreasing costs, we can expect to see increased use of portable computers in pest management. However, to use these in a rational manner would still require that information on pest-loss relationships, on thresholds and on control options be available.

Conclusions

Crop loss assessment presents the technology to quantify the magnitude of a pest infestation while IPM appears to be the contemporary concept for solving a pest problem. Thus, whether a pest problem requires a strategic (large area, long time frame) or tactical (small area, short time frame) solution, it is illogical to attempt problem resolution before the problem is adequately defined. The past decade has seen an increase in research on how to actively use crop loss assessment in decision making, and more recently computers have played an increased role. In the tropical areas of the world, one can also expect to see the above trends, as these areas are not immune from the same demands for environmentally-sound and socially-acceptable plant protection, both of which crop loss assessment supports.

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TRADITIONAL AND ECO-PHYSIOLOGICAL APPROACHES FOR DETERMINING THE EFFECTS OF HERBIVORY ON PERENNIAL CROPS

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ABSTRACT Spider mites continue to be important pests in many perennial crops due to disruptive suppression tactics targeted at other key pests. Direct damage to leaves due to spider mite feeding can be readily assessed. In contrast, indirect effects on crop quality and/or productivity are difficult to ascertain, particularly in perennial crops.

As an example, damage by spider mites on grapes caused immediate reduction in the percent soluble solids per berry, an important element of grape quality. However, reductions in grape yield did not occur until one year after initial infestation. Significant yield reductions up to 18 percent were detected at high levels of mite damage. Complete recovery of grapevines from spider mite damage required two years.

Spider mite damage resulted in many changes in plant physiology which included decreased stomatal conductance and reduced photosynthetic rates. Interactions between grapevine canopy architecture, patterns of carbon allocation, and the effects of mite feeding damage are discussed. The uses and limitations of data on plant physiological responses to herbivory are discussed. Suggested uses for plant physiological data include efficient allocation of research efforts, the identification of important variables that modify economic injury levels, and establishment of interim economic injury levels.

Economic injury levels (EIL's) for many pest-plant pairings are either non-existent or based largely on a general consensus of experienced personnel (Pedigo et al. 1986). The absence of meaningful EIL's appears especially prevalent for indirect pests of perennial crops. Various factors have discouraged the development of EIL's for many serious pest species. These factors include intense labor requirements for precise sampling of pest densities; the potential for cumulative or delayed effects of feeding damage on perennial crops; the length of time required to complete a single study (minimum of two years); and the potentially limited nature of conclusions drawn from such studies. Despite the fact that the EIL provides an intellectual platform for most integrated pest management strategies, the difficulty of determining meaningful EIL's discourages many researchers from undertaking these studies.

Techniques are needed to better focus research efforts and resources on important plant-arthropod interactions; identify potential crop/pest pairings previously overlooked; and identify biological or abiotic variables that might enhance the abilities to generalize with respect to differing geographic regions and crops. I feel that a more plant oriented perspective to understanding herbivory may increase our ability to meet these objectives. In this paper, data from the literature and my own research findings on the effects of spider mites on crop productivity will be used to illustrate the usefulness of plant eco-physiological data. Limitations of these data and the problems associated with EIL studies on perennial crops will be discussed. Definitive EIL's have yet to result from physiological data, yet these data may be used to: 1) direct the allocation of research efforts with short term studies; 2) identify variables that limit one's ability to develop general EIL's; 3) establish interim EIL's until manipulative yield studies are forthcoming; and 4) provide insights into the potential importance of changes within a single variable (e.g., pest species, plant cultivar, or plant water status). The following examples were selected in part on my familiarity with the various studies and are not intended as a comprehensive review.

Eco-Physiological Approaches

Entomologists have started to utilize a wide array of techniques to understand the physiological effects of arthropod herbivory on plants. The ease of use of these technologies (e.g., the development of the LI-COR portable photosynthesis system) has resulted in a small, but distinct increase in publications involving plant responses to arthropod damage. Crop photosynthesis, water use efficiency, nitrogen fixation, leaf temperature, and nutrient allocation are some of the physiological processes affected by herbivory. Whereas the data are easy to analyze statistically, the implications of the data are less clear. As such, I would like to suggest several ways to use these data that may be helpful to entomologists attempting to generate EIL's. These methods are not expected to provide foolproof conclusions or intended to replace more traditional studies. However, insights into relative physiological effects may provides insights into associated economic effects.

Spider Mites on Almonds

The effects of various density levels of spider mites, *Tetranychus* spp., on almond productivity were established within a series of two year experiments (Welter et al. 1984). Damage levels as low as 178 mite-days reduced almond growth, whereas 424 mite-days were required to show statistically significant yield reductions. A trend towards reduced productivity was observed at 178 mites. A threshold of 178 mite-days avoids any potential for economic loss, yet allows growers to use predacious mites to biologically control spider mites under most conditions. However, many other spider mite species such as the European red mite, *Panonychus ulmi* (Koch), citrus red mite, *Panonychus citri* (McGregor), and brown fruit tree mite, *Bryobia rubrioculus* (Scheuten), are also commonly found on almonds in fairly high numbers, and acaricides often are applied for these within commercial orchards (Andrews & Barnes 1981). In contrast to the *Tetranychus* species, no information on the effects of other mite genera on almond productivity exists nor are studies currently underway in California. Therefore, growers are faced with either adopting thresholds established for *Tetranychus* species or implementing their own thresholds based on some visceral impression and observations.

Youngman et al. (1986) examined the effects of feeding of the four most common mite species (named above) considered to be serious almond pests. Their data indicated that feeding damage by *Panonychus* species resulted in 8.5 percent reductions in photosynthesis compared to 16.6 percent reductions for similar numbers of mite-days caused by *Tetranychus* species. Thus, equal levels of feeding damage by *Tetranychus* mites appeared to cause twice the damage to almond gas exchange as *Panonychus* mites. The reduced effect on plant gas exchange by *Panonychus* species was consistent with the observation by pest management personnel that *Panonychus* species are less commonly associated with early season leaf loss. Therefore, growers were encouraged to sustain at least 178 mites-days per leaf by *Panonychus* species, whereas higher levels were most likely tolerable. Until data on the effects of *Panonychus* species on productivity are available, eco-physiological data can provide some basis for comparison and recommendation. These recommendations can be tempered and integrated with field observations and experience. Integrating data from *Tetranychus* spider mite effects on yield (Welter et al. 1984) with information on the effects of different mite species on plant gas exchange (Youngman et al. 1986) permits interim EIL's to be suggested. Similarly, if the Youngman et al. (1988) plant gas exchange study had been conducted prior to the *Tetranychus* EIL study, the *Tetranychus* species would have been targeted first for detailed yield effect studies. Similar comparisons and conclusions could be obtained for the different *Tetranychus* species of spider mites on cotton (Marcono-Brito 1980).

Spider Mites on Grapes

Effects on grape physiology. Use of plant physiological data to identify overlooked problems was demonstrated in a series of papers examining spider mite effects on grapes. Two spider mites species are found commonly on grapes in California. Of these, Pacific spider mite, *Tetranychus pacificus* McGregor, is considered the most important pest species with foliar damage often associated with tissue death or leaf defoliation. Damage caused by Willamette spider mite, *Eotetranychus willametti* Ewing, is so much less severe that low infestation levels are recommended and encouraged as alternate prey for predacious mites that regulate Pacific spider mite infestations. These recommendations stemmed from research by Flaherty & Huffaker (1970) on both mite species on the vigorous 'Thompson Seedless' grape cultivar. However, examination of the relative effects of Willamette and Pacific spider mites on photosynthetic rates of grape leaves demonstrated that photosynthetic reductions in light saturated leaves due to cumulative mite-days were not significantly different for the two mite species (Figs. 1,2) (Welter et al. 1989a). Mite-days, an indirect measure of mite damage, are calculated from duration of infestation and pest density. Using mite days as a measure, Willamette spider mite and Pacific spider mite caused equal foliar damage at similar levels of mite-days. Severe infestations of Willamette mite have been shown to influence grape quality within the year of initial infestation (McNally & Farnham 1988). Using multiple damage levels on 'Zinfandel' grapes, Welter et al. (1990) also demonstrated significant quality and yield reductions from Willamette mite damage. Thus, physiological data could have been used to easily identify Willamette mite as a potentially serious pest problem that merited further study.

In contrast to these findings, Flaherty & Huffaker (1970) found that Willamette mite feeding on 'Thompson Seedless' grapes did not cause yield reductions. It is likely that differences in the plant canopy structure of 'Thompson Seedless' and 'Zinfandel' grapes used in the two studies accounted for this difference in mite impact. 'Thompson Seedless' grapes have a dense, closed canopy that provides little light for the interior leaves. Smart (1973) showed for dense canopies, such as those of 'Thompson Seedless' grapes, only the upper leaf layers contribute significantly to the overall photosynthate pool. Conversely, the 'Zinfandel' vines used by Welter et al. (1990) were head trained vines with a vase-shaped structure that allowed light into the center of the canopy.

It has been demonstrated that Willamette spider mites distribute themselves on interior shaded leaves when present (L. T. Wilson, personal communication). Because shaded leaves are readily available in dense foliage canopies of 'Thompson Seedless' grapes, Willamette mite feeds predominantly on light limited leaves. Clearly, severe mite damage that causes a 90 percent reduction in the photosynthesis rate of a shaded

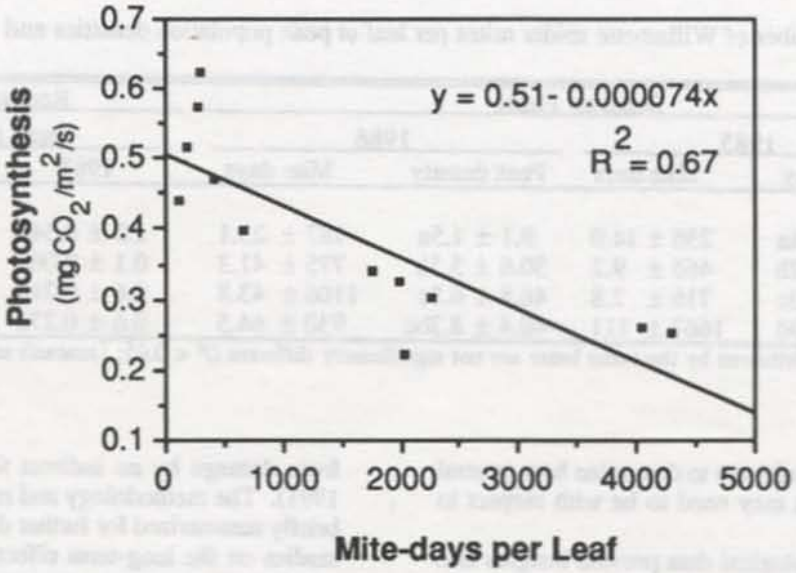

Fig. 1. Effect of Pacific spider mite damage on the photosynthetic rate of 'Thompson Seedless' grapes.

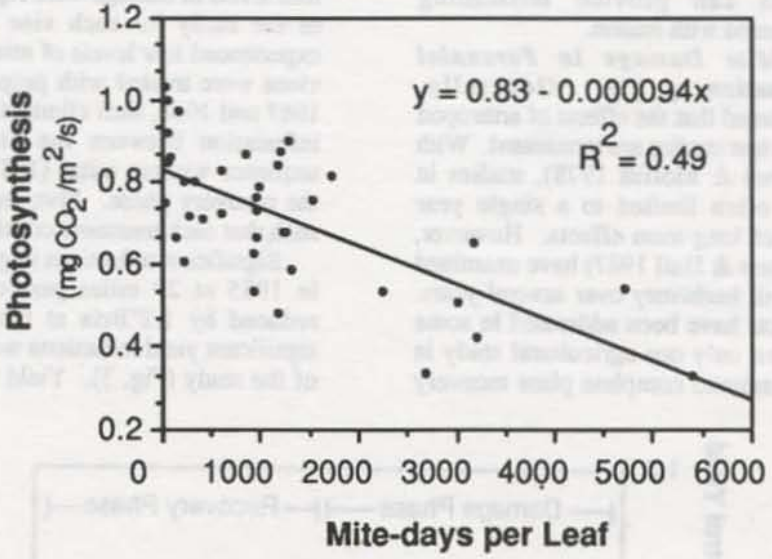

Fig. 2. Effect of Willamette spider mite on the photosynthetic rate of 'Zinfandel' grapes.

leaf is of little consequence to the overall photosynthate pool produced by the vine. Conversely, because the foliar canopy of the 'Zinfandel' grapes was open to light penetration, Willamette mite feeding damage occurred on light saturated leaves that were photosynthesizing at normal rates. Data collected on mite damage on densely canopied vines appears to be inappropriate for estimating mite impact on grapes grown under other pruning regimes. Recommendations for EIL's for spider mites on grape vines are currently based in part on vine canopy structure.

An understanding of the plant canopy combined with mite-induced effects on plant gas exchange provides a reasonable hypotheses for grouping EIL recommendations for grapes. Alternative explanations such as direct cultivar effects or abiotic factors have not been ruled out to date, but these could be partially tested using the same approaches. Before final recommendations are made, the validity of the grouping would have to be tested experimentally. However, the investigation of arthropod effects on plant physiological processes did identify a variable of potential importance.

These data illustrate the problems of using data collected from different agronomic settings (e.g., different cultivars, irrigation regimes, or locations) to develop general recommendations. Instead, entomologists in conjunction with plant breeders, agronomists, or plant physiologists need to look at the characteristics and

Table 1. Mean number of Willamette spider mites per leaf at peak population densities and mite-days per leaf from 1985 to 1988.

Treatment	Damage Phase				Recovery Phase	
	1985		1986		Peak density	
	Peak density	Mite days	Peak density	Mite days	1987	1988
1	12.0 ± 1.24a	236 ± 14.0	9.1 ± 1.5a	187 ± 23.1	1.0 ± 0.54a	3.3 ± 0.76a
2	20.0 ± 1.02b	465 ± 9.2	30.6 ± 5.5b	775 ± 41.3	0.1 ± 0.06a	3.3 ± 0.75a
3	29.0 ± 1.93c	716 ± 2.8	46.8 ± 6.5c	1106 ± 43.8	0.6 ± 0.21a	3.5 ± 0.90a
4	57.0 ± 3.79d	1667 ± 111	40.4 ± 8.3bc	930 ± 64.5	0.6 ± 0.27a	3.3 ± 0.71a

Means within a column followed by the same letter are not significantly different ($P < 0.05$; Duncan's multiple range test, [Wilkinson 1986]).

variability of different cultivars to determine how general their recommendations may need to be with respect to EIL's.

In short, eco-physiological data provide insights into the relative importance of particular variables; help structure our understanding of pest-crop interactions; and help generate interim EIL's until more direct studies on organismal responses are possible. Like most data, physiological effects can provide misleading conclusions, if not tempered with reason.

Recovery from Mite Damage in Perennial Crops and Determination of EIL. Generally, entomologists have assumed that the effects of arthropod feeding damage cease when studies are terminated. With some exceptions (Barnes & Moffitt 1978), studies in perennial crops were often limited to a single year without consideration of long-term effects. However, more recent studies (Beers & Hull 1987) have examined the cumulative effects of herbivory over several years. While cumulative effects have been addressed in some non-agricultural systems, only one agricultural study in perennial crops has examined complete plant recovery from damage by an indirect foliar pest (Welter et al. 1991). The methodology and results from this study are briefly summarized for further discussion. A sequence of studies on the long-term effects of Willamette mite on 'Zinfandel' grapes were reported by Welter et al. (1989b; 1991). Four levels of damage, as indicated by peak mite densities (Table 1), were replicated 34 times within a dry-land farmed Zinfandel vineyard in California. The four levels of damage were repeated in the first two years of the study for each vine (e.g., low damage vines experienced low levels of mites in 1985 and 1986). All vines were treated with propargite (Omite® 30WP) in 1987 and 1988, thus eliminating the differences in mite infestation between the vines. The phase of the sequence without mites (1987 - 1988) is referred to as the recovery phase. Five replicates were lost in 1987 such that each treatment consisted of 29 replicates.

Significant reductions in grape quality were observed in 1985 at 29 mites per leaf. Soluble solids were reduced by 1.2°Brix at the end of the season. No significant yield reductions were detected in the first year of the study (Fig. 3). Yield reductions of 17.9 percent

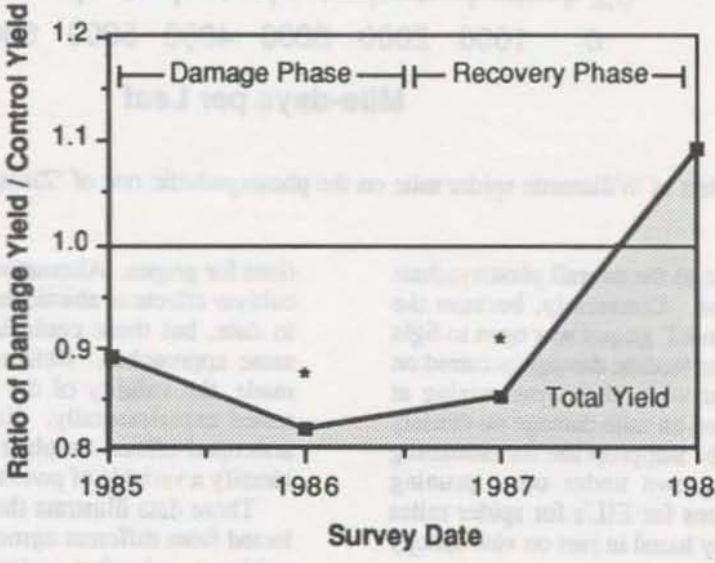

Fig. 3. Proportional yield of the high mite damaged vines compared to the control vines over four years. Damage phase refers to the years with mite infestation, whereas the vines were kept mite-free during the recovery phase. * indicates significant differences at $P < 0.05$.

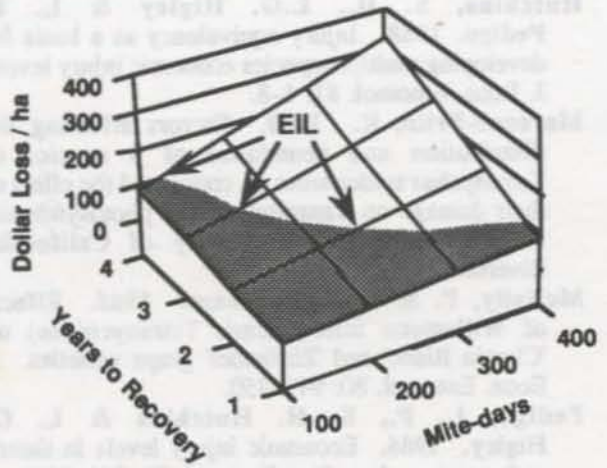

Fig. 4. Interactive effects of time required for recovery from feeding damage and the level of feeding damage on the determination of economic injury levels.

were detected in the second year of the study at 1,308 mite-days per leaf. Yield reductions of 14.9 percent continued in the first year of recovery for the vines most heavily damaged in 1985 and 1986 despite the absence of any mite infestations in 1987. No statistically significant differences were detectable by the second year of recovery. As such, there was a relatively symmetrical shape to the depression and recovery phases to the studies.

Many general questions arise from our data. How often is recovery from herbivory delayed by greater than one year? Are patterns of depression and recovery generally symmetrical? Does recovery occur all in one year or partially over several years? From an economic perspective, how does recovery affect our determination of economic losses and economic injury levels?

The general problem is illustrated with the hypothetical data set graphed in Fig. 4. The general question addressed with this graph is what effect do different recovery times have on total economic losses associated with a single year of damage? The model shows how recovery times of 1 - 4 years influence the determination of economic injury levels. The model is based on the assumptions that: 1) dollar loss (D) within a season is defined as D = 0.2 multiplied by the number of mite-days accumulated (M); 2) no recovery occurs until the final year; 3) damage only occurs in Year 0; 4) cost of control = $100; and 5) all indirect costs such as effects on natural enemies are ignored for ease of presentation. Total damage over the entire recovery period is defined as T = (0.2 X M) X N, where N = number of years required for complete recovery. For "four years to recovery", the effects of the damage are manifested in Years 1 - 3, and the plants recover completely in Year 4. Because of its simplicity, the model is not intended to provide an economically meaningful estimate of any particular economic injury level (e.g., spider mites on grapes), but is intended to illustrate graphically a potentially serious problem that has been overlooked. Many different scenarios could have been shown in the model such as partial recovery each year.

As shown in Fig. 4, the point at which the control cost ($100) is reached is a function of both mite damage and time required for recovery. If complete recovery occurred within Year 1, then the economic injury level would not have been reached below 400 mite-days. Conversely if 2, 3 or 4 years are required for recovery, then the economic injury level would have been reached at 250, 167 and 125 mite-days, respectively. Longer recovery times require lower economic injury levels, because the damage is distributed over more years. Economic injury level studies in perennial crops that do not consider long-term recovery from damage run the risk of underestimating crop losses.

Another largely unexplored area is the long-term effects of low herbivory levels on perennial crop productivity. More typically, relative high levels of damage are maintained on a plant by researchers until statistically significant reductions are observed. Lower damage levels that did not indicate statistically significant reductions are presumed often to be non-damaging. Given our understanding of plant reserves, it would seem quite likely that low levels of damage could become economically significant if plant reserves were depleted over time. The subtle, long-term nature of this type of damage may preclude direct experimental measurement, whereas the issue can be addressed most easily with crop physiological models containing herbivore subcomponents.

The potential for long-term effects of herbivory are easily predicted from the recognition of the reserve capabilities of perennial crops. While the implications of the model in Fig. 4 run counter to general efforts to minimize intervention through the use of economic injury levels, we need to provide growers and pest management personnel with complete understanding of the economic costs associated with their decisions.

Physiological Guilds

Hutchins et al. (1988) suggested the grouping of pests into guilds based on their effect on plants (e.g., plant architecture, water use, or assimilation). One assumption in guild determination was a need for independence of effects between guilds. For example, a spider mite could either reduce assimilate uptake, reduce water use, or change the architecture of a plant, but not all three effects. While this assumption may be met by some pest groupings (e.g., soybean defoliators), this assumption may be more difficult to meet in other pest groupings .

For example, ample evidence exists that leaf defoliation may affect the photosynthesis or carbon uptake rates of the remaining undamaged leaf tissue (Welter 1989). Similarly, defoliation may also affect water use by altering leaf stomatal conductance. Direct damage to fruiting structures may affect other plant

processes by alteration of source/sink relationships. Given the strong interactions between various plant processes, caution must be used when accepting the physiological independence of these guilds.

From a pragmatic perspective, I feel that Hutchins et al. (1988) provided a useful first step for clustering insect damage. Rather than assume effects of different mite species are independent, the combined effect can be weighted and totaled at any point in the season. This approach has been used for assessing mite effects on almonds wherein species identification in the field was impractical (Welter et al. 1984).

The long-term solution for development of EIL's appears limited by our abilities to integrate multiple interacting factors successfully. Development of plant physiological models that allow the incorporation of herbivore components appears to hold the greatest promise for integration. The relationships between arthropod feeding damage and plant physiological processes provides the basis for integrating herbivory into some plant models. As plant models improve, our ability to understand the physiological basis of herbivory will increase.

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ADVANCES IN INTEGRATION OF PESTICIDE EFFECTS ON PLANT PHYSIOLOGY INTO IPM PROGRAMS

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ABSTRACT. Recent studies on the effects of pesticides on plant physiology and yield are briefly reviewed and their importance for economic threshold studies discussed. In addition, an empirical model which predicts reduction in photosynthesis over time is described. This equation allows prediction of the duration a pesticide affects plant physiology and, when integrated over time, allows estimation of damage for any given time period after pesticide application. These approaches may be useful in the development of IPM systems on crops were pesticides impact crop physiology. Altered plant responses may be expressed as damage equivalents.

Pesticides are commonly used in many agroecosystems to provide quick, inexpensive and easy control of arthropod, weed and disease problems. Estimates of the importance of pesticides to agricultural production vary. If pesticides were banned completely, Walker (1970) estimated a 30 percent crop loss, whereas Borlaug (1972) and Pimentel et al. (1978) estimated 50 and 42 percent crop losses, respectively. These values indicate that without a replacement technology (i.e., biological control, resistant varieties, microbial control) pesticide use will continue in most agroecosystems.

Despite the importance of pesticides for crop production, they are far from being panaceas in IPM. Problems associated with arthropod control using pesticides include destruction of natural enemy complexes (McMurtry et al. 1970), selection of resistant pest populations (Georghiou 1972), and unplanned effects on non-target pests and natural enemies. These latter effects are quite varied with stimulation of reproduction (Jones & Parrella 1984, Maggi & Leigh 1983), impairment of natural enemies searching abilities (Walker & Chapman 1978), and increased dispersal being only a few of the effects currently documented (Penman & Chapman 1983, Jones 1990).

In addition to effects on arthropod populations, pesticide effects on plant physiology are quite common. Most entomologists are familiar with the visible phytotoxicity various pesticides may cause on certain crops. However, less recognized are subtle effects on plant physiology produced by some pesticides. These effects vary from plant hormone-like effects (carbaryl on apples), to severe depression in photosynthetic rate and concomitant yield loss (parathion on lettuce). These effects are difficult to document unless they are specifically investigated, but even then, differences in pest population levels between the control and other treatments often makes interpretation of results difficult. For these reasons, most studies of pesticide effects on plants rely primarily upon measurements of plant photosynthetic rate (P_n). Although there is often not a direct correlation between P_n and plant yield, the ease with which P_n measurements can be taken allows a rapid assessment of pesticide-induced changes in plant physiology and hence is the method employed in most studies.

Review of Recent Literature

In a review of pesticide effects on plant physiology, Jones et al. (1986) surveyed the literature on apples, pecans, citrus, chrysanthemum, lettuce, strawberry, tomato and cotton. Materials and methods used by the various researchers on these commodities were different which generally prevented comparisons across crops. However, even across fairly closely related plants (orange and lemon), Jones et al. (1983) found that effects of certain acaricides varied dramatically. Until a standardized methodology is used, it is unlikely that a universal synthesis of pesticide effects will be possible. Therefore, for the purposes of this brief review, only the effects of pesticides on apple, *Malus domesticus* Bork, and lettuce, *Lactuca sativa* L., (where the bulk of the information is available) will be addressed.

Apples. Ayers & Barden (1975) provided a comprehensive survey of the effects of 33 pesticides on photosynthesis rate of apples. They found that only 12 of the 33 pesticides (36 percent) significantly affected P_n. The pesticides carbaryl, formetanate hydrochloride and cyhexatin all increased P_n approximately 16 percent, while trees treated with the fungicide maneb exhibited a 7 percent increase. The effect of carbaryl is interesting because low doses of this material are used to thin apples early in the season in many fruit growing areas. Application of the remaining eight pesticides resulted in reductions from 6 to 66 percent (Table 1). Additionally, the pesticide application method significantly affected P_n readings; those treated by dipping (used to simulate dilute applications) had much more severe reductions in P_n than those treated by mist application (simulating a low-volume application).

Table 1. Effects of pesticides on P_n of apple. Data summarized from Ayers & Barden (1975) and Sharma et al. (1978).

Pesticide	% Change in P_n
Chlorpropylate 2EC	-22
Dikar 80W	-12
Karthane 25W	-10
Parathion 8EC	-11
Superior oil	- 64, -66
Morestan 25W	-8
Sulfur 95W	-6
Diazinon 50WP	-27
Dicofol 3.6E	-24
Omite 30W	-15

Sharma et al. (1978) also tested pesticide effects on apple P_n. They found that of 37 pesticides tested, 5 increased P_n and 20 decreased P_n by more than 5 percent. Those causing the most severe reductions were diazinon, dicofol and superior oil (Table 1). It is interesting to note that the oil application tested resulted in virtually identical reductions in P_n as reported by Ayers & Barden (1975) (66 vs 64 percent).

Lettuce. Investigations on pesticide effects on lettuce in California cover many publications over a seven year period. These studies are interesting because both photosynthetic and yield data are available. In addition, recent studies included chemical analysis to support proposed mechanisms of reduction.

Toscano et al. (1982a) investigated the effects of methoxychlor, methomyl, methyl parathion and permethrin on lettuce P_n. They found that methoxychlor treated plants did not exhibit significant reductions in P_n, but plants treated with the other materials exhibited approximately 18 percent reduction eight days later.

In other studies, Toscano et al. (1982a) examined the effects of the above pesticides on plantings treated during the inital 1-3 weeks (germination to thinning), weeks 8-11 (head formation to harvest) and plots treated throughout the season. Treatments were applied once or twice weekly. In general, lettuce treated the entire season exhibited lower yields than lettuce not treated during the period of 4-8 weeks (thinning to head formation). Plants treated with methyl parathion exhibited a 24 and 30 percent decrease in mean head weight for plots treated once and twice weekly, respectively. This data led Toscano et al. (1982a) to conclude that a "pesticide threshold" for methyl parathion use on lettuce should be implemented.

Toscano et al. (1982b) provided further evidence of pesticide induced yield reductions. In an experiment designed to show effects of different levels of lepidopterous pests on lettuce yield, results indicated that the highest yields did not result from plantings with the fewest number of larvae present. Instead, plots with moderate levels of larvae had the highest yields. Different numbers of sprays were used to manipulate pest populations and examination of the application frequency showed that reductions in yield were closely related to the number of pesticide applications.

Johnson et al. (1983) continued the line of research initiated by Toscano et al. (1982a). They varied the number of pesticide treatments between thinning and head formation. Mean lettuce head weight, mean head density and percentage of bolted plants was linearly correlated with number of methyl parathion applications. Although Johnson et al. (1983) stated there was a linear decrease in gas exchange with increasing application rate, examination of their curves suggest that the relationship is more closely approximated by a saturation-type curve, which suggests that percentage reduction was rather stable above rates of about 1 kg AI/ha. Based on yield results, Johnson et al. (1983) suggested that a pesticide threshold of no more than three applications of methyl parathion be used to avoid a yield reduction of greater than 20%. They further speculated that the mechanism for reduction by methyl parathion was the hydrolysis of methyl parathion to *p*-nitrophenol which is chemically similar to the herbicide DNOC.

Youngman et al. (1989) investigated the possibility that the hydrolysis of methyl parathion resulted in *p*-nitrophenol being formed in or on lettuce and cotton leaves. They found that methyl parathion did degrade to *p*-nitrophenol in sufficient quantities to result in plant damage. Treatment of plants with methyl parathion or *p*-nitrophenol resulted in similar reductions in whole-plant dry weights (51 and 32 percent reductions, respectively). Further, plants treated with formulating agents alone were found to exhibit a non-significant 4 percent reduction in plant dry weight, indicating that formulating agents had little effect on plant yield.

Integration into IPM Programs

While pesticide effects on plant physiology may be important by themselves, perhaps of equal or more importance is their possible influence on the results of studies aimed at quantifiying yield-damage relationships (economic thresholds) for various arthropod pests. These studies often use different pesticide application regimes to manipulate pest populations. If effects of pesticides used to manipulate pest densities on plant yield and physiology are not considered, erroneous conclusions may be drawn and pest damage may be over- or underestimated. The error may be further compounded because thresholds from one area are often accepted with minor modifications in other areas (because of the expensive and difficulty of the required experiments) and hence the original error may be multiplied many times in various localities.

The task of integrating pesticide effects into economic injury level calculations is quite formidable. Jones et al. (1986) illustrated a simple conceptual model which showed the importance of pesticide effects in certain situations. However, this model was very simplistic and did not adequately address several points. First, it assumed that every application resulted in a fixed decrease in yield or P_n and no recovery or plant

compensatory response was possible. This assumption is unlikely to be true if the reduction was caused by either physical blockage of the stomata or if the pesticide interfered with electron transport as suggested by Murthy (1983). In the case of physical blockage, once stomata are blocked, further pesticide applications will probably only extend the duration of the blockage, not the extent of reduction in P_n. Likewise, if electron transport is disrupted, further application of the pesticide may not increase the extent of the reduction, but only extend the duration of the reduction. This latter point is suggested by the saturation-type curves obtained by Johnson et al. (1983) when investigating the effects of different doses on P_n. In both of the above cases, the effect of the additional pesticide is probably less than the sum of the two applications would predict. This was empirically observed by Toscano et al. (1982a) when two applications per week of methyl parathion only caused an additional 5 percent reduction in yield (from 25 to 30 percent), and not the 50 percent suggested by the conceptual model.

Other serious problems in the model suggested by Jones et al. (1986) were that duration of P_n reduction could not be predicted and total damage over a period of time could not be quantified. As an example of the importance of the latter, consider what 20 percent reduction in P_n signifies. Obviously, without knowing the duration of the reduction or when that 20 percent reduction occurs (how many days after application?), the figure is meaningless. However, if the reduction can be quantified as to a 20 percent net reduction in P_n over the time period from application to 10 days later, then at least the door is opened to utilize damage equivalents like the pest-day concept used for indirect pests (which also reduce photosynthesis by their feeding).

Perhaps the easiest method of solving the problems with the model above is to abandon it completely. Instead, if an empirical equation relating photosynthesis to time could be developed and parameters estimated by non-linear regression, the problems of the conceptual model can be directly addressed through a combination of mathematics and biology. For example, an empirical model would predict when reductions in P_n would be significant and integration of the equation over time would allow the definite integral (area under the damage curve) to be calculated between any two times desired. In addition, because the damage curve can be predicted, the effects of multiple pesticide applications could be accounted for without assuming simple additive P_n reductions (Fig. 1).

Examination of Ayers & Barden's (1975) time series data on P_n reduction suggests that a model of the form:

$$\text{Percent } P_n \text{ reduction} = A(t) + B(t)^n$$

where A and B are empirically defined constants relating to the penetration and detoxification of the pesticide, predicts the change in reduction well (Fig. 2). Implicit in this model is a two component effect; one based on penetration into the leaf and etoxification of the pesticide in the leaf. It should be emphasized that this is an empirical equation and that many other equations may provide as good or better fit to larger data sets. Again, we are simply showing that any sort of reasonable empirical model provides better predictions than the earlier conceptual model.

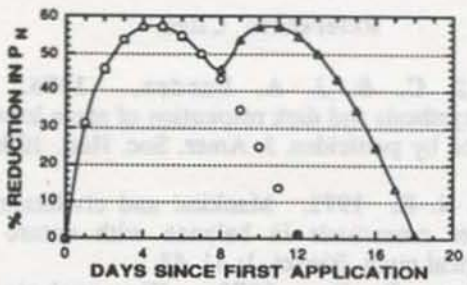

Fig. 1. Use of an empirical model to predict the reduction in P_n caused by multiple pesticide applications 5 days apart.

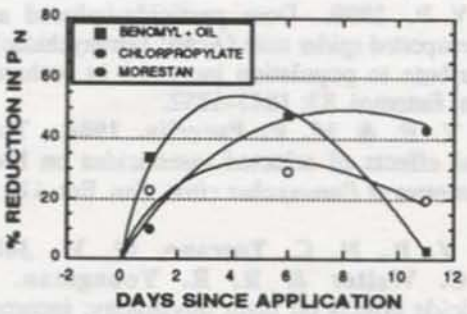

Fig. 2. Fit of an empirical model to the data of Ayers and Barden (1975). Lines indicated predicted reduction in P_n

Using this model for the pesticides morestan, chlorpropylate and benomyl + low rate of oil, the model accurately predicts the shape of the damage curve and provides the estimates of 36, 18 and 36 percent reduction in P_n over the first 10 days after pesticide application (Fig. 2). In addition, the effects are basically complete for chlorpropylate and benomyl by 11 days, while the effects for morestan are estimated to be complete by about 21 days.

The use of any reasonable empirical model provides much more information than a conceptual model. The new information gained using this model may provide a more useful modification of the economic threshold concept than is presently available. However, for the model to be utilized, there must be time-series information on effects of photosynthesis. Such information should probably be required for pesticide registration so that more informed recommendations can

be made by pest control advisors and state and county extension personnel.

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YIELD RESPONSE OF FRESH MARKET TOMATOES TO GREENHOUSE WHITEFLY INFESTATIONS IN HAWAII

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ABSTRACT Impact of the feeding of immature greenhouse whitefly (GHWF), *Trialeurodes vaporariorum* (Westwood), on tomato production was determined using small field plots. Total and grade A fruit weight harvested were negatively correlated with cumulative "immature GHWF days". Five percent yield loss of grade A fruit was estimated at ca. 69 "immature whitefly days" per cm^2 of tomato leaflet. Percentages of fruit contaminated with sooty mold were positively correlated with cumulative immature GHWF days. Five percent sooty mold contamination was estimated at 298 cumulative immature GHWF days per cm^2. Cumulative immature GHWF days were positively correlated with peak immature whitefly densities during the growing cycle of the plant. Based on this correlation, a density treatment level of 0.7 immature GHWF per cm^2 of tomato leaflet (= 35 immature GHWF per 50 cm^2 leaflet) would result in a 5 percent yield loss.

Fresh market tomatoes are one of Hawaii's most important vegetable crops valued at ca. 3.4 million dollars in 1988 (Anon. 1989). During the past three years, the development of an integrated pest management program has been in progress for this commodity in Hawaii. Like many of Hawaii's vegetable crops, tomatoes are infested by numerous pests which cause direct and indirect damage. Direct pests include the tomato fruitworm, *Helicoverpa* (=*Heliothis*) *zea* Boddie; tomato pinworm, *Keiferia lycopersicella* (Walsingham); beet armyworm, *Spodoptera exigua* (Hubner); melon fly, *Dacus cucurbitae* Coquillett; and southern green stinkbug, *Nezara viridula* (L.). The lepidopterous species cause injury as a result of internal and external feeding on fruit which may permit entry of secondary pathogens that further destroy fruit tissues. The melon fly deposits eggs underneath the fruit epidermis and hatching larve consume fruit tissues. Although not as destructive, stink bug injury reduces fruit value by producing unsightly blemishes on the fruit. The total injury caused by many of these pests must be limited to less than 5 percent of the total fruit so that the grower will be able to market the produce. Thus, few options are available in regards to strategies that limit direct damage to a tolerable level.

Indirect pests of Hawaii's tomato crop include *Liriomyza* leafminers; greenhouse whitefly (GHWF), *Trialeurodes vaporariorum* (Westwood); and western flower thrips, *Frankliniella occidentalis* (Pergande). Although these species indirectly affect the fruit, they may cause economic losses through feeding damage or by transmission of plant pathogens. Because they damage the non-marketable portions of the plant, low densities of pests which only feed on plant tissues or nutrients (and do not transmit plant pathogens) can be tolerated by the plant without reducing fruit yield. A secondary problem associated with greenhouse whitefly is sooty mold growth in large quantities of honeydew produced during feeding. Low incidence of sooty mold can be tolerated, but must be washed off fruit prior to shipment to market. Fruit heavily covered with sooty mold are usually unacceptable for sale.

Densities at which indirect pests cause significant damage depend on several parameters including the specific type of injury induced, the plant's response to the injury, the change in pest densities over time, and environmental conditions (e.g., temperature, humidity, rainfall). Field-grown plantings may respond differently to pest injury than greenhouse crops. The impact of a pest may not always be correlated with the weekly densities observed in a planting. Although pest density indicates a level of pest impact, it does not account for the length of time the pest density remains at a given level. Ruppel (1983) suggested the use of *insect-days* to better quantify this impact. One insect-day (or *pest day*) is equivalent to one individual member of a given pest species feeding for one day. Highly significant negative correlations have been found between pest days accumulated over a crop cycle and the resulting crop yield in several crops with a variety of pests (Sances et al. 1982, Welter et al. 1984, Welter et al. 1990).

Maintenance of sub-economic populations of indirect pests which do not transmit plant pathogens can be beneficial for several reasons. First, these populations provide a food source to maintain effective natural enemy populations within a planting. Secondly, avoiding repeated applications of pesticides needed to maintain zero tolerance levels can slow development of pesticide resistance and prevent resurgences and secondary upsets of *Liriomyza* leafminers and GHWF.

The objective of this study was to quantify the impact of immature GHWF feeding and honeydew

production on field grown fresh market tomatoes in Hawaii.

Materials and Methods

Two field studies were conducted at the University of Hawaii Branch Experiment Station at Poamoho, Oahu, during July - October 1987 and April to July 1988, respectively. For each study, sixteen small field plots (12.2 m X 3 rows) containing 60 tomato plants each were established in a randomized complete block design. Plants were grown according to local practices (irrigation, fertilizer, staking, fungicide applications, etc.).

Four experimental treatments were initiated which corresponded to desired levels of GHWF infestations: near zero; low; medium and high densities. Whitefly densities were manipulated by the application of insecticides at various times during the crop cycle. The near zero density treatment received weekly insecticide applications to maintain the lowest whitefly densities possible. The high density treatment never received insecticide treatments directed at GHWF so pest numbers would not be suppressed. Low and medium density treatments received varying numbers of insecticide applications to establish low to moderate whitefly populations.

In 1987, permethrin (0.224 kg AI/ha) and oxamyl (1.12 kg AI/ha) were used weekly to suppress GHWF. Avermectin (0.022 mg AI/ha) was occassionally applied to maintain live *Liriomyza* larval densities below 2 per tomato leaflet. Malathion (1.4 kg AI/ha) was occassionally applied to suppress green peach aphid densities. In 1988, permethrin and avermectin were used again to suppress GHWF and *Liriomyza* larvae, respectively. Methomyl (1 kg AI/ha) was used weekly to suppress lepidopterous pests. Pesticides were applied with a CO_2 charged boom sprayer delivering 76 to 153 liters water/ha at a pressure of 80 psi.

Foliage samples composed of 30 randomly selected mature leaflets were collected weekly from each plot through the plant growth cycle. Numbers of foliar arthropods (GHWF nymphs and pupae; live *Liriomyza* leafminers; immature and adult *Thrips* spp.; and active spider mites) found on the leaflets were recorded and mean densities calculated. Cumulative immature (nymphs & pupae) GHWF days were calculated for each small plot according to the methods of Ruppel (1983).

In each study, all small plots were harvested once weekly for six weeks beginning with the initial harvest. Fruit were picked when slightly pink to red in color. Fruit were examined for insect and other types of damage (e.g., sooty mold, physiological abnormalities), sized, weighed and counted. Percentages of fruit contaminated with sooty mold were tabulated for each small plot. Numbers of plants per plot were recorded weekly during harvest. To account for the few plants lost (< 5 plants/plot) in each plot to disease or other problems during the crop cycle, final harvest data per plot were based on mean fruit production per tomato plant adjusted to 60 plants per plot. Fruit weights per individual plots were expressed as kg/ha.

Given the uneven immigration of GHWF adults into the experimental area, analysis of variance could not be used to determine differences among the treatments. Thus, yield impact of immature GHWF on fruit production was analyzed by regressing the weights of total fruit and "grade A" fruit (> 6.35 cm diam.) harvested per small plot against cumulative immature GHWF days per plot, respectively. Additionally, percentages of fruit contaminated with sooty mold were regressed against cumulative immature GHWF days per plot.

Regression analysis was used to determine relationships between cumulative immature GHWF days and peak immature GHWF densities recorded in small plots during the crop cycle.

Results and Discussion

Direct impact of GHWF. Fruit production in the 1987 study ranged from ca. 28,000 to 44,400 kg/ha for total fruit and from ca. 24,600 to 43,000 kg/ha for grade A fruit. A significant regression was obtained between the number of cumulative immature GHWF days and reductions in tomato yields as indicated by weight of total fruit ($r = -0.728$, $P < 0.01$) and grade A fruit ($r = -0.756$, $P < 0.01$). This indicated that tomato yields decreased as cumulative immature GHWF days increased. An immature GHWF day equaled the injury caused by one immature whitefly feeding for one day. Fruit production in the 1988 study ranged from ca. 23,400 to 45,800 kg/ha for total fruit and from ca. 18,000 to 43,600 kg/ha for grade A fruit. Again, a significant negative correlation occurred between yield and cumulative immature GHWF days (total fruit: $r = -0.785$, $P < 0.01$; grade A fruit: $r = -0.811$, $P < 0.01$). Slopes of the yield responses were not significantly different between the 1987 and 1988 studies. Slopes for total fruit (1987 study = -24.4 ± 6.1SE; 1988 study = -25.4 ± 6.4SE) and grade A fruit (1987 study = -28.7 ± 6.6SE; 1988 study = -27.0 ± 6.2SE) were not significantly different ($P < 0.05$). However, the intercepts of the lines were significantly different. Intercepts for total and grade A fruit 1987 equaled 40,789 and 39,784 kg/ha, respectively, compared to total and grade A fruit 1988 which equaled 53,227 and 51,421 kg/ha, respectively. Various reasons for these differences are unclear, but may be related to seasonal differences in sunlight between the studies. Interestingly, even though the intercepts differed, the actual maximum fruit production (about 45,000 kg/ha) in each study were similar. This suggests that during periods of longer daylight (summer), greater numbers of cumulative immature GHWF days may be necessary to reduce yields.

Reductions due to sooty mold. Yield losses reported above pertain only to the direct effects of immature whitefly feeding on fruit yield. Additional problems may result from accumulation of sooty mold on fruit which reduces its market value. When data from both years were pooled, significant regressions were

found between cumulative GHWF days per cm^2 (X axis) and percentage sooty mold contaminated total fruit ($P < 0.0001$) and grade A fruit ($P < 0.0001$). For total fruit, the intercept and slope equaled -0.984 and 0.01, respectively, ($r = 0.845$; 26 df) whereas for grade A fruit the intercept and slope equaled -0.119 and 0.018, respectively, ($r = 0.728$; 26 df). In general, this indicated that increases in cumulative GHWF days resulted in increased percentages of sooty mold contaminated tomatoes.

When compared to the direct impact of GHWF feeding, it is evident that significant yield losses are experienced due to GHWF feeding before sooty mold contamination becomes important. For example, a 5 percent yield loss in grade A fruit from direct feeding (as estimated from the 1987 data) occurs when 69 cumulative GHWF days are reached. In contrast, a 5 percent yield loss from sooty mold contamination occurs when 298 cumulative GHWF days are obtained. At that level, production losses from direct feeding reach ca. 21 percent of grade A fruit, respectively . Thus, growers who time their control actions based on low levels (1 to 5 percent) of sooty mold contamination are probably loosing significant yields due to GHWF feeding alone.

GHWF days vs. GHWF foliar densities. From the practical viewpoint, a problem exists with the use of cumulative whitefly days as a measure of whitefly feeding impact on fruit yields. It would be difficult for growers to determine numbers of whitefly days accumulated weekly without access to accurate whitefly counts and microcomputers. However, if a positive correlation exists between the peak density a whitefly population reaches over a given time period and the total cumulative whitefly days, it may be possible to express density treatment levels in conventional densities (Welter et al. 1989, Welter et al. 1990). Thus, peak immature whitefly densities (X axis) recorded in the 1987 and 1988 yield response studies were pooled and regressed against respective numbers of cumulative whitefly days (Y axis). A significant positive regression was found (intercept = 48.81; slope = 30.08; $r = 0.967$; d.f. = 30; $P = 0.0001$) indicating a good fit between increases in peak whitefly densities and cumulative GHWF days. Using this relationship one can estimate the cumulative whitefly days produced by a given peak density of whiteflies. Based on this, a 5 percent yield loss in grade A fruit resulting from ca. 69 cumulative whitefly days per cm^2 would be achieved when the immature whitefly density reached ca. 0.7 whiteflies per cm^2 tomato leaflet area (= 35 whiteflies per 50 cm^2 leaflet). A 10 percent yield loss in grade A fruit would result if whitefly densities reached ca. 2 whiteflies per cm^2 tomato leaflet area (= 100 whiteflies per 50 cm^2 leaflet). To prevent whitefly densities from reaching critical levels, growers may apply pesticides or rely upon natural enemies.

Conclusions

An understanding of the impact of GHWF on tomato yield is necessary for the development of effective GHWF management strategies. Knowledge of the yield response of the crop to direct feeding and the relationship between sooty mold contamination and GHWF numbers provides the first steps in the development of useful density treatment levels. Once these action levels are established, levels of necessary control either by chemical or biological means can be identified. Additionally, simple sampling methods such as "presence/absence" (or "binomial") can be developed to aid growers in routine monitoring of GHWF. Use of density treatment levels may not only increase tomato yields, but may also reduce unnecessary pesticide treatments which promote pesticide resistance and secondary pest upsets.

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METHODOLOGIES OF REARING, INTRODUCING, AND ESTABLISHING PHYTOSEIID MITES

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ABSTRACT Phytoseiid mites are important predators of spider mites and some thrips. Techniques were developed for their large-scale rearing for biological studies, for colonization and establishment of exotic species, and for evaluation of augmentative releases for pest suppression. These techniques can be modified for commercial mass production. Specialized predators of spider mites (e.g., *Phytoseiulus persimilis*) are reared on *Tetranychus* spp. washed from bean plants and fed to predators on artificial substrates. General predators (e.g., *Euseius* spp.) are reared on spider mites plus pollen, or on pollen alone. Spider mites are harvested (by washing plants) within two weeks after planting.

Mites in the family Phytoseiidae are among the most important natural enemies of tetranychid mites on agricultural crops (McMurtry 1982). These predaceous mites also may have a significant impact on certain insect pests, such as thrips (Tanigoshi et al. 1985). Augmentative mass releases of phytoseiids is a common commercial practice for control of the two-spotted spider mite, *Tetranychus urticae* (Koch) on certain high value crops, such as greenhouse-grown vegetables and field-grown strawberries (McMurtry 1982). Phytoseiids also have been used commercially for control of *Thrips tabaci* Lind. on vegetables in the greenhouse environment (Hansen 1989).

Our laboratory has been involved in large-scale production of phytoseiid mites since the early 1960's for (1) studies on biology and predatory behavior of phytoseiids; (2) experimental releases in the field or greenhouse to determine impact of augmentative releases on pest mite populations; and (3) colonization and attempted establishment of exotic species to lower pest equilibrium levels. The principles and methodology of rearing and release are outlined herein.

Rearing

Phytoseiids can be categorized into four different ecological groups based on their feeding habits: (1) specific predators (e.g., *Phytoseiulus persimilis* Athias-Henriot) of spider mites in the genus *Tetranychus*; (2) preference for, but not limited to *Tetranychus* spp. (e.g., *Typhlodromus occidentalis* Nesbitt and *Neoseiulus fallacis* (Garman)); (3) general predators (e.g., *Typhlodromus pyri* Scheuten, and *Neoseiulus barkeri* Hughes) not associated with *Tetranychus* spp., but preying on tetranychids in other genera, such as *Panonychus*, on other families of mites, and on thrips; (4) polyphagous pollen feeders (e.g., *Euseius* spp.). We have reared species in all of these groups (>40 species) on one of two basic foods, either eggs and larvae of *Tetranychus pacificus* McGregor, pollen, or a combination of the two.

Spider mite production. *T. pacificus* is reared on pole lima bean plants growing in vermiculite in plastic trays in a greenhouse at temperatures ranging from 29 to 40°C (Fig. 1). In general, this method is similar to that described in detail by Scriven & McMurtry (1971). Seven days after seeding in vermiculate, plants are infested with spider mite eggs and larvae at the rate of 1 g/tray (ca. 240 plants). Plants are heavily infested and ready to "harvest" seven days later. Plants are cut and placed in a mite-washing machine (Fig.2). The water containing the washed mites flows through a series of screens of different size mesh, retaining mites of three size groups (females, males plus nymphs, and eggs plus larvae) (Scriven & McMurtry 1971). Mites are dried in front of a fan and stored at 4°C until used, normally within three weeks.

Pollen collection. Although "generalist" phytoseiids feed and reproduce on many kinds of pollen, for convenience and dependability, we use *Malephora crocea* Jaquin, a common ground cover plant which blooms the year round in southern California. Flowers bearing pollen are picked and the pollen is collected by means of a vacuum aspirator (Fig. 3), and refrigerated as with the spider mites. Refigerated pollen remains favorable for phytoseiid reproduction for as long as three months.

Starting a Phytoseiid culture. Usually, only a relatively small number of source individuals is available to initiate a culture of phytoseiids, especially if the desired species is discovered and collected in the field by a foreign explorer or a local scientist with limited time. Moreover, the phytoseiids may have to be initially contained and reared in an authorized quarantine facility. This type of starting culture is best observed and managed in a small unit, such as an excised leaf "arena" (Fig. 4). We use avocado leaves, placed upper side down on water-saturated polyurethane foam pads in

Fig. 1. Trays of bean plants infested with *Tetranychus pacificus*.

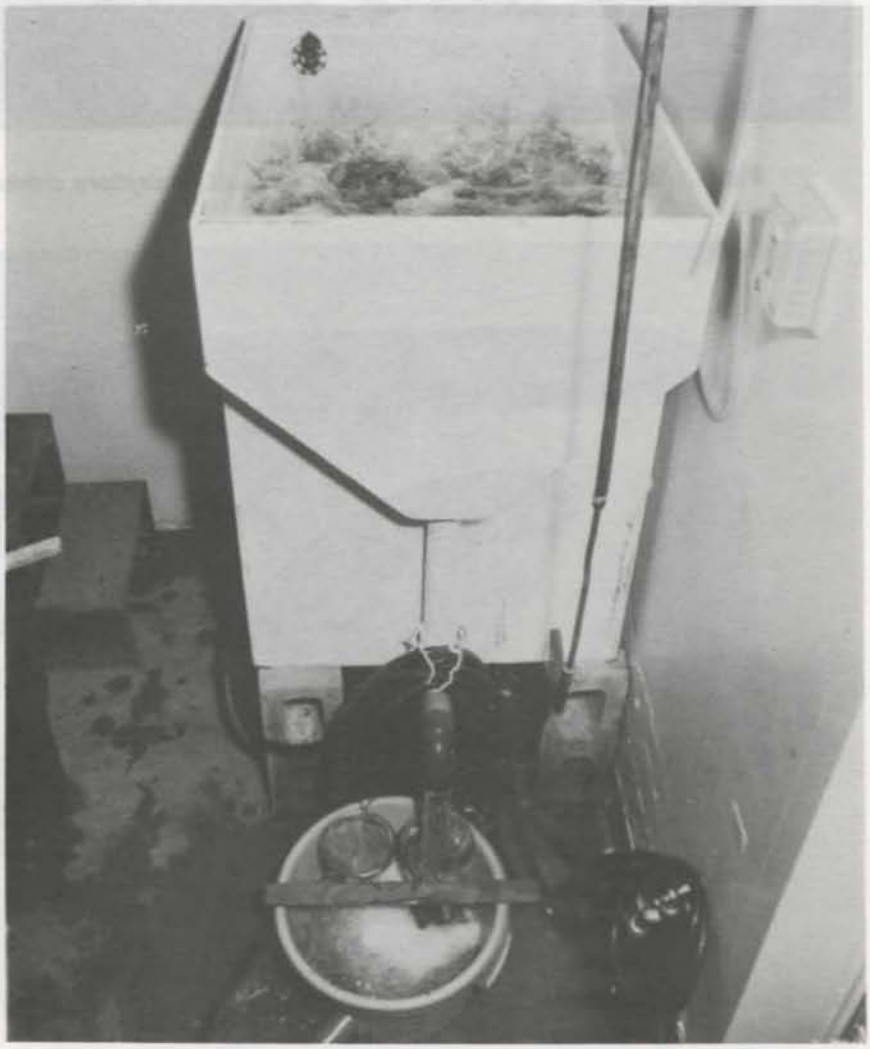

Fig. 2. Mite washing machine.

Fig. 3. Aspirating pollen from flowers of ice plant, *Malephora crocea*.

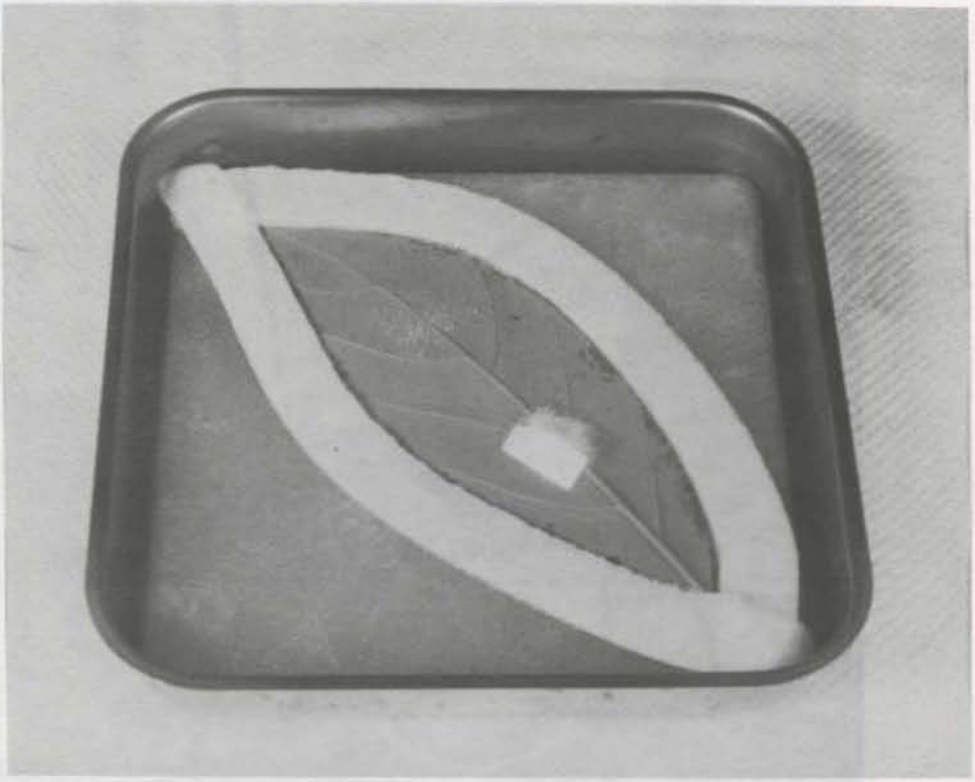

Fig. 4. Avocado leaf arenas for initiating phytoseiid cultures.

pans of water. The leaf is bordered with a strip of "cellucotton," which serves as an additional deterrent to escape of the predators. Avocado leaves can be maintained for several weeks without deterioration under these conditions. One or two plastic microscope cover slips are placed over a few strands of cotton in each arena. Most phytoseiid species rest under the cover slips and lay eggs in the strands of cotton. This is not a requirement for the more specialized predators of tetranychid mites, as these species generally remain in the piles of host mites added to the culture units.

Small amounts of food, usually both pollen and spider mite eggs plus larvae (unless the species is known to be a specific predator of spider mites), are shaken onto the leaves from the refrigerated vials of food material. Cultures should be inspected daily to monitor survival and reproduction of predators. As the phytoseiid populations increase in these units, they can be transferred to the larger units, described below, for expansion.

Large-scale Phytoseiid production. Our standard rearing unit consists of a stainless steel cake pan containing a polyurethane foam mat and a metal tile resting on the foam mat (Fig.5) (McMurtry & Scriven 1975). Sufficient water is kept in the pan to saturate the foam mat and maintain a water film at the edges of the tile. This water barrier effectively confines most species of phytoseiids to the tile surface provided they are supplied with sufficient food. The edges of the tiles can be bordered with strips of "cellucotton" for an additional deterrent to escape of especially active species. Four cover slips, with a few cotton strands underneath, are placed on each tile, except when rearing such specialized predators as *Phytoseiulus persimilis* or *Typhlodromus occidentalis*.

T. pacificus eggs plus larvae and/or pollen grains are shaken onto the tiles twice weekly, increasing the amount of food as the predator population density increases (McMurtry & Scriven 1975). Observation of the units before each feeding is important. Numerous spider mite larvae wandering over the tile surface indicates that excessive prey was placed in the arenas, while a high activity of predators indicates that too few prey (spider mites plus eggs) were provided. McMurtry & Scriven (1975) estimated that 1 g of spider mite eggs plus larvae can produce up to 15,000 *Phytoseiulus persimilis*. Most species consume fewer prey than *P. persimilis* (Sabelis 1981, McMurtry & Rodriquez 1987); therefore, fewer prey probably would be required to produce a given number of most other phytoseiids. Phytoseiids are collected by means of a vacuum aspirator into plastic straws (Fig. 6) for release in field plots or onto tiles to start new units. The predators can be released in the field directly from the straws in which they were collected. Repeated collections, totalling several thousand mites, can be made from a given unit. After 6-8 weeks, there is considerable accumulation of fecal material, dead mites, etc., and this results in a decline in production efficiency. Individual units are kept on racks, each holding three trays, in ventilated boxes. Legs on the boxes can be coated with a sticky material to prevent movement of the phytoseiids between boxes (Fig. 7). Numerous cultures of different species thus can be kept in the same room with minimal cross-contamination. *Neoseiulus fallacis* and related species, which readily cross the water barrier surrounding the tile arenas, are the only ones with which we have had contamination problems. These species are reared in separate rooms.

Production problems. Problems with prey mite production include contamination by other predators and seasonal variability in production. Because of the rapid turnover of plant material in the greenhouse (2 weeks from bean seedling emergence to "harvesting" of mites), we have had few cases of contamination by insect or other phytoseiid predators. Spider mite production usually declines during the winter months, even though high greenhouse temperatures are maintained and supplemental light is provided. We have not identified the reason for this decline.

Potential problems in predator production include contamination and genetic deterioration. Specimens should be taken from each culture several times annually, mounted and identified, to ensure that contamination by other phytoseiids has not occurred. Although it has not been adequately documented that genetic deterioration is a serious problem in phytoseiid production programs, wherever possible, new cultures should be started periodically from new material from the field.

Introduction and Release

Species to consider for specific problems. Phytoseiid species in categories 1 or 2 described above are the most promising for the control of *Tetranychus* species. These phytoseiids are attracted to spider mites in this genus, develop in prey patches of high density and profuse webbing, and, like their prey, have a high intrinsic rate of increase. In the Pacific Basin area, *Phytoseiulus macropilis* Banks and *Neoseiulus longispinosus* (Evans) are representatives of categories 1 and 2, respectively. For other genera of tetranychid mite pests or other mite pest families, such as Tarsonemidae (e.g., broad mite, *Polyphagotarsonemus latus* (Banks)), or small insect pests such as thrips, phytoseiid species in category 3, or even 4, might be better candidates. For example, *Typhlodromus pyri* Scheuten (category 3) is considered an effective predator of European red mite, *Panonychus ulmi* (Koch), though its reproductive potential is relatively low (McMurtry 1982, Nyrup, 1988). *Euseius* species and the *Amblyseius largoensis* group can have a negative impact on citrus red mite, *Panonychus citri* McGregor (McMurtry 1982). *E. stipulatus* had the highest rate of oviposition of nine species of phytoseiids tested on the broad mite (McMurtry et al. 1984). *Euseius* species also show promise as controlling agents of some species of thrips (Tanigoshi et al. 1985) in the field, and *Neoseiulus barkeri* Hughes has been used for control of thrips on greenhouse-grown vegetables (Hansen 1989). This species is reared on grain mites grown on bran, thus

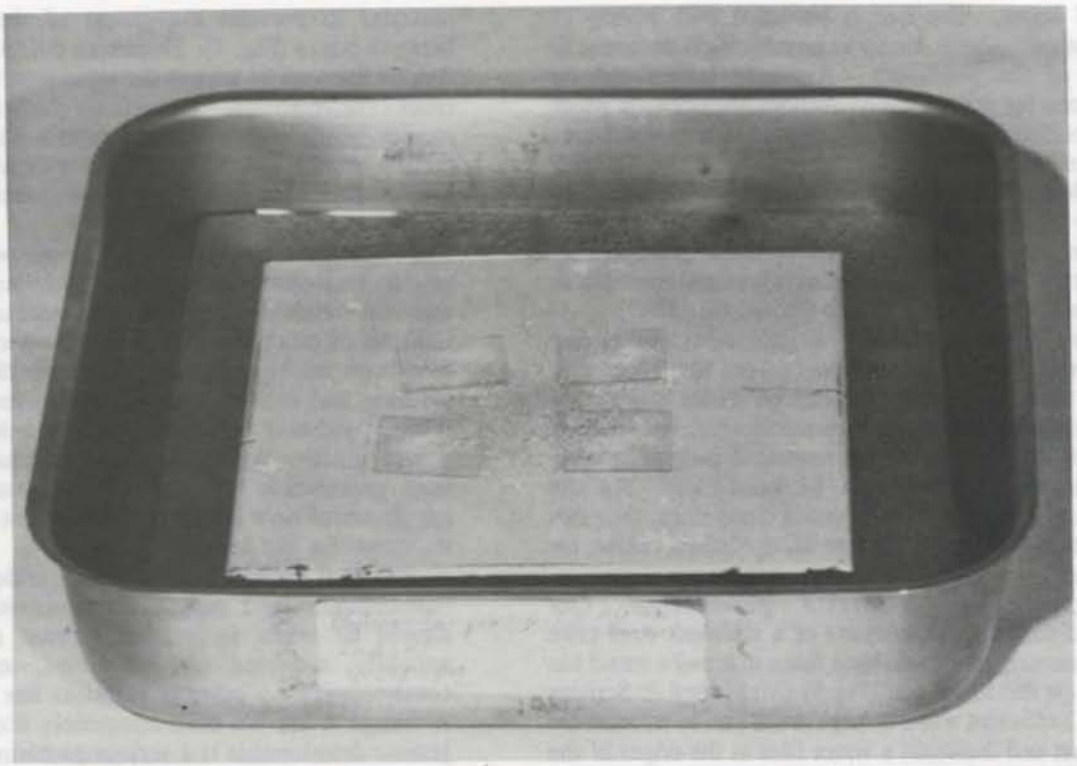

Fig. 5. Standard phytoseiid rearing units.

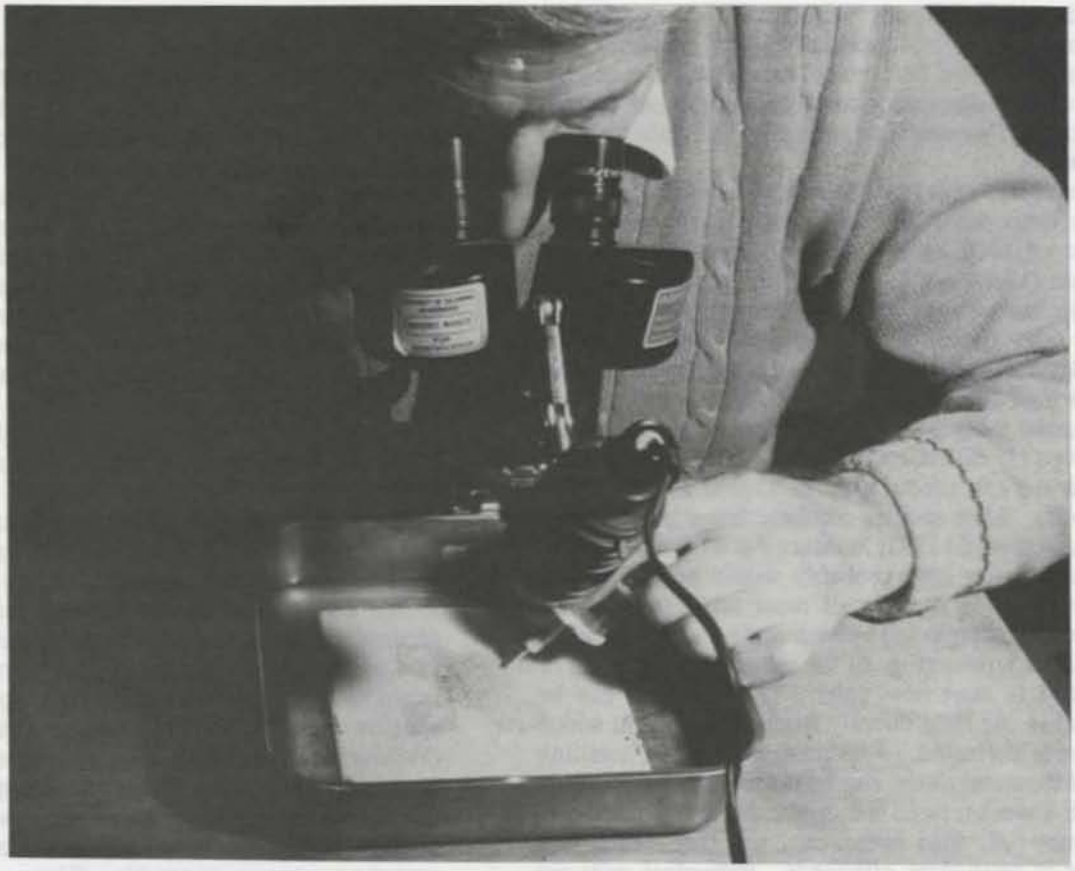

Fig. 6. Aspirating phytoseiid mites into plastic straws for transport to field release sites.

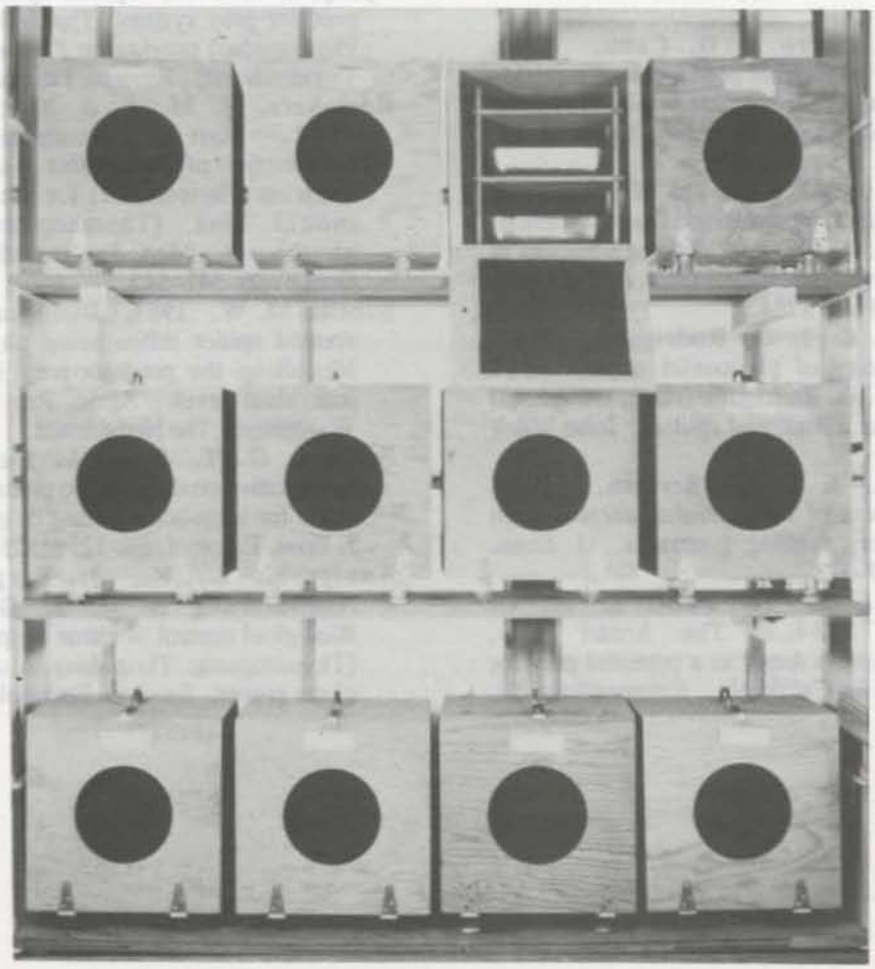

Fig. 7. Ventilated boxes containing standard rearing units. Boxes are isolated from one another so that different species can be maintained in the same room.

eliminating the need for growing plants (Ramakers & van Lieburg 1982).

Release methodology. Release methods are dictated by the objective (i.e., establishment of imported species or periodic augmentative release for economic suppression). For the former objective, there are no proven strategies or guidelines. We concentrate releases in relatively small areas (e.g., at least 1000/tree in a block of 4 - 6 trees) in several different growing regions. After initial establishment, spread is encouraged by additional releases or movement of predator-infested foliage to other parts of the orchard or field. We know little about minimum or optimum numbers needed to effect establishment of an exotic species of phytoseiid. It may be only coincidence that the three species for which establishment was achieved in California, *P. persimilis*, *Typhlodromus rickeri* Chant, and *Euseius stipulatus* Athias-Henriot, were also the ones we released in the largest numbers (from one-half to more than one million of each). Interestingly, *P. persimilis* and *E. stipulatus* have become common and widespread in southern California (McMurtry 1982), whereas *T. rickeri* is uncommon and probably never reaches sufficient population densities to have an impact on pest mite populations.

Release strategies for effective pest suppression vary according to the pest species, predator species, and type and value of the crop. Presently, this method has been proven feasible only on high value crops, such as greenhouse vegetables and field-grown strawberries, although supplemental releases in orchards or vineyards, especially of resistant strains developed by genetic improvement programs, show promise of economic feasibility (Hoy et al. 1982, McMurtry 1982).

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METHODS FOR REARING A TREE-INHABITING LEAFMINER AND ITS PARASITOIDS

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ABSTRACT *Phyllonorycter* species (Lepidoptera: Gracillariidae) are serious leafmining pests of apple throughout North America. Research indicates that in each region a complex of parasitoids is capable of providing adequate natural control, but is usually interfered with by orchard insecticides. Laboratory rearing methods are necessary for parasitoid research, such as genetic improvement, and for augmentative biological control.

Methods were developed for rearing spotted tentiform leafminer, *Phyllonorycter blancardella* (F.), and two parasitoids, *Pholetesor ornigis* (Weed) (Hymenoptera: Braconidae), and *Sympiesis marylandensis* Girault (Hymenoptera: Eulophidae). At 23°C, developmental time from oviposition to adult emergence was 28, 21, and 10 days for *Phyllonorycter*, *Pholetesor*, and *Sympiesis*, respectively. One technician working 12 hr/wk for 6 months produced 2.5 million leafminers and 200,000 parasitoids.

A faunistic survey of leafminers and their parasitoids was conducted in south central Wisconsin in 1988. Approximately 100 species of leafminers amd 1500 parasitoids were reared from about 60 host plant species. The rearing techniques used during this study are described.

Leafmining insects are found worldwide. Many species are serious pests of agronomic and horticultural crops and landscape plants. There are approximately 33 families of insects in four orders which contain leafmining species. The most common and economically important groups of leafminers are in the Coleoptera (beetles in the families Chrysomelidae, Buprestidae and Curculionidae), Lepidoptera (moths in about 20 families, significantly the Gracillariide, Nepticulidae, Heliozelidae, and Coleophoridae), Diptera (flies in about 9 families, especially the Agromyzidae and Anthomyiidae), and Hymenoptera (sawflies in the family Tenthredinidae).

Natural populations of most leafminer species are regulated by complexes of natural enemies. Although predators such as larval chrysopids and entomophagous Hemiptera can exert significant local population suppression, the most important natural enemies are parasitoids in two groups: 1) the superfamily Chalcidoidea (several families but especially the Eulophidae); and 2) the family Braconidae (superfamily Ichneumonoidea). Reviews of the taxonomy and biology of leafmining insects and their natural enemies have been presented by Needham et al. (1928) and Hering (1951). Parrella (1987) has reviewed the biology of the agriculturally important genus *Liriomyza* (Agromyzidae).

Most types of leafminer studies necessitate rearing. Such studies include faunistic surveys and taxonomic research; identification of interesting or agriculturally important species; biological studies such as comparative phenology and insect-plant interactions; and control studies including chemical, cultural and biological methods. Further the laboratory production of colonies of leafminers may be important for field inoculation of plants for biological or control studies, or to provide hosts for natural enemy research or mass production for biological control. Similarly, rearing of parasitoids may be important for identifications, systematic research, basic biology studies, candidate screening for biological control, and research on genetic improvement. Mass production of parasitoids is important for biological control releases, either by introduction of exotic beneficial species or augmentation of existing natural enemies.

The very close obligate relationships between leafminers and their host plants can present challenges in the development of rearing techniques. Methods become more complex when it is also necessary to rear leafminer parasitoids. For several years our laboratory has been studying the biology, natural enemies, and control of spotted tentiform leafminer (STLM), *Phyllonorycter blancardella* (F.) (Lepidoptera: Gracillariidae) (Ridgway & Mahr 1985, 1986, 1989, 1990). This insect is a pest of apples in the northeast and Great Lakes region of the United States and the southeastern and south central provinces of Canada (Pottinger & LeRoux 1971, Johnson et al. 1979, Weires et al. 1980, Mahr & Ravdin 1983, Van Driesche & Taub 1983). This paper summarizes rearing information for STLM and its parasitoids, especially *Pholetesor ornigis* (Weed) (Hymenoptera: Eulophidae). Also reported are rearing techniques developed during a leafminer faunistic survey of south central Wisconsin.

Materials and Methods

Rearing field collected STLM and parasitoids. To identify the species of STLM parasitoids in Wisconsin, apple leaves containing active mines were collected throughout the state during each of the three leafminer generations in 1982 and 1983 (Ridgway & Mahr 1985). These were taken to the laboratory and briefly stored at 4°C until they were set up for adult eclosion. Mined leaves were placed in petri dishes lined with filter paper moistened with a few drops of distilled water. These were held in a growth chamber at 23°C until adult emergence.

Lab rearing of STLM. STLM were reared on 1-yr-old "Mailing 7" cloned apple rootstocks acquired from a nursery as 0.8 cm diameter dormant bare root trees (Ridgway & Mahr 1989). Dormant trees were stored up to 8 mo under refrigeration (2 - 4°C) and taken out as needed. Each tree produced 20 - 30 leaves within 10 wk after planting. The trees were grown in a greenhouse at 22 - 32°C and a 16:8 (L:D) photoperiod. Trees were planted in 237 ml plastic beverage cups, using a 1:1:1 mix of field soil, peat moss, and Perlite. Trees were fertilized weekly with a 15:30:15 soluble plant food. Pests such as aphids, mites and thrips were controlled as necessary with applications of a 2.5 percent solution of Safer's Insecticidal Soap. These applications were discontinued 1 wk before trees were infested with STLM.

Rectangular bags of fine mesh mosquito netting with a drawstring closure at the bottom were used to cage STLM on trees (see Ridgway & Mahr 1989, for photograph). Moths were introduced through a small opening in one corner that could be folded shut and held with a paper clip. Water was supplied to STLM by spraying the netting with about 10 ml water twice daily. Prior to infestation, trees were lightly sprayed with a 10 percent sucrose solution as a nutrient source for the adult moths.

STLM adults were obtained from field collected leaves containing active mines, or from a continuing laboratory culture. Groups of 16 male and female moths each were introduced into each cage for oviposition. Trees with caged moths were held at 23°C for 48 h, after which the moths were removed and placed onto new trees where they were again held for 48 h. The moths were then removed and destroyed.

To determine the length of the STLM life cycle at 23°C using the above rearing technique, STLM adults were removed 24 h after the start of oviposition, eggs were coded on the leaf with a felt marker, and individuals were examined twice daily until pupation. After pupation, leaves were removed and placed in petri dishes and examined twice daily until adult emergence.

We have conducted many studies which have required large numbers of STLM adults. The two primary sources have been from field collected mines and from laboratory rearing. In fall and early spring we have collected fallen leaves from heavily infested orchards by hand picking or raking. These leaves contain overwintering pupae. Two people working for one half day can collect several bushels of leaves and several thousand miners in this manner. We have successfully collected thousands of miners in the middle of winter by first raking off the snow cover and then collecting the fallen leaves from the soil surface. If dry, the fallen leaves were held in clear plastic bags; if wet, they were held in bags of fine mesh mosquito netting to facilitate drying. During the growing season, leaves with active mines were harvested after the majority of the population had pupated (pupation occurs within the leaf). These leaves were held in mesh bags until adult eclosion. As adults emerged, they were collected from the bags 2 - 3 times daily with an aspirator. Moths were collected in a similar fashion from colonies reared on trees in the greenhouse or growth chambers.

Rearing of STLM parasitoids. The parasitoids *Pholetesor ornigis* and *Sympiesis marylandensis* (Girault) were collected as overwintering pupae from leaves in the same manner as described for STLM. *P. ornigis* prefers to oviposit in host instars 1 - 3 (Ridgway & Mahr 1990) whereas *S. marylandensis* will oviposit only into host instars 4 - 5 (Ridgway 1986). Prior to introducing parasitoids onto the caged trees, the trees were lightly sprayed with a 10 percent sucrose solution as a nutrient source for the adult parasitoids. One- to two-day old adult parasitoids were introduced onto caged trees having the appropriate host stage present, and allowed to oviposit for 24 h. Developmental time for both parasitoids at 23°C was determined in a fashion similar to that for STLM.

Additional leafminer rearing methods. In 1988, we conducted a survey of leafminers and their natural enemies found in south central Wisconsin. Four locations were sampled every second week during the growing season. The areas included woodlands, grasslands, prairie and disturbed sites. All vegetation was examined for leafmines. Leaves with active mines were excised and the peticles immediately emersed in florist water piks filled with water. Up to 40 mines of each type from each species of host plant were taken in this fashion. Leaves with mines were taken to the laboratory for emergence of adult leafminers and parasitoids.

Leafminers pupate either within the mine or outside the leaf, depending on the species. Some species that pupate outside of the leaf will do so on any adjacent substrate, such as a leaf or the soil surface. Others emerge from the leaf as active last instar larvae that crawl or drop to the soil where they pupate below the surface. Success at rearing adults requires knowledge of the pupation strategy of each species. Those species requiring soil for pupation were handled as follows. Mined leaves were held in water piks. These were placed into 473 ml jars containing 2 - 3 cm of loose soil. After emergence from the mines, larvae would usually pupate in the soil, which was then sifted to search for pupae. Leafminer and parasitoid pupae were usually transferred to petri dishes or no. 00 gelatin capsules for adult eclosion.

Some leafminers are extremely sensitive to changes in their host leaves; these will often exit the leaf during

the collecting or rearing process. As most leafminers can not develop a new mine, these larvae usually die unless they are sufficiently advanced to pupate. Whenever possible, attached leaves containing mines of these species were caged in the field, using small bags of fine mesh mosquito netting. Emerged adult leafminers or parasitoids were collected from these cages at a later sampling date.

Results and Discussion

STLM parasitoids in Wisconsin. During 1982 and 1983, over 33,000 STLM mines were collected in the field and examined in the laboratory for parasites. In 1982 and 1983, 24.2 and 21.9 percent, respectively, of the total STLM collected were parasitized. A total of 5754 adult parasitoids were reared from field collected hosts and identified (Ridgway & Mahr 1985). Ten species of parasitoids were found, the most abundent being *Sypiesis marylandensis* and *Pholetesor ornigis* (Table 1).

Table 1. Parasitoids of spotted tentiform leafminer, *Phyllonorycter blancardella* (Lepidoptera: Gracillariidae), reared in Wisconsin, 1982 - 1983.

Family	Species	Percent of Total
Eulophidae	*Sympiesis marylandensis* Girault	49.5
Eulophidae	*Sympiesis dolichogaster* Ashmead	0.4
Eulophidae	*Sympieses bimaculatipennis* (Girault)	0.2
Eulophidae	*Pnigalio flavipes* (Ashmead)	0.8
Eulophidae	*Pnigalio maculipes* (Crawford)	2.4
Eulophidae	*Horismenus fraternus* (Fitch)	0.2
Eulophidae	*Closterocerus tricinctus* (Ashmead)	1.1
Eulophidae	*Cirrospilus cinctithorax* (Girault)	1.0
Eulophidae	Unidentified species	1.2
Braconidae	*Pholetesor ornigis* (Weed)	41.7
Ichneumonidae	*Scambus decorus* Walley	1.5

Rearing of STLM and its parasitoids. The method described for infesting seedling apple trees with STLM resulted in the production of 10 to several hundred viable eggs per tree, with at least 50 eggs on most trees. We found that an ideal STLM larval density was 50 - 100 mines per tree, or a maximum of 8 evenly-spaced mines on the larger leaves. STLM larvae are cannibalistic if their mines should merge, a situation which confused interpretation of some studies. Therefore, if the egg density was greater than the optimum or the distribution on a leaf was too clumped, unwanted eggs were removed with a moist cotton swab.

For some studies it was necessary to have more adult STLM than would eclose in one day. When this occurred, emerging moths would be held in 7 ml vials at 4 - 5°C until sufficient numbers had been accumulated. For most studies the storage time was 24 - 48 h, but we were successful at storing adults as long as 6 - 8 days without appreciable mortality.

The number of days from oviposition to adult emergence of STLM and the two parasitoids are shown (Table 2) (Ridgway & Mahr 1989).

Table 2. Development time from oviposition to adult eclosion of spotted tentiform leafminer, *Phyllonorycter blancardella* (Lepidoptera: Gracillariidae), and two of its parasitoids (from Ridgway & Mahr 1989).

	Development Time (Days)	
Species	Males	Females
Phyllonorycter blancardella	28.3	29.1
Pholetsor ornigis	20.5	21.3
Sympiesis marylandensis	9.6	10.9

In the first 6 mo of 1986, we infested 1,700 trees using 80,000 adult STLM, which produced 2.5 million offspring for experimental purposes and maintaining the colony. One thousand parasitoids were used in experiments, and these produced 200,000 viable offspring. About 12 h per week were required for tree planting and maintenance, rearing and collecting adult moths, and infesting trees. Additional time was required when STLM egg numbers needed to be adjusted.

Results of faunistic survey. The following results of the 1988 faunistic survey of south central Wisconsin are preliminary, with species identifications continuing. Approximately 100 leafminer species were reared. Of these, about 40 percent were from 22 species of woody shrubs, herbaceous dicots and grasses. The majority of the leafminers were Lepidoptera, primarily in the family Gracillariidae. The Diptera constituted the second most common order, with representatives of the Hymenoptera and Coleoptera also reared.

In addition to the leafminers, approximately 1500 parasitoids have been reared, but not yet identified.

Acknowledgment

Some of rearing techniques used in the faunistic survey were developed by Mr. Chinaka Steady while working on an undergraduate fellowship in our lab. Mr. Steady was an extremely bright and personable young man with tremendous potential. His sudden and untimely death has deprived the world of an excellent young scientist. This paper is devoted to his memory. We also wish to thank P. Dolan and C. Nordby for technical assistance with these studies. The research was supported by the College of Agricultural and Life Sciences, Univ. of Wisconsin - Madison, and by Hatch grants 2566 and 2873.

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NATURAL ENEMY REARING TECHNIQUES USED SUCCESSFULLY IN BIOLOGICAL CONTROL IN HAWAII

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ABSTRACT The Hawaii Department of Agriculture (HDOA) has been rearing natural enemies for biological control since the 1890's. Many different rearing techniques have been developed or adapted for a wide variety of immigrant pest insects and weeds and their natural enemies. Most of these techniques have used simple and relatively inexpensive equipment that could be easily used by agencies initiating biological control programs.
A basic set of equipment and tools has been selected through many years of trial and error of insect rearing work. Rearing techniques used by the HDOA are well suited to semitropical and tropical climates and are likely to be applicable throughout the Pacific basin. Hawaii has the best record of successful classical biological control programs in the world and has done so without sophisticated or costly facilities.

Biological Control was first attempted in Hawaii in 1890, only two years after the recently celebrated first biological control program in California, one hundred years ago. It was in fact the same pest insect, the dreaded cottony cushion scale, *Icerya purchasi* Maskell, that prompted this new control method. The same predator that saved the California citrus industry, the vedalia beetle, *Rodolia cardinalis* (Mulsant), was introduced to Hawaii from California in 1890 by Albert Koebele. According to Pemberton (1964) it provided "remarkable control." Several introductions were made subsequently for biological control of mealybugs, scales and armyworms before 1903, at which time the territorial legislature of Hawaii established the Board of Commissioners of Agriculture and Forestry. This organization was the predecessor of the Hawaii Department of Agriculture (HDOA). From 1903 until the present, a multitude of natural enemies have been introduced to control a wide variety of insect and weed pests. The first classical biological control of a weed worldwide was attempted in Hawaii (Pemberton 1964). Beginning in 1902, Albert Koebele initiated shipments of insects to Hawaii to attack *Lantana camara*, a thorny weed that rapidly dominated lower elevation shrub lands on the main islands. Since then, eight weed species have been substantially or completely controlled in Hawaii using insect natural enemies (Lai 1988).
Introduced biological control agents have also contributed to substantial control of approximately 48 phytophagous insect pests. Of these, 38 are under complete control, eliminating the need for other forms of control.

Preliminary Research

Prior to starting a rearing program for natural enemies of a pest, a thorough literature review is an important early step in deciding if or how a new arthropod pest can be controlled. The search may reveal that other countries have already conducted investigative biological control work. Suggestions on natural enemies to test, host and natural enemy rearing techniques, and release methods for control agents may be found in the literature. Some natural enemies may be unsuitable due to their broad host range, rearing difficulties, or failure to control the pest when used for biological control elsewhere. Host range tests of candidate natural enemies are extremely important to insure the protection of native and beneficial non-target organisms. If the natural enemies have been through host range tests elsewhere they should still be held in a quarantine facility for at least one generation to rear out hyperparasites and isolate disease organisms. If host range tests are completed and the insect or mite is considered safe for release and approved by proper authorities, it can be released from quarantine for mass propagation. HDOA has reared both predacious and phytophagous mites in the past, but these will not be discussed here.

Indoor vs. Outdoor Rearing

There are a variety of enclosures used to contain and rear insects, but the requirements of an insect's biology may dictate where these enclosures should be located. Enclosures may be kept indoors, in a greenhouse, or outdoors. Each location has advantages and disadvantages and only one of these locations may be suitable for a certain pest.

Indoor rearing is often the most convenient, but lighting, temperature and humidity requirements of the host plants and insects may be incompatible with the indoor environment. However, some species of pests and their natural enemies can be effectively reared on live plants using plant-growth fluorescent lamps with timers and by adjusting the microclimate of the host plant/insect enclosure. Potted host plants may also receive adequate light if positioned near windows. Household humidifiers are useful in dry indoor conditions. Water reservoirs with wicks can raise

humidity in rearing jars as well as provide drinking water for pests or natural enemies. If a greenhouse is available or can be built, it may be more suitable for insect rearing than a building shared with humans. Some host plants do poorly under artificial light but grow well in greenhouses.

Rearing in outdoor enclosures may be necessary for some pests if covered structures are unavailable or if the host and pest cannot be easily reared indoors. Outdoor cages can be simple and built to fit the host plants. PVC pipe makes a good frame for temporary cages and can be easily disassembled and stored. Sleeve cages slipped over branches of plants are also useful for propagation in a more natural environment.

Insect Rearing Enclosures

Two basic types of enclosures have been used by HDOA to hold insects for rearing; cages and bottles. Each of these has two different forms. All cages HDOA has used have been either made with screen sides or a combination of screen and glass. Wooden frame cages can easily be made on site with the appropriate dimensions. Metal frame cages (preferably aluminum) usually must be made by a sheet metal shop, but are easier to sterilize and are more durable. Compared to glass containers, cages provide better access and ventilation.

Glass containers may sometimes be better than cages for rearing certain insects. HDOA regularly uses two types of glass containers; one gallon mayonnaise jars and 24 cm diameter battery jars. Mayonnaise jars may be free locally while battery jars are quite expensive. Glass containers usually take up less room than cages and can be placed close together on racks. They are easier to sterilize than cages and it is usually easier to find small insects inside them. Ventilation is not as good as in a cage, but this may be an advantage if high humidity is needed.

Food Sources for Phytophagous Insects

Propagation techniques used by the HDOA can be most easily categorized according to the form of the food presented to the insect in culture. Phytophagous pests reared as hosts of natural enemies and natural enemies of weeds have similar requirements. The food may be made available as whole plants, bouquets of plant parts, individual leaves, fruits, seeds, or artificial media.

Rearing phytophagous insects on whole plants usually requires cages large enough to enclose whole plants. This can be either in an outdoor bottomless cage placed over a plant rooted in the ground, or on a potted plant in a totally enclosed cage. The advantages and disadvantages of outdoor cages have already been discussed. Small potted plants can be kept in cages indoors or in a greenhouse if the microclimate is suitable for the insects. Once the plant is in place, it may be possible to rear more than one generation without replacing the plant. Whole plant rearing is most useful for many homoptera, spider mites, thrips, and leafmining insects such as the Agromyzids. Natural enemies can be introduced into the cages or a few host insects can be removed to feed predacious insects or mites. Some parasitized host insects such as agromyzids can be removed in their pupal stage to be held for parasite emergence in jars or small cages. Most life stages of the homoptera, however, cannot survive long periods without their host plants.

The spiraling whitefly, *Aleurodicus dispersus* Russell, is a good example of a homopteran pest that had to be reared on whole plants to raise the whitefly's natural enemies. The spiraling whitefly was first detected on Oahu in 1978 and soon spread to all the major Hawaiian islands. Its host range of over 100 plants and its high fecundity made it a serious pest of ornamental plants as well as food crops such as banana (*Musa paradisiaca*), mango (*Mangifera indica*), guava (*Psidium guajava*) and citrus. Using potted guava plants in 66 X 43 X 43 cm cages, four species of natural enemies were reared and released. These comprised three species of coccinellid beetles and two species of aphelinid wasps. Field collected *A. dispersus* adults were used to inoculate the guava plants in outdoor cages. When plants were heavily infested, they were moved into the indoor cages. Adult predacious coccinellid beetles were then introduced into the cages and left to mate and lay eggs. A modified hair dryer was used to aspirate insects from cages when needed. This ingenious tool has since been replaced by modified Black & Decker Dust Buster Plus® miniature vacuum cleaners.

Bouquets of plant parts in a container of water in a cage are a simple food source that can be used to rear lepidoptera or thrips. Bouquets are particularly well suited to rearing lepidopterous larvae. The lepidopterous larvae may be a pest reared as host of natural enemies or they may be a natural enemy themselves, used in the control of a weed pest. Bouquets are convenient because they take up less room than whole plants, do not require potting media, and can be easily replaced. They can be used in either cages or jars.

The banana skipper, *Pelopidas thrax* (L.), was discovered on Oahu in 1973 and spread to all major Hawaiian islands by 1975. This pest was raised by HDOA on banana leaf bouquets to provide larvae for the braconid larval parasite, *Apanteles erionotae* Wilkinson and an encyrtid egg parasite, *Ooencyrtus erionotae* Ferriere. Due to the large size of banana leaves and the large space requirements for the moths to mate and oviposit, a walk-in outdoor cage was used for rearing with good results. Both parasites were mass reared and released and are now well established. Subsequent collections of banana skipper eggs and larvae indicated a high rate of parasitism and the pest is no longer considered economically important.

Recently, another insect has been raised on leaves in the HDOA insectary. The blue coconut leaf beetle, *Brontispa chalybeipennis* (Zacher), is a new immigrant pest, first discovered in Honolulu in 1985. Larvae and adults of this chrysomelid beetle feed on the epidermis of young coconut (*Cocos nucifera*) leaves, causing them to turn brown and dry. Weak trees may be killed by

extensive feeding damage. The beetles are presently reared in gallon jars with cut pieces of young coconut leaflets. Beetle pupae are regularly collected and exposed to the larval-pupal parasite, *Tetrastichus brontispae* Ferriere, in separate gallon jars. The tiny eulophid wasps are supplied with drops of honey and a water vial with a wick. Large numbers of the gregarious parasite can be produced in very little space.

An example of an insect reared on "fruit" (seed pods) is the southern green stinkbug, *Nezara viridula* (L.), which has been raised on various seed pods such as string bean (*Phaseolus vulgaris*), spider flower (*Cleome spinosa*), Kiawe seed pods (*Prosopis pallida*), and corn (*Zea mays*). Both an adult parasite, *Trichopoda pilipes* (F.), and an egg parasite, *Trissolcus basalis* (Wollaston) have been reared and released by HDOA and are now established.

Commercial artificial diets for insects have been recently developed for many common crop pests and have greatly simplified rearing. A wide selection of media is available from commercial supply companies. The small disposable cups, in which the diet and insects are held, take up little space and can be sterilized before use and segregated to prevent cross-contamination. Paper lids for the cups can also be sterilized and allow excess moisture to escape. The biggest disadvantage of the commercially available diets is that they are expensive. Another disadvantage is that few diets are available for tropical and semitropical pests common to the Pacific Basin. Also, refrigeration is necessary to store prepared media until it is used.

The HDOA has had limited experience with artificial diets. The first time an artifical diet was used was in 1968 to rear the New guinea sugar cane weevil, *Rhabdoscelus obscurus* (Boisduval). The Vanderzant-Adkisson diet (Adkisson et al. 1960) was modified by adding ground coconut which proved successful. However, rearing the weevil larvae was labor intensive and preparation of a complicated artificial environment was required for the imported tachinid parasite, *Lixophaga sphenophori* (Boisduval), to attack the larvae. The tachinid is now well established in Hawaii and appears to have brought the weevil under control.

The HDOA did not use any artifical diets for rearing between 1972 and 1986, when the lesser cornstalk borer (LCB), *Elasmopalpus lignoscellus* (Zeller), was found established on Kauai. This pyralid moth has since become a major pest of sugar cane on the island of Maui and causes sporadic economic damage on the other islands. Several natural diets such as corn seedlings, young sugar cane shoots, and nut sedge (*Cyperus* sp.) were all used for larval food with mediocre results. Propagation of the host plants was time consuming and insect rearing was poor. Rearing techniques for this pest on artificial diet had already been developed by Stone (1968). A newer, similar diet is now available from Bio-Serv® Inc. in a kit form that is relatively easy to prepare. When our insectary switched to the Bio Serv® diet, production increased substantially, augmented by techniques developed by Dr. Asher Ota, Hawaiian Sugar Planters' Association (personal communication). Rearing is now relatively systematic and an incubator is used to store the maturing larvae at a constant temperature.

Two species of parasites of lesser corn stalk borer are now in culture in the HDOA insectary. These are a braconid wasp, *Orgilus elasmopalpi* Muesebeck, and a eulophid wasp, *Horismenus* sp. Third through fifth instar LCB larvae are removed from the small rearing vials and placed in a gallon jar with a thin layer of vermiculite in it. Honey dabs and a water source are put in the bottle for the parasites. The parasites are then put in and left for 3 days. Parasite eggs are left to develop as the LCB larvae mature and pupate. The new generation of parasites emerge in the bottle and are collected and held in separate jars for mating and future use.

Summary

The Hawaii Department of Agriculture has developed or adapted a variety of insect rearing techniques that have been used in many successful biological control programs. Using cages or jars and simple tools, natural enemies have been reared and released and have controlled many different pests. These techniques could be used on other Pacific islands to rear natural enemies for control of immigrant crop pests or weeds. The relatively low cost of using these techniques and the potential for decreasing reliance on pesticides makes biological control attractive for smaller crop protection programs. However, risks to non-target endemic or beneficial species should always be evaluated through host range tests prior to releasing any natural enemy. Biological control can provide virtually permanent reduction in crop damage if it is well planned and natural enemies are provided with a suitable crop habitat in which to reproduce.

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REARING PARASITES OF STALK-BORING LEPIDOPTERA ATTACKING GRAMINACEOUS PLANTS

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ABSTRACT Lepidopterous stalk borers are serious pests attacking graminaceous crops throughout the world. Immatures of these insects generally bore within or between plant tissues and therefore are difficult to control with conventional pesticide technologies. Biological control historically has been successful in management of populations of stalk borers, and classical biological control projects against this complex of pests are being pursued worldwide. One major barrier to successful importation and colonization of stalk borer parasites is the development of laboratory rearing methods for initial colony establishment and rearing for field colonization.

A project conducted over the period 1982 - 1988 in Texas for biological control of stalk borers in graminae investigated simple rearing methods based on the requisites of each parasite species for host insect, host plant, and other factors. Some 30 species of parasites representing a wide array of families in Hymenoptera and Diptera were imported and rearing was attempted. Some general principles were established and standard procedures adapted for rearing parasites on natural and nonnatural host insects with and without host plants. Results of these investigations may be applied to rearing other species of parasites attacking stalk borers.

Utilization of applied biological control has often been prescribed for population suppression of stalk boring lepidoptera attacking Graminae. The intentional introduction and colonization of parasites against these stalk borers has been credited with complete biological control of pest species in certain areas, while in other situations where it has been attempted, no significant benefit has been realized. Although success or failure in achieving biological control is difficult to predict, it is clear that the interactions between the host plant, stalk borer species, and parasite species greatly influence the outcome of biological control attempts.

The Mexican rice borer, *Eoreuma loftini* (Dyar), a borer species native to western Mexico (Osborn & Phillips 1946) has recently expanded its range throughout most of Mexico and south Texas (Johnson & van Leerdam 1981). A project initiated in 1981 for biological control of this pest in Texas led to the importation of more than 30 species of hymenopterous and dipterous parasites from sources worldwide and subsequent evaluation of these parasites for potential field colonization efforts in Texas (Browning et al. 1985). The objective of this paper is to discuss the importance of parasite rearing in attempting biological control of the Mexican rice borer and stress its importance to other similar biological control efforts.

Host Rearing

While laboratory rearing of stalk borers is not treated extensively in this paper, continuous availability of various life stages of borer species is prerequisite to successful laboratory rearing of parasites. The specific requirements for host rearing are dependent upon seasonal availability of borers in the field, projected numbers required for parasite rearing, and availability of facilities, supplies, and equipment for laboratory host rearing. In the case of the Mexican rice borer (MRB), a modified soybean-wheat germ diet (Shaver & Raulston 1971) was utilized by the USDA, APHIS, Sugarcane borer rearing facility, Mission, Texas, to produce large numbers of borers (ca. 25,000 - 50,000 per week) for parasite rearing purposes. Alternatively, parasite rearing at moderate levels can be accommodated on host colonies maintained on whole plants, plant parts, or on synthetic diets.

Stalk Borer Biology and Development

Stalk borer biology and host plant characteristics dictate the requisites which must be met for successful parasitism. Borer feeding sites change as development progresses, and feeding behavior varies with the size (diameter) of the stalk on which they are feeding. In general, the developmental biology of *E. loftini* is typical of most stalk boring pyralids (van Leerdam 1986), and will serve as a model upon which to base the discussion of parasite rearing. Major differences in the biology of this borer and other species will be noted as they relate to parasite attack.

Egg masses of *E. loftini* are deposited in folds of dry leaf material near the base of the plant (van Leerdam et al. 1986). These sites are preferred over green leaf blades commonly used by sugarcane borer (Fuchs & Harding

1978). Because egg masses are laid on dry leaf surfaces, movement to living leaf tissue is required before feeding can commence. Larvae chew into and begin feeding on the soft tissue inside the leaf sheath which is wrapped around the stalk. Larvae feed in leaf sheaths for several weeks and molt 2 or 3 times at this location. As larvae complete the 3rd or 4th instar and are 0.95 to 1.27 cm in length, they enter the plant stem, generally chewing directly into the internode adjacent to the leaf sheath on which they were feeding. Within a few hours of initiating stalk entry, the larva has progressed into the stalk interior, and from this time onward, the larva feeds internally by boring inside the internode. Tunneling behavior of MRB in large stems differs from that of other stalk borers in that much of the tunneling occurs near the outer surface of the stalk adjacent to the rind and winds horizontally as well as vertically. This tunneling behavior of the MRB deviates dramatically from that of *Diatraea saccharalis* (F.) in that the tunnel is generally restricted to one internode and that peripheral tunneling is common (Johnson 1985). *Diatraea* spp. typically excavate vertical tunnels through the center of the stalk (Fuchs & Harding 1979), while *Eoreuma* tunnels form a meandering trail across and around the periphery of the stalk. The appearance of MRB tunnels also differs from other lepidopterous borers in the presence of frass throughout the tunnel. Other borers, notably species of *Diatraea*, periodically remove frass from their tunnels to the outside, leaving deposits in the area between the leaf sheath and the stalk (Fuchs 1977). MRB rarely removes frass to the outside, and thus has tunnels which are packed with frass.

Upon completion of larval development, stalk borers excavate a pupal chamber and create a moth emergence window to the outside of the stalk. The window generally is not open, but is covered with leaf sheath or rind epidermis. The larva then pupates within the chamber and the emerging moth escapes through the window.

Parasite Prerequisites

It is clear that stalk borer parasites must specialize in attacking particular life stages in specific plant locations. Because different borer species exhibit similar feeding behaviors, some typical parasite attack opportunities can be identified. First, the borer eggs, whether laid on dry or green leaf material, are vulnerable to parasitization by hymenopterous parasites. Subsequently, early larval stages provide a target for parasitization while feeding in leaf sheaths. Later larval stages within the stalk are more protected, but nevertheless, are susceptible to parasite attack. Finally, prepupae and pupae within the stalk can be available for parasitization by certain parasites. Cues derived from both host borer and plant are important in the parasitization process, since indirect evidence of borer presence (plant tissue damage & frass) is often evident, whereas the borer is rarely exposed (van Leerdam et al. 1985).

Thus, the combination of host stage and plant location provides the basis upon which parasite attack strategies are developed, and successful parasite rearing in the laboratory depends upon meeting the requisites of a parasite species for successful attack and development.

Parasite Biology

Biological attributes of stalk borer parasites influence their ability to be manipulated in laboratory culture. Many parasite species are for the most part unknown when imported into quarantine, and rapid determination of the basics of their biologies is essential to successful culture establishment. In addition to the host stage and locational characteristics discussed above, there are innate characteristics of the parasites which must be identified. Obviously any information from literature on the parasite species in question or related species can provide useful information. Whether the species is uniparental or biparental would appear straightforward, but may not be immediately apparent, particularly if small numbers of parasites are initially received. This poses problems for initiating laboratory cultures. If all-female populations are indicated, host exposures should be made immediately and females then should be held under cool temperatures awaiting the development of their progeny. Subsequently, if only males emerge from these exposures, the species is obviously arrhenotokus and emerging males can be mated with surviving female parents to establish a colony. If on the other hand, females emerge from the initial exposure, then it is clear that the species is uniparental and the culture is established. Aside from the extreme case involving uniparental reproduction, it is useful to have an indication of normal sex ratio for biparental species. Sex ratios often are skewed in culture establishment, and rearing conditions may need to be modified to obtain a normal balance. Initial field collection records or previous culturing efforts may provide data indicating natural sex ratios, and the sex ratio of new cultures should be evaluated according to these data.

Gregariousness is common among stalk borer parasites, but as with sex ratios, initial rearing efforts may not indicate expected normal progeny numbers per host. Host size, stage, and behavior may influence the clutch size of parasites, and this variable should be monitored in parasite rearing. Unusually large clutch sizes may indicate multiple parasitism, and if not controlled, can lead to competition and decreased parasite production. Solitary species often will oviposit repeatedly on the same host if suitable hosts are limited and this behavior also leads to reduced parasite production. Polyembryony is a phenomenon which may be encountered with stalk borer parasites. For example, the braconid *Macrocentrus prolificus* Wharton (Hymenoptera: Braconidae) is polyembryonic, producing hundreds of parasites from one or few eggs. While this is not a liability in rearing, it can create some confusion in establishing rearing procedures and culture methods. In the case of *M. prolificus*, initial rearing efforts failed due to parasite exposure to inappropriate host stages.

Although *M. prolificus* larvae pupate within penultimate larval stages of the host, oviposition actually occurs on 1st or 2nd instars behind leaf sheaths (Wharton 1984), and this characteristic was not evident during early culture attempts.

The final requisite discussed here is adult parasite nutrition. An understanding of the nutritional needs of adult parasites can lead to increased fecundity, longevity, and increased overall culture success. While some species require nourishment to produce viable eggs, other species obtain required nutrients through host-feeding. Still other short-lived species apparently do not require or benefit from availability of nectar, honey, or other sources of nutrition.

Parasite Attack Strategies

The remainder of this paper will discuss various strategies used by parasites of stalk borers in locating and successfully parasitizing their hosts located in plant tissues, and how these strategies may be manipulated for laboratory rearing purposes. A summary of available parasite strategies is provided (Table 1), and a discussion of each follows the table.

Table 1. Summary of attack strategies for parasites of lepidopterous stalk borers of Graminae.

Host stage	Host location	Mode of parasite attack
Egg	Exposed on leaf	Direct contact
	Concealed in leaf	Drill through tissue
Larva	Leaf sheath	Probe behind sheath
		Drill through sheath
	Tunnel in stalk	Probe into tunnel openings
		Drill into stalk
		Oviposit at tunnel opening
		Enter tunnel
Pupa	Pupal chamber in stalk	Probe into pupal chamber
		Drill into stalk
		Enter pupal chamber

Egg parasites. Hymenopterous parasites which attack eggs of stalk borers use two different methods of attack, depending to a great extent upon the level of exposure of the egg masses. The first is most common, and involves direct contact between parasite and egg mass, achieved by the adult parasite climbing onto or between eggs in the mass and parasitizing individual eggs directly. This strategy is utilized by trichogrammatid parasite species (Hymenoptera: Trichogrammatidae) and is only limited when eggs are not adequately exposed. Egg masses of *E. loftini* are generally located between leaf folds and thus are only partially vulnerable to this strategy. Factors which determine the ability of trichogrammatids to parasitize *E. loftini* eggs involve the ability of the adult parasite to gain access to eggs in the mass, and normally only the most exposed eggs along the edges of the masses are susceptible to attack (Browning & Melton 1987). The alternative strategy for egg parasites is to gain access to egg masses by drilling or probing through plant tissue. While this strategy is less commonly encountered, it allows for the parasitization of eggs concealed by leaf tissues.

Larvae in leaf sheaths. Strategies used by parasite species attacking larvae of stalk borers are more varied due to the concealed nature of the host larvae in different plant parts. Parasites attacking young larvae in leaf sheaths generally must locate their hosts either by probing behind the leaf sheath with long, flexible ovipositors (*Agathis stigmaterus* (Cresson) (Hymenoptera: Braconidae), and *Macrocentrus prolificus*) or by drilling through the leaf sheath in the vicinity of the borer (*Bracon* spp., *Allorhogas pyralophagus* Marsh (Hymenoptera: Braconidae), and *Rhacanotus roslinensis* Lal (Hymenoptera: Braconidae)). In either case, parasites are responding to the presence of the larva indicated by leaf sheath wounding or the presence of frass. There are indications that certain species also perceive vibrations emitted by feeding larvae and focus their attack based on this information. In developing rearing techniques for these species of parasites, it is essential to recreate to some degree the leaf sheath situation under laboratory conditions. This may be most readily accomplished by larval infestation of bouquets of leaf material held together by tape or staples or by infesting stalk pieces with intact leaf sheaths. Both methods require availability of plant material, and involve timely dissection of plant tissues to recover host larvae following exposure. Alternative exposure methods involve the substitution of leaf material bouquets with artificial "bouquets" of paper or with larvae contained within thin layers of artificial diet. The addition of fresh larval frass to artificial "bouquets" may be necessary to promote parasitization, and larvae cannot be held in this manner without provision of food.

Larvae in tunnels. Borer larvae located within stalk tunnels present additional challenges for parasite rearing. Parasite species attacking these larvae must gain access to their prospective hosts by probing holes in the stalk produced by borer larvae, drilling into stalk tissue, ovipositing at tunnel openings or by actually entering the tunnels to contact larvae directly.

Parasite species probing into tunnel openings generally have long ovipositors and make physical contact with host larvae on which they oviposit. Access may be either through holes made by larvae upon entry into the stalk or through holes made by larvae constructing pupation chambers. Parasitization of the host may or may not be accompanied by paralysis. In the laboratory, parasites using this strategy generally will parasitize larvae located in short stem pieces of host plant material. Alternatively, larvae placed in plastic or paper straws often will chew openings in the straw, allowing access to parasites using this method (*Mallochia pyralidis* Wharton (Hymenoptara:

Ichneumonidae), and *Stenobracon deesae* Cameron (Hymenoptera: Braconidae)).

Parasite species which drill into host larval tunnels through stalk tissues in large-stemmed grasses may be limited to tunnels near the outer surface of the stalk. This limitation is imposed by the length of the ovipositor and the density of the stalk through which they must drill. Such is the case with *Allorhogas pyralophagus* attacking *E. loftini* in sugarcane (Melton & Browning 1986) and *Rhacanotus roslinensis* (Hawkins & Smith 1986). Laboratory rearing of these species may be accomplished in plant stems infested with the appropriate host stage, or paper straws infested with larvae and plugged at the ends may be substituted for plant pieces. This method is useful because parasite species using this method paralyze their hosts and thus there is no borer food requirement following parasitization. Unparasitized larvae generally will escape the straw pieces after a few days.

Strategies utilized by the tachinid flies (Diptera: Tachinidae) differ from those already described for parasitization of larvae within tunnels in the stalk. Some parasite species within the Tachinidae larviposit at the entrance to the tunnels, after which parasite maggots move into the tunnel seeking a host larva. In other species, adult female flies wait at tunnel openings for borer larvae to become exposed, then the fly oviposits directly on the host. One additional strategy used by tachinid fly parasites of stalk borers is oviposition in the vicinity of host tunnels, whereupon feeding of host larvae at tunnel openings results in the ingestion of parasite eggs. One modification of these strategies for laboratory rearing is mechanically placing eggs or maggots dissected from gravid female flies directly onto host larvae.

Difficulties in rearing tachinid flies generally arise in providing conditions in the laboratory suitable for mating and maturation of parasite eggs. Preoviposition (or prelarviposition) periods up to intervals of 9 - 10 days are common in some species, and factors such as space, humidity, light, air movement, and availability of food for adult flies may influence survival and reproductive success.

A strategy utilized by species such as *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae), *Apanteles minator* Muesebeck (Hymenoptera: Braconidae), and *Goniozius natalensis* Gordh (Hymenoptera: Bethylidae) involves the entry of female parasites into the larval tunnel through openings in the tunnel (van Leerdam 1981). These parasites oviposit directly on or in the host. Host paralysis may or may not be involved in this strategy. Limitations of this strategy are encountered when larval frass obstructs the tunnel and precludes passage of certain parasite species. In this manner, *Cotesia flavipes* apparently is prevented from gaining access to *Eoreuma loftini* larvae within stalks, whereas, *Goniozius natalensis* gains access to hosts by digging through frass- obstructed tunnels. Additionally, the potential of host defensive behavior exhibited by borer larvae can reduce successful parasitization and may result in adult parasite injury or death. Laboratory rearing of parasites using this strategy is simplified by the fact that these species will attack naked larvae on artificial diet. This simplifies rearing immensely since no plants or plant parts are required to stimulate oviposition.

Pupae in stalks. Stalk borer parasites whose favored hosts are pupae utilize similar strategies to those employed by larval parasites. Parasite probing through open or closed emergence windows created by borer larvae prior to pupation is a common method of gaining access to host pupae, and a variation of this strategy is used by *Dentichasmius busseola* Heinrich (Hymenoptera: Ichneumonidae). After probing into the pupal chamber with its short ovipositor, the female of this species partially enters the chamber oriented backwards to make contact with the pupa. Further modification of this behavior is exhibited by *Pediobius furvus* Gahan (Hymenoptera: Eulophidae), a small parasite that probes the pupal chamber and subsequently enters the chamber much in the same manner as exhibited by the larval parasites *Cotesia flavipes* and *Apanteles minator*. A third strategy which potentially can link pupal parasites with their host is drilling through stalk tissue into the pupal chamber. This behavior has not been observed with parasites discussed here, but offers a pathway which is commonly used by larval parasites.

Adaptation of rearing techniques for laboratory culture of pupal parasites is simplified because most species physically contact the host. Some species will attack a naked pupa (*Trichospilus diatraea* Cherian & Margabandhu (Hymenoptera: Eulophidae)), while others may require the pupa to be immobilized. Small strips of corrugated paper or cardboard have functioned well in holding pupae for parasitization by *Pediobius furvus*. In other cases, pupae may need to be placed in natural or artificial chambers in plant stems in order to stimulate parasite attack. Such is the case with *Dentichasmius busseola*.

General Considerations for Rearing

Based on the foregoing discussions, some general considerations for rearing parasites of stalk boring lepidoptera can be suggested. These include the following:

1) Simplify the rearing situation to the extent possible. Removing the requirement for host plant material greatly simplifies most rearing applications and reduces labor requirements;

2) When initiating new parasite colonies, especially those with unknown biologies, consider the potential attack strategy or strategies that the parasite might employ, and attempt to provide those requisites in the laboratory. Obtain background information on the species (or genus) to assist in establishing rearing procedures. Initial information should be supplemented by close

observation of the parasites in the field and laboratory. Diversification of the approaches to rearing an unknown parasite increases the chances of success. Recreating the conditions under which the parasites function in the field is often the most difficult barrier which must be overcome in initiating new cultures;

3) Once cultures are established, attempt to increase the efficiency of rearing through substitution of methods, streamlining handling, and maximizing the use of host insects. The goal is to increase the numbers reared per unit of effort and/or time without sacrificing the quality of the parasites produced;

4) When altering rearing methods, evaluate modifications in pilot tests before adopting the change across the entire rearing operation. This minimizes the chances of colony failure or disruption; and

5) Maintain rearing records so that changes in parasite size, sex ratio, fecundity, development time, mortality, or longevity might be noted and corrected. Periodic infusion of new genetic stock into cultures will assist in the prevention of genetic deterioration of parasite colonies.

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MASS REARING THE GREENHOUSE WHITEFLY PARASITOID *ENCARSIA FORMOSA* FOR AUGMENTATIVE RELEASES IN FRESH MARKET TOMATOES IN HAWAII

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ABSTRACT A method of mass rearing the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) and associated parasitoid, *Encarsia formosa* Gahan in Hawaii is described using limited rearing facilities. Parasite cultures cycle on a weekly basis producing ca. 75,000 *E. formosa* parasitized whitefly pupae per week.

Studies were conducted to evaluate the effectiveness of augmentative releases of *E. formosa* in fresh market tomatoes grown in the greenhouse and field. Overall, significantly fewer whiteflies were found in the parasite release treatments as compared to an untreated control. Significantly greater numbers of whiteflies were found in methomyl treated plots than untreated controls or parasite release treatments in the field.

Greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), is one of several indirect pests of fresh market tomatoes grown in Hawaii (Tsuda 1988). Infestations are common in both field and greenhouse tomato plantings. Field-grown tomatoes are often inundated with dispersing adult whiteflies originating from neighboring crops (e.g., tomatoes, beans, cucumbers, eggplant) with large *T. vaporariorum* infestations. Five percent yield reductions in harvested fruit weight can occur at pest densities as low as 0.7 immature whiteflies per cm^2 tomato leaflet area (Johnson et al. 1991). Economically significant losses due to honeydew and sooty mold accumulation occur at pest densities greater than 10 immatures per cm^2 tomato leaflet area. Hawaii's growers report poor pesticidal control due most likely to high levels of pesticide resistance in whitefly populations. In addition, pesticides applied for whitefly control may destroy effective natural enemies of the agromyzid leafminers *Liriomyza sativae* Blanchard and *Liriomyza trifolii* (Burgess) resulting in secondary pest upsets (Johnson et al. 1980).

Several parasitoids in Hawaii use *T. vaporariorum* as a host. These include *Encarsia formosa* (Gahan), *Encarsia* (= *Prospaltella*) *transvena* (Timberlake), *and Eretmocerus* nr. *haldemani* Howard (Gerling 1983). Although natural enemies commonly parasitize immature *T. vaporariorum* on weeds surrounding vegetable plantings, control of pest populations in tomatoes is insufficient. This may be due to poor parasitoid dispersal or natural enemy destruction due to pesticide applications.

Successful biological control of the greenhouse whitefly by augmentative releases of *E. formosa* has been acheived on various vegetables grown in European glasshouses (van Lenteren et al. 1980). Many commercial insectaries mass produce and market *E. formosa* worldwide (Woets & van Lenteren 1983). Unfortunately, importation of insectary produced natural enemies into Hawaii is illegal without quarantine inspection and release from the Hawaii State Department of Agriculture. Given the difficulties of routinely inspecting large shipments of *E. formosa* parasitized whitefly pupae, this option is logistically impractical. The objectives of this study were to modify previously reported methods of mass rearing *E. formosa* for use in situations with limited rearing facilities and to evaluate the effectiveness of inundative releases of *E. formosa* for greenhouse whitefly control in fresh market tomatoes grown in greenhouse and field environments in Hawaii.

Materials and Methods

Cultures of *T. vaporariorum* and *E. formosa* were maintained in the rooftop facilities of Gilmore Hall, University of Hawaii at Manoa, Honolulu. Culture maintenance procedures reported by Scopes & Biggerstaff (1971) and Tsuda (1988) were modified for our logistical limitations and environmental conditions.

Host Plants. Tobacco, *Nicotiana tabacum* cv. burley, was used as a host plant for *T. vaporariorum* production. Insect-free tobacco plants were grown in an enclosed greenhouse. All plants necessary for culture maintenance were grown on one 1.2 m X 2 m bench. Seeds were germinated in vermiculite in a 10 cm dia. plastic pot. One cm tall seedlings were transplanted into a peat pearlite potting mix (Sunshine® Mix Blend #4) held in styrofoam speedling trays with 24 cells (5 cm X 5 cm). When plants were ca. 10 cm tall, they were potted in 20 cm dia. pots in the same potting mix. Gaviota® liquid fertilizer (19-19-19) was applied as a weekly soil drench to all plant stages. When plants were ca. 50 cm tall (8-10 leaves) they were exposed to adult whiteflies for oviposition.

Due to the lack of adequate greenhouse space, four outdoor cages were constructed to rear both the whitefly

and parasite (Fig. l). One cage (2.4 m X 1.2 m X 1.3 m) was required for whitefly oviposition. Another cage, identical in size, was used for holding whitefly-infested plants for development of whitefly immatures. Two cages (1.8 m X 1.2 m X 1.3 m) housed plants with developing and adult *E. formosa*.

Whitefly Rearing. To maintain the whitefly culture, tobacco plants were rotated through the whitefly oviposition cage which contained ca. 13,000 adult whiteflies per 1 m^3. Each week, two clean plants were introduced into the cage. Five pairs of plants were in the cage at all times. Adult whiteflies deposited eggs on leaf undersurfaces. Plants were rinsed with water weekly to remove accumulated honeydew thereby reducing sooty mold growth. Plant pairs remained in the cage for five weeks at which time they were cut at their base and hung from the cage ceiling. Cut foliage remained in the cage for one week to allow adult whiteflies to emerge.

Parasitoid rearing. Four insect-free tobacco plants were introduced weekly into the whitefly oviposition cage described above to provide host material for *E. formosa* rearing. Plants were exposed to ovipositing whiteflies for one week. Plants were gently shaken to remove as many of the adult whiteflies as possible and then placed into the whitefly holding cage for one week prior to exposure to adult *E. formosa* females. Alternating every week, plants with third and fourth instar whitefly nymphs were placed into one of the *E. formosa* cages containing high densities of adult parasitoids (ca. 28,000 adults per m^3). Plant meristems were removed to promote lower leaf expansion. Plants were held in the *E. formosa* cage ca. two weeks until parasitized whiteflies turned black. Afterwards, tobacco leaves with parasitized whitefly pupae were removed from plants and rinsed with water to remove the pupae. Pupae were collected in a screened container as described by Tsuda (1988) and afterwards air-dried and brushed into 237 ml plastic containers covered with organdy cloth. Pupae were held at 15°C for five days to delay development and emergence of adult *E. formosa* (Tsuda 1988). Afterwards, pupae were held at room temperature (22 ± 2°C) until adult parasites emerged (ca. three days) at which time they were used for *E. formosa* stock culture maintenance. The following week, the second *E. formosa* cage was set up in a similar fashion, so that cages were used alternately each week. *E. formosa* stock cultures were thus maintained.

Augmentation studies

Experiments were conducted on Oahu in tomato plantings in a commercial greenhouse facility at Unisyn Farm, Waimanalo, and an experimental field planting at the University of Hawaii Poamoho Experiment Station.

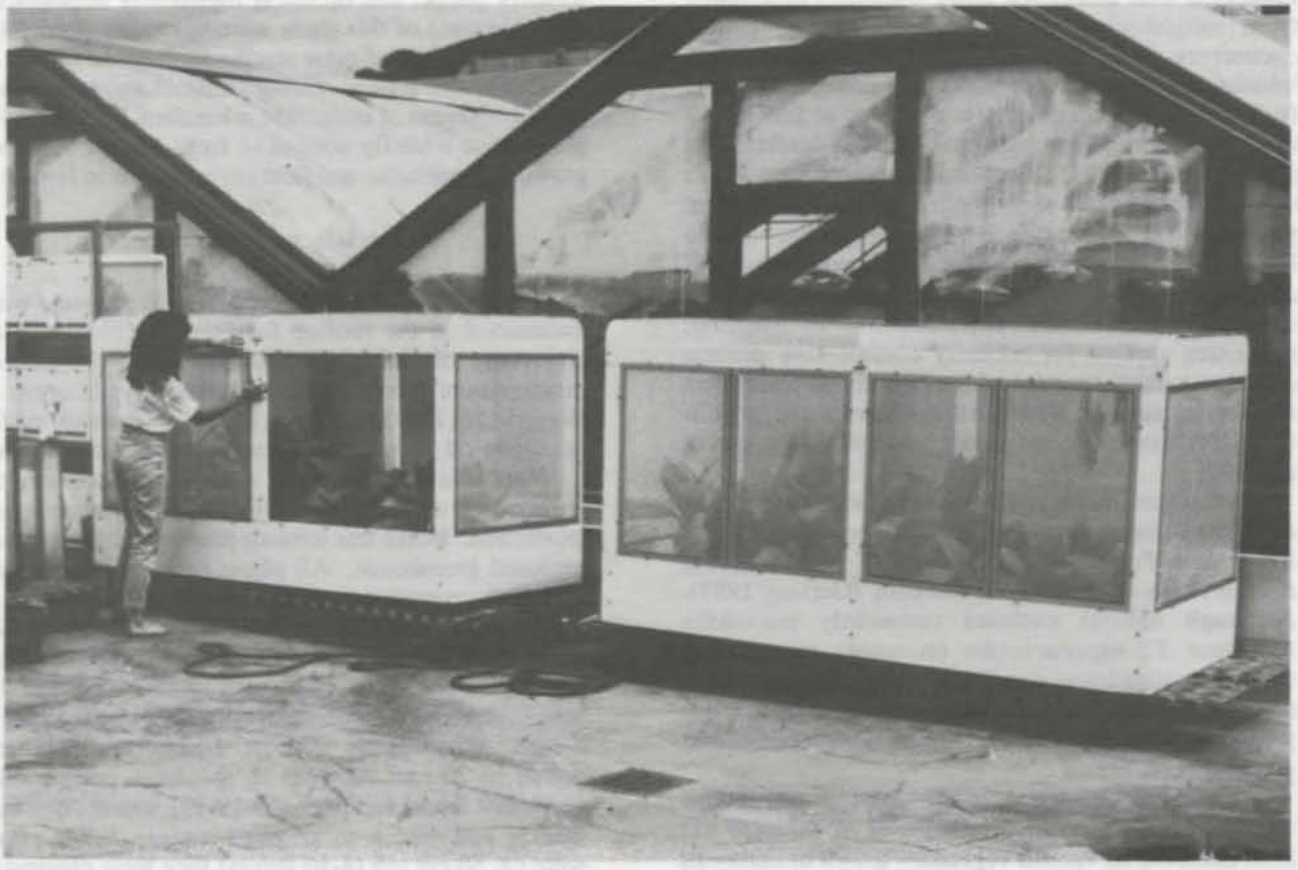

Fig. 1. Oviposition cage for greenhouse whitefly rearing.

Parasitoid Release Techniques. Parasitoid augmentation was conducted in a manner similar to that used in European greenhouses. Because *E. formosa* adults do not survive long without suitable host stages to parasitize, European researchers found better parasitoid establishment if low densities of third and fourth instar whitefly nymphs were present during parasitoid releases. Thus, plots were artificially infested with whitefly pupae. Upon emergence from pupae, whiteflies deposited eggs. Parasitoids were released when third and fourth instar whitefly stages were present.

Greenhouse studies. Whitefly control was evaluated by comparing a parasitoid release sector with a control sector. Studies were conducted in a 2,260 m^2 greenhouse unit of which ca. 1,130 m^2 were used on the north side of the facility. This area contained fifteen 14.1 m double rows of tomatoes. Thirty cm tall tomatoes were transplanted (ca. 110 plants/double row) into sawdust bags supplied with drip irrigation lines providing nutrient solution. Seven and six tomato rows were used as the experimental release and untreated check study plots, respectively. Release and check plots were separated by two tomato rows. Tomatoes were grown according to commercial practices except no pesticides were applied during the experiment. To provide acceptable whitefly stages, small plastic cups (30 ml) holding 12 whitefly pupae each were attached with clothespins to every 4th plant throughout the greenhouse release plot on 20 April 1988. Parasitized whitefly pupae were counted and placed into plastic cups and covered with organdy screened lids with a drop of honey to provide nourishment for emerged parasites. On 4, 11, 18, and 25 May and 1 June 1988, individual containers holding 40, 40, 50, 25, and 25 parasitized whitefly pupae, respectively, were attached to every fourth plant throughout the release plot. An average of 9 parasitoids/plant were released on each date. Total numbers of parasitized pupae introduced during the study were 34,650 pupae which equaled a rate of ca. 568,965 pupae/ha.

Plots were surveyed weekly for pest and natural enemies from 20 April to 6 June 1988. One hundred tomato leaflets were sampled from each treatment. From 20 April to 9 May, leaflets were randomly sampled from the total plant. After 9 May, 50 leaflets each were collected from the upper and lower halves of the plants. Numbers of unparasitized and parasitized stages of immature greenhouse whitefly per leaflet were recorded.

Field studies. Three treatments were conducted which consisted of weekly *E. formosa* releases, weekly applications of the broad spectrum pesticide methomyl (Lannate®), and an untreated control. Individual plots consisted of four tomato rows 6 m long with 2.3 m between rows. Treatments were replicated four times in a randomized complete block design. Tomatoes were transplanted on 29 August 1988. Tomatoes were grown according to commercial practices.

To insure the presence of parasitoid-acceptable whitefly immatures at the time of parasitoid release, five whitefly pupae per plant were distributed throughout the parasite release plots on 29 August. No whitefly pupae were placed into the untreated check plots nor the weekly methomyl treated plots. From 12 September to 17 October, 10 to 25 *E. formosa* parasitized whitefly pupae per plant were distributed weekly throughout the release plots. Total numbers of parasitized pupae introduced during the study were 40,000 pupae which equaled a rate of ca. 1,811,600 pupae/ha.

Plots were surveyed weekly for greenhouse whitefly and natural enemies from 12 September to 27 November 1988. Twenty tomato leaflets were sampled from each treatment plot. Leaves were taken to the laboratory and numbers of healthy whitefly immatures per 4 cm^2 of leaf area were recorded for each leaflet. Numbers of parasitized whiteflies were recorded per leaflet.

Results and Discussion

Parasitoid rearing. Using the described rearing methods, ca. 75,000 parasitized whitefly pupae were produced weekly. Production could be readily increased by increasing the number of host infested plants introduced into the parasite rearing cages. This rearing system can be modified for temperate regions by altering the culture cyles to compensate for differences in the duration of the life cycles of the host and parasite. All culture maintainence was performed within six hours on one day every week.

Augmentation studies

Greenhouse studies. On 20 April, a mean of 13.8 and 10.5 immature whiteflies per tomato leaflet were present in the release and check plots respectively, prior to the release of whitefly adults (Table 1). Between 20 April and 25 April, the grower removed whitefly-infested cucumber plants from the southern half of the greenhouse unit. This action resulted in the movement of large numbers of whitefly adults from the infested cucumbers into the tomatoes. This action in itself invalidated the parasitoid introduction strategy that we had initiated. Instead of having relatively low numbers of whiteflies early in the season, the whitefly densities were higher than permissable for the augmentation experiment to be a success. This was because the success of parasitoid augmentation was based on the ratios of parasitoids to whiteflies. Successful augmentation required that the parasitoid: whitefly ratio be high. In this case it was low. When the first parasitoid release was made on 2 May, immature whitefly densities were > 55 whiteflies/leaflet in each plot. *E. formosa* development required ca. 3 weeks before parasitized whitefly pupae were first detected in the release plots on 23 May in the lower strata. From 23 May to 6 June, parasitized whitefly pupal densities increased from 2.0 to 37.1 parasitized whiteflies/leaflet. Parasitized whiteflies appeared in the upper plant strata on 30 May and rose to 19.7 parasitized whiteflies on 6 June. No parasitized whiteflies were recorded in the check plots. This suggests that the parasitoid had poor dispersal which correlated with earlier

Table 1. Mean densities of healthy and parasitized immature whiteflies/leaflet recorded in *Encarsia formosa* augmentation studies conducted at Unisyn Farm, Waimanalo.

Survey Date 1988	Release Plot				Check Plot[b]	
	Lower Strata		Upper Strata		Lower Strata	Upper Strata
	WF	*E. formosa*	WF	*E. formosa*	WF	WF
20 April	13.8	0.0	—	0.0	10.5	—
25 April	22.8	0.0	—	0.0	14.3	—
2 May	64.1	0.0	—	0.0	57.7	—
9 May	83.0	0.0	48.3	0.0	119.2	68.5
16 May	107.5	0.0	150.1	0.0	159.7	153.1
23 May	19.9	2.0	476.7	0.0	99.2	486.8
30 May	57.5	16.6	695.5	0.2	134.7	819.7
6 June	590.0	37.1	907.7	19.7	249.9	1465.0

[a] *Encarsia formosa* release dates were 4, 11, 18 & 25 May and 1 June 1988.

[b] No parasitized whitefly pupae were found in the check plots.

field observations. Prior to 6 June, the grower became concerned with whitefly dispersal from the experimental plots to other vegetable plantings in the greenhouse facility. After 6 June, the grower destroyed the tomato plants in the experimental plots. This terminated the study at a time when the parasitoid numbers were reaching high numbers. It should be noted that on 23 May, whitefly densities in the lower strata of the plants in the release plot were 19.9 individuals/leaflet compared with 99.2 individuals/leaflet in the check plots. Perhaps if the release plot and check plots could have been isolated from each other, even more dramatic reductions in the whitefly population could have occurred in the release plot.

Although complete biological control of the greenhouse whitefly was not achieved in the greenhouse study, results were encouraging. Data showed that 1) *E. formosa* survived under greenhouse conditions in Hawaii; 2) *E. formosa* rapidly reached high densities in relatively short time; and 3) if parasitoid augmentation is to be successful, a major problem facing researchers and growers is the dispersal of large numbers of whiteflies from one planting to another.

Field Studies. Through the survey period, mean immature whitefly densities remained below 0.7 and 3.0 individuals per 4 cm^2 tomato leaflet area in the parasite release and untreated check plots, respectively. These densities equal ca. 8.8 and 37.5 individuals per leaflet. Overall, significantly fewer ($P < 0.05$) immature whiteflies were found in the release plots compared with the untreated check plots. Densities in the methomyl (Lannate®) treated plots peaked at a level higher than 13 immature whiteflies per 4 cm^2 (ca. 162 immature whiteflies per leaflet) which was greater than the threshold for 5 percent yield loss (ca. 3 immature whiteflies per 4 cm^2 leaflet area). Significantly greater ($P < 0.05$) densities of whiteflies were found in the methomyl treated plots as compared with the release and check plots. *E. formosa* parasitized whitefly pupae were commonly found in the release plots after 31 October with densities peaking (0.35 parasitized pupae/4 cm^2 leaflet area) on 27 November. No parasitized whiteflies were recorded in the untreated control plots until the last two survey dates. Parasitized whiteflies were found in the weekly methomyl treated plots only on 20 November, when the mean parasitized whitefly density was 0.01 individuals per 4 cm^2 tomato leaflet area. Reasons for high whitefly numbers in the weekly pesticide treated plots were unclear. Predatory insects (e.g., syrphid larvae, coccinellids) which feed on whitefly immmatures may be decimated by pesticide sprays but difficulties in monitoring these populations prevent validation of this theory in the present study. Pesticide residues may stimulate reproduction of the whitefly, but this idea is purely conjecture at this time. However, it is definite that methomyl sprays growers currently use for lepidopterous pest control are probably aggravating the whitefly problem.

Summary

Further research is necessary to determine the usefulness of *E. formosa* releases for greenhouse whitefly control in greenhouse and field plantings of tomatoes in Hawaii. Initial results suggest that the potential is high for managing *T. vaporariorum* using this technique. However, several factors must be considered before this technique can be implemented commercially. These factors include parasitoid rearing costs and the numbers needed for successful whitefly control, the importance of mass movements of dispersing adult greenhouse whitefly in perpetuating injurious whitefly infestings among neighboring fields, and the necessity of lepidopterous suppression techniques compatible with augmentative releases of *E. formosa*.

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INVESTING IN BIOLOGICAL CONTROL: INITIATION OF A PARASITE MASS REARING PROGRAM FOR MACADAMIA NUT ORCHARDS IN HAWAII

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ABSTRACT Southern green stink bug (SGSB), *Nezara viridula* (L.), feeding damage on macadamia nuts causes discolored spotting and pitting on nut kernels. This damage results in downgrading of nuts and increased processing costs. A scelionid egg parasite of the SGSB, *Trissolcus basalis* (Wollaston), was successfully released in Hawaii in 1963 as a classical biological agent, and has since been released periodically.

Excessive SGSB damage has been recorded on macadamia nuts during the past three years. In 1988, an insectary was established by Mauna Loa Macadamia Nut Corporation to mass rear and release *T. basalis*. Because mass rearing techniques had been established previously, the emphasis of the insectary has been to modify rearing techniques to increase parasite production for augmentative releases. Efforts to expand parasite production have resulted in problems with host cannibalism, temperature and humidity control, and labor limitations.

A parasite mass rearing project was started in October 1988 with the objective of reducing damage by the Southern green stink bug (SGSB), *Nezara viridula* (L.), through parasitoid augmentation in macadamia nut orchards. The following discussion will include a brief description of the macadamia nut industry in Hawaii, the rationale behind starting this project, an overview of the rearing procedures and problems, and finally a summary of the monetary costs of the project.

Industry Description

Macadamia nut orchards in the state of Hawaii encompass 21,900 acres of which 16,600 were bearing nuts in 1988. Among the diversified agricultural commodities in Hawaii, that is all agricultural commodities except sugar and pineapple, macadamia was second in value behind the flower and nursery industry in 1987 (Hawaii Agricultural Statistics Service 1988). Forty seven million pounds of kernels were produced in the 1988 - 89 season, and had an estimated farm value of $43,240,000. Growers expected to receive a record 92 cents/lb dry kernel (prior to roast) in 1989, which was indicative of the growing demand and value of this crop.

Project Rationale

Historically the macadamia nut industry in Hawaii has been fortunate to have few insect pest problems requiring control measures. Of the insect damage that does occur, the SGSB was projected to cause the most damage in the 1988-89 season with 0.5 million pounds of rejected nuts (Hawaii Macadamia Nut Association 1989). Feeding by the SGSB causes discolored pits and spots on the kernel, which results in losses from 1) increased processing costs by slowing down the production line in order to segregate SGSB damaged nuts; 2) downgrading due to direct kernel damage described above or from the introduction of contaminants leading to unusable nuts; and, 3) possibly increasing premature drop of nutlets. Mitchell et al. (1965) reported SGSB feeding does not cause premature drop. However unpublished data indicated that nutlets dropped prior to the normal premature nut drop had a high percentage of SGSB feeding damage. Thus, further study is necessary to assess premature nut loss throughout the entire season.

In 1986, SGSB damage increased dramatically over previous years in an orchard on the island of Maui. Damage continued to increase the following season and an insecticide (malathion) was applied to the entire orchard. In spite of this treatment damage was still unacceptably high. In addition, cultural control methods (e.g., trap cropping with weed hosts) were also tried, but again damage levels were unacceptable. At that time, the Hawaii Department of Agriculture (HDOA) was releasing a scelionid egg parasitoid of the SGSB, *Trissolcus basalis* (Wollaston). However relatively low numbers of parasitoids were released, and not necessarily in macadamia orchards that had SGSB problems. Only 9,000 parasites were released in the Maui orchard during the 1987 - 88 season.

It was projected that SGSB damage could potentially amount to $400,000 or more in increased processing costs if damage increased just one half of one percent. Hence, in an effort to find a long term solution, the decision was made to invest in a biological control program for the following reasons:

1) A record of success in using *T. basalis* to control SGSB (Debach 1974);

2) High potential feasibility of a mass rearing program based on previous HDOA programs; and

3) Potential for success as a long term management solution, unlike continued insecticide applications.

Rearing Procedures

To establish and/or augment the *T. basalis* populations in orchards with high SGSB damage, a mass rearing program was initiated with the completion of an insectary in October 1988. Since the parasitization of eggs within the clustered SGSB eggs may average over 90 percent, the limiting factor in *T. basalis* production is the availability of SGSB eggs. Consequently emphasis is placed on rearing stink bugs to provide host material. Rearing procedures currently being used for both the SGSB and *T. basalis* are modifications of techniques used by the HDOA, Hilo, Hawaii, and Dr. Ronald F. L. Mau, University of Hawaii at Manoa.

SGSB egg clusters are obtained by cutting them from lengths of paper towels suspended in cages (76.2 cm L x 48.3 cm W x 55.9 cm H). Clusters to be used for the colony are placed in 236.6 ml covered plastic containers. The eggs become red as they approach eclosion, which occurs 4-5 days after oviposition. A day prior to, or when the first eggs hatch, seed pods of the fuzzy rattle pod plant, *Crotalaria incana* L., or the smooth rattle pod, *C. mucronata* Desv. are placed in the containers to increase humidity and to provide a substrate the first instar nymphs can congregate on.

Five days after eclosion the majority of the first instars have become second instars, and the containers are placed into plastic storage boxes (40.6 cm L x 27.9 cm W x 15.2 cm H) filled with wild host plants, usually rattle pod or indigo, *Indigofera suffruticosa* Mill. This allows the nymphs to move from the small container to the boxes with minimal handling. The nymphs remain in the boxes for a total of three weeks. Upon reaching the third and fourth instars, the diet is switched from wild host plants to green beans and raw peanuts. Because beans are bought from the market, they are carefully washed to remove possible insecticide residues. Wild host plants are not used exclusively because they do not remain as succulent as the beans, especially in the presence of the more voracious fourth and fifth instars. By the end of the third week in the boxes, some stink bugs have developed into fifth instar nymphs and even a few adults. At this time the stink bugs are placed into large cages.

Peak egg production occurs on the third week after nymphs were transferred to the large cages. Thus, it takes a total of 7 weeks before peak egg production is reached at maximum and minimum temperatures of 29.4 and 23.3°C, respectively. Egg clusters are removed daily and are attached to a piece of cardboard to facilitate handling.

Egg clusters are exposed to *T. basalis* for 2 days in 3.78 liter glass jars. After exposure, parasitized eggs are held in covered plastic containers. Time required from egg to oviposition is 14 days. This period is comprised of 12 days from egg to adult emergence, and 1 day preoviposition. Because the parasitoids are shipped to other orchards, the parasitized eggs are refrigerated (4.4°C) from 1 to 5 days to synchronize parasitoid emergence. Just prior to emergence, honey is streaked on the cover to provide a food source for the adult parasitoids. Ganesalingam (1966) reported that food is not required for oviposition, however adult longevity was shortened and less female progeny were produced by unfed *T. basalis*. Parasitoids are held in the container until the majority of them have emerged. Subsequently they are released on a weekly basis in weed borders or other areas SGSB may inhabit.

Ganesalingam (1966) reported that most of the oviposition by *T. basalis* occurs from the second to sixth days after adult emergence with peak oviposition on the second day. He also determined adult longevity to be 22 - 38 days for females under lab conditions (20.6 - 26.1°C, 62 - 55% RH), and the female to male ratio was 5.5:1.0. Superparasitism also occurs with one surviving parasitoid.

Production of 50,000 to 100,000 *T. basalis* parasitoids per month was set as a tentative goal. At the height of the HDOA parasite release project against the stink bug in 1963, an average of 64,000 parasites was released per month (Davis 1964).

Problems

In expanding the production of *T. basalis*, several problems have arisen. The most prevalent problems have been temperature and humidity control, mold, cannibalism, and labor.

Because SGSB is not raised in environmental chambers, it has been a constant challenge to maintain optimal conditions for fast development. Attempts were made to maintain temperatures at 26.7°C, and relative humidities above 55 percent. Temperatures are maintained by placing heating pads under the storage boxes that contain nymphs. This provides direct heat in the locality of the bugs, and humidities remain close to 80% by leaving the boxes partly covered.

In the large cages, humidities decrease below 50%, and temperatures range from 22 - 30°C. To help maintain temperatures, heating pads again have been installed, and air bubble packing is placed over the cages at night to conserve heat. Also ceiling fans are run at night to prevent cold air layers from settling around the cages. Obviously these measures are only applicable during the cooler months. Humidity control has not been achieved in the cages.

While warm, moist conditions are favorable for stink bug development, mold and fungus have become prevalent on the food. Currently beans and peanuts are rinsed with a 2 percent bleach solution, and are changed twice and once a week, respectively. By using larger containers, the nymphs can move away from pockets of

mold, thereby allowing time for the removal of moldy food before the bugs become entangled.

Egg cannibalism by the stink bugs has caused a loss of host substrate for the parasitoids. Davis (1964) stated that oviposition occurs mainly in the early morning. Thus to minimize cannibalism, egg clusters are collected in the morning everyday. More food is also provided to prevent starvation driven cannibalism.

Finally, the lack of personnel may prove to be a problem as parasitoid production increases. The obvious answer would be to hire more help, but assuming that is not an option, reducing the manual workload has been a high priority. Generally, reduction in the handling of the bugs is attempted by keeping transfers to a minimum. Before using the plastic storage containers, glass gallon jars were used in rearing the stink bug nymphs, but these were too small, and difficult to access. Other time saving steps are always being evaluated, such as the use of micro-scissors to facilitate the collection of egg clusters. Because labor costs are the largest operating expense, any labor saving technique is examined.

Production Costs

A rough estimate of the cost to start up the mass rearing program would be between $75,000 and $100,000. If costs are divided into capital and operating expenses, 66% of capital expenses would go to the construction of the building. With respect to operating expenses, 71 percent goes to labor, and another 11 percent goes toward the depreciation of the building and equipment (Table 1). While start up costs are high, recall that cost savings of $400,000 may be realized if the SGSB damage is reduced by a half of one percent. Furthermore, costs should decrease as modifications to rearing methods increase efficiency.

Table 1. Percentages of costs to initiate a parasite mass rearing program against the Southern green stink bug.

Type of Expense	Item	Percent of Total Costs
Capital	Building	66
	Equipment & Furnishings	19
	Vehicle	15
	TOTAL	100
Operating	Labor	71
	Maintenance & Services	9
	Supplies	9
	Depreciation	11
	TOTAL	100

Conclusions

The decision by Mauna Loa Macadamia Nut Corporation to invest in a parasite mass rearing program against the SGSB may be attributed to the following reasons:

1) Development and research costs would be minimal since the basic rearing procedure was established and easy;

2) *T. basalis* had already been used successfully, and so in essence the risk was small;

3) A solution through the use of a biological control agent would fulfill the goal of developing a long term solution; and

4) Lastly, the potential cost savings could easily cover expenditures.

While the reasons may seem mercenary, it is a welcome change to know that a non-chemical control method has been implemented amidst the monetary considerations, and the desire for immediate action and results.

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GUIDELINES FOR THE INTRODUCTION OF BIOLOGICAL CONTROL ORGANISMS INTO THE SOUTH PACIFIC

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ABSTRACT In recent years interest in the use of biological control for insect pests and weeds has increased in the countries of the South Pacific. This method is particularly appropriate because most of the countries are small, have limited fauna, and most of the serious pests and weeds were introduced without the biological control agents that suppress them in their countries of origin. When host specificity of a biological control agent is established, introduction efforts may begin. It is then essential that no other organisms are unknowingly released simultaneously with the desired organism. Hence, the agent to be introduced should be bred for at least one generation under quarantine in the importing country to ensure that the culture is free of all unwanted organisms. Unfortunately, many countries of the South Pacific do not have adequate quarantine facilities or suitably qualified staff to carry out this breeding.

In order that management programmes based on biological control can be safely implemented in the South Pacific, a series of guidelines has been developed by the senior author in conjunction with the South Pacific Commission Plant Protection Service. These guidelines are presented for discussion.

The island countries of the South Pacific are small and have a limited fauna and flora. Many of the pest and weed problems are caused by non-indigenous organisms which have arrived either from neighbouring countries or outside the region. Biological control is a very useful technique for bringing these pests and weeds under control and the method has been in use in the region since early this century (Cock 1986, Rao et al 1971, Wilson 1960, Young 1982).

Recently there has been increased interest in biological control in the region. In 1985, a workshop on biological control in the South Pacific was held in Tonga, under the sponsorship of the Australian Centre for International Agricultural Research (ACIAR) and the German Agency for Technical Cooperation (GTZ), and this led to the publication of a series of dossiers on individual pests and weeds under the title Biological Control: Pacific Prospects (Waterhouse & Norris 1987). Many organizations and programmes are now involved with assisting South Pacific island countries with biological control efforts; they include ACIAR; GTZ; Commonwealth Scientific and Industrial Research Organization (CSIRO); Agricultural Development in the American Pacific (ADAP); Department of Scientific and Industrial Research (DSIR); South Pacific Commission (SPC); and the University of Guam. The South Pacific Commission's Plant Protection Service (SPC-PPS) has recently increased in size to include, amongst others, a Biocontrol Officer.

To assist South Pacific Countries with introductions for biological control, a series of guidelines has been developed by the senior author in conjunction with SPC-PPS. They have been published in a recent supplement to Biological Control: Pacific Prospects (Waterhouse & Norris 1989).

These guidelines cover the practical details of making an introduction safely and of minimizing the risk of introducing other organisms with the biocontrol agent. They take into account the fact that many countries in the South Pacific do not have qualified entomologists or adequate quarantine facilities.

Guidelines

Before a biological control agent is introduced into a country it is necessary to ensure that it will only attack the desired target pests and weeds. This is established by host specificifity testing which, for the South Pacific countries, is usually carried out by an outside agency. If these tests give acceptable results it is essential to ensure that no other organisms are introduced with the agent. It is suggested that the following guidelines be followed:

1) Apart from exceptional cases, the organism should be bred through one or more (<10) generations under secure quarantine in the importing country before release. This will allow confirmation of the identity of the imported species and the elimination of any undesirable fellow travellers, such as parasites, hyperparasites or pathogenic organisms.

2) If there are no secure quarantine facilities or trained staff to conduct a breeding programme it is permissible to accept stocks bred for one or more generations **in secure quarantine** in another

country. Under these conditions, after presumed 'clean' material has arrived in the importing country, it is desirable for each individual living biological control agent to be placed in a small container (a gelatin capsule or small tube) for careful examination under a microscope before being cleared for release. The transfer to a capsule or tube should be carried out in a sleeved cage to prevent escape of living material that has emerged from the imported material. When eggs are imported they should be held until they have hatched. Imported larvae or pupae should be bred through to adults. These activities should be carried out under such conditions that emerging parasites can be retained until they can be destroyed. Any diseased individuals should be preserved for later examination and, if there are many, the advice of an insect pathologist should be sought before any material is liberated. In certain cases great care must be taken not to introduce serious fungal infections (e.g., coffee rust or leucaena fungus) as unintended contaminants of biological control agents.

3) If any fellow travellers are detected, a careful review of the situation should be made by the importing authority before permitting the release of *any* material in the field, even after individual examination. Either the entire consignment should be destroyed or the species should be cultured for a generation in the laboratory under the most secure conditions available, examining each individual from this culture separately before field release, to make sure it is healthy and of the intended species.

4) Voucher specimens of the biological control agent(s), and of any other organisms in the shipment, should be killed and pinned or preserved in alcohol, fully labelled and stored in-country. It would be highly desirable to lodge voucher specimens for safe-keeping with the Entomology Division, DSIR, Private Bag, Auckland, New Zealand which, for some years, has been building up a major reference collection of insects of importance in the southwest Pacific.

5) Except for healthy specimens of the desirable species all other imported material should be destroyed by (i) placing in a deep freeze overnight and later burning; (ii) immersing in alcohol or formalin or (iii) autoclaving.

6) It is extremely hazardous to make field collections of parasites or predators of a given pest, or of herbivorous insects attacking weeds, in one Pacific country and, without further processing as above, hand carry or dispatch these to another Pacific country for liberation in the field. If, in spite of this strong discouragement, this procedure is proposed, skilled advice should be sought in each instance about how to minimize the risks involved. The procedures outlined above *must* be followed to make sure serious mistakes do not occur.

7) If the foregoing conditions cannot be met, then the importing country should seek assistance from outside agencies in the region that have appropriate facilities and experienced personnel (e.g., Division of Entomology of the Commonwealth Scientific and Industrial Research Organisation, Australia; Entomology Division, Department of Scientific and Industrial Research, New Zealand; Hawaii Department of Agriculture; or Plant Protection Service of the South Pacific Commission).

8) Prior written approval (letter or import permit) *must* always be obtained from the relevant authority of a country before introducing a living organism intended for biological control. This authorization will often specify the conditions under which an introduction can be made. In some countries two authorizations are required, one to introduce into quarantine and the other to permit releases.

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BIOLOGICAL CONTROL POTENTIAL OF ENTOMOPATHOGENIC NEMATODES AGAINST INSECT PESTS IN THE PACIFIC

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ABSTRACT The susceptibility of certain tropical insect species to All strain and Mexican strain of the entomopathogenic nematode, *Steinernema carpocapsae* (Weiser) (previously know as *S. feltiae* Filipjev, and *Neoaplectana carpocapsae* Weiser) was tested under laboratory conditions. Larvae of the green garden looper, *Chrysodeixis chalcites* (Esper), and adults of sweetpotato weevil, *Cylas formicarius elegantulus* (Summers), and third instar larvae of the agromyzid leafminer, *Liriomyza trifolii* (Burgess) were susceptible to the nematode with >80 percent mortality. Results indicated that the nematode will also infect larvae of *L. trifolii* parasitized by the larval-pupal parasitoid, *Ganaspidium utilis* Beardsley. Third stage larvae of the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), were not as susceptible to the nematode with 53 percent mortality. An endemic Hawaiian pomace fly, *Drosophila grimshawi* Oldenberg, adults of the banana root borer, *Cosmopolites sordidus* (Germar), and Chinese rose beetle, *Adoretus sinicus* Burmeister, showed low susceptibility to the nematode with no dosage-mortality response. This study demonstrated the biological control potential of entomopathogenic nematodes against certain tropical insect species such as sweetpotato weevils and the agromyzid leafminers.

The entomopathogenic nematode, *Steinernema carpocapsae* (Weiser) (previously know as *S. feltiae* Filipjev, and *Neoaplectana carpocapsae* Weiser) has enormous potential as a biological control agent of insect pests in the Pacific Basin. It possesses a wide host range, including hundreds of insect pest species (Poinar 1979, Gaugler 1981, 1987, Kaya 1985, 1987) and has high virulence. Most biological control agents have a slow debilitating action while this nematode species and its associated bacterium kill their hosts in 24 - 48 hours.

Few studies have been conducted on the biological control potential of *S. carpocapsae* in the Pacific Basin. Lindegren & Vail (1986) determined the susceptibility of third instar larvae of Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), melon fly, *Dacus cucurbitae* Coquillett, and oriental fruit fly, *D. dorsalis* Hendel, to *S. carpocapsae*. They concluded that medfly larvae were significantly more susceptible to *S. carpocapsae* than melon and oriental fruit fly and suggested field applications were feasible for medfly control only. Because of the wide host range of *S. carpocapsae*, the susceptibility of other tropical pest species and non-target organisms, such as endemic insects and parasitoids, should be known prior to field applications of *S. carpocapsae*.

This study was designed to test the susceptibility of various tropical pest species as well as a leafminer parasitoid, *Ganaspidium utilis* Beardsley, and an endemic Hawaiian species, *Drosophila grimshawi* Oldenberg, to *S. carpocapsae* under laboratory conditions.

Materials and Methods

Adults of the Chinese rose beetle, *Adoretus sinicus* Burmeister; banana root borer, *Cosmopolites sordidus* (Germar); and sweetpotato weevil, *Cylas formicarius elegantulus* (Summers), were field collected and placed individually in 60 X 15 mm plastic petri dishes prepared with filter paper (55 mm dia., Whatmann® No. 1) saturated with 0.5 ml of sterile distilled water which contained either 0, 2, 20, 50, 200, 500 or 5000 infective juveniles (All or Mexican strain). Petri dishes were placed in a plastic bag to prevent desiccation and incubated at 23°C. Insects were dissected 7 days after treatment and examined for the presence of nematodes.

Green garden looper, *Chrysodeixis chalcites* (Esper), was laboratory reared on a commercially prepared medium (F9000, Bio-Serv Inc., Frenchtown, N.J.) and sixth instar larvae tested against *S. carpocapsae* using the procedure described above.

Zucchini leaves containing *Liriomyza trifolii* (Burgess) larvae were collected from a unsprayed field in Mt. View, Hawaii. Leaves were punched into 15 mm dia. leaf discs each containing one third instar larva in a leafmine. Ten infested leaf discs were placed in a 100 X 15 mm plastic petri dish in which 0, 1000 or 10,000 infective juveniles (Mexican strain) in 1.0 ml of sterile distilled water had been pipetted onto a 90 mm dia. filter paper (Whatman No. 1). Petri dishes were placed in a plastic bag to prevent desiccation and incubated at 23°C. Dead larvae in mines and dead pupae were dissected seven days after treatment and examined for the presence of nematodes. Remaining live pupae were held until adult leafminer or parasitoid emergence.

An endemic Hawaiian pomace fly, *Drosophila grimshawi* was laboratory reared on artificial medium (Wheeler & Clayton 1965) and the medfly was reared on artificial medium developed by Tanaka et al. (1970). Plastic cups (30 cc) containing 25 g of beach sand and standard pupation medium for Hawaiian *Drosophila* (sieved through 12 mesh per inch) were inoculated with 0, 25, 250, 2,500 or 25,000 infective juveniles (Mexican strain) in 3.5 ml of sterile distilled water. After 12–24 hours, five third instar larvae of *D. grimshawi* or *C. capitata* were placed in each cup covered with a plastic lid. Cups were held at 20°C and dead larvae or pupae dissected 14 days after treatment and live pupae held for adult emergence. Larvae of the greater wax moth, *Galleria mellonella* L., highly susceptible to the nematode, served as a treated control. Greater wax moth were reared on artificial medium (*Galleria* Medium 1, Woodring & Kaya 1988).

At least three separate trials were conducted with a minimum of 10 insects per treatment per trial for all tests. Arcsin transformation was performed on data before analysis.

Results and Discussion

This study demonstrated that larvae of the green garden looper and adults of sweetpotato weevil were highly susceptible to the nematode (Tables 1, 2). Sweetpotato weevils showed higher susceptibility to the All strain than the Mexican strain of *S. carpocapsae*. Chinese rose beetle and banana root borer showed low susceptibility to the All strain of *S. carpocapsae* with no dosage-mortality response (Tables 1, 2).

Table 1. Susceptibility of the *Adoretus sinicus* and *Chrysodeixis chalcites* to the All strain of the nematode *Steinernema carpocapsae*.

Dosage	Percent Dead[a]		Percent	Dead
No. nemas per insect	with nematodes	without nematodes	Alive	per 30 insects
	A. sinicus			
0	0.0 ± 0.0	22.4 ± 0.7	77.6	7
200	1.2 ± 1.2	6.7 ± 1.9	92.1	4
	C. chalcites			
0	0.0 ± 0.0	0.0 ± 0.0	100.0	0
200	100.0 ± 0.0	0.0 ± 0.0	0.0	30

[a] Mean ± SE.

The third instar *L. trifolii* larvae were susceptible to the nematode with >82 percent mortality at 1000 infective juveniles per larvae (Table 3). The control treatment showed that >65 percent of the leafminers were parasitized by the larval-pupal parasitoid *Ganaspidium utilis*, and may indicate that the nematode will also infect parasitized larvae of *L. trifolii*. However, combined mortalities due to *G. utilis* (11.3 percent) and *S. carpocapsae* (82.7 percent) resulted in 94.0 percent mortality of *L. trifolii*, a higher mortality than caused by the parasitoid alone.

Table 2. Susceptibility of *Cylas formicarius elegantulus* and *Cosmopolites sordidus* to the Mexican and/or All strain of the nematode *Steinernema carpocapsae*.

Strain	Dosage No. nemas per insect	Percent Dead[a] with nematodes	Percent Dead[a] without nematodes	Percent Alive	No. Dead
		C. f. elegantulus			
Mexican	0	0.0 ± 0.0	0.6 ± 0.6	99.4	0
	2	0.0 ± 0.0	2.2 ± 0.6	97.8	2
	20	24.9 ± 0.1	0.0 ± 0.0	75.1	15
	200	55.1 ± 1.1	0.6 ± 0.6	44.3	33
		C. f. elegantulus			
All	0	0.0 ± 0.0	0.0 ± 0.0	100.0	0
	20	6.5 ± 0.1	1.1 ± 1.1	92.4	6
	20	35.6 ± 2.0	1.1 ± 1.1	63.3	24
	200	83.5 ± 1.4	0.0 ± 0.0	16.5	49
		C. sordidus			
All	0	0.0 ± 0.0	0.6 ± 0.6	99.4	1
	50	4.5 ± 1.1	0.0 ± 0.0	95.5	2
	500	0.6 ± 0.6	0.0 ± 0.0	99.4	1
	5000	3.5 ± 0.9	3.5 ± 0.9	93.0	4

[a] Mean ± SE.

[b] Numbers dead per 60 sweetpotato weevils and per 38 banana root borers.

Greater wax moth larvae were highly susceptible to the All strain of the nematode in sand as compared to *C. capitata* and *D. grimshawi* (Table 4). *D. grimshawi* was less susceptible to the nematode than *C. capitata*. No dosage-mortality response was obtained with *D. grimshawi* with 22–33 percent of the dead larvae with no nematodes present. Further investigations are needed to clarify death without nematodes. The nematodes may have entered the host, released its associated bacterium which eventually killed the host, and were encapsulated by the host larva and unable to develop. In laboratory tests, Lindegren & Vail (1986) reported that at 3,640 nematodes per larva, *C. capitata* had 90 percent mortality, while in this study, at 5,000 nematodes per larva, *C. capitata* had only 53 percent mortality. Difference in dosage-mortality response may have been due to Lindegren & Vail (1986) using vermiculite, while this study used sand as the pupation medium. Differences in moisture and nematode searching abilities in vermiculite or sand probably affected nematode infection rate.

Field tests with *S. carpocapsae* have clearly established that appropriate choice of target habitat and insect pest are essential for their effective use. The most encouraging trials have been conducted against insects in cryptic habitats and soil, where the nematodes are

Table 3. Susceptibility of an agromyzid leafminer, *Liriomyza trifolii* and a larval-pupal parasitoid, *Ganaspidium utilis* to Mexican strain of *Steinernema carpocapsae*.

No. *Liriomyza* larvae exposed	Dosage No. nematodes per larvae	Mean percent dead[a] with nematodes	Mean percent dead[a] without nematodes	Mean percent emergent adults *L. trifolii*	Mean percent emergent adults *G. utilis*	Dead Pupae No.	Dead Pupae Mean percent
150	0	0.0 ± 0.0	1.0 ± 1.0	17.3	67.3	4	12.7
150	100	40.6 ± 0.1	5.0 ± 0.2	8.0	37.3	69	8.7
150	1000	82.7 ± 0.1	0.2 ± 0.2	1.3	11.3	125	4.0

[a] Mean ± SE.

protected from environmental extremes (Gaugler 1981). Based on this study, *S. carpocapsae* is most promising against sweetpotato weevils and agromyzid leafminers (Table 5). These insects were susceptible to the nematode and occupy cryptic habitats. Sweetpotato weevil adults occur in the soil on sweet potato and agromyzid leafminer larvae occur within leafmines, both in cryptic habitats. In addition, sweetpotato weevil larvae and pupae occur within sweet potatoes and stems, and *L. trifolii* pupates in the soil. These are habitats favorable for nematode survival and infectivity. Although the green garden looper was highly susceptible to the nematode, field use is not promising because it feeds and pupates openly on the foliage and does not occupy a cryptic habitat.

Table 4. Susceptibility of larvae of *Drosophila grimshawi*, *Ceratitis capitata* and *Galleria mellonella* to the Mexican strain of *Steinernema carpocapsae*.

Insect Species	n	Dosage No. nematodes per insect	Percent Dead[a] with w/nematodes	Percent Dead[a] without w/o nematodes	Percent Alive	No. Dead
D. grimshawi	45	0	0.0 ± 0.0	1.5 ± 1.5	98.5	2
	45	5	0.0 ± 0.0	24.6 ± 2.0	75.4	12
	45	50	4.1 ± 4.1	26.2 ± 0.5	69.7	17
	45	500	5.7 ± 1.8	32.9 ± 0.5	61.4	19
	45	5000	7.6 ± 2.0	22.2 ± 0.3	70.2	15
C. capitata	75	0	0.0 ± 0.0	0.0 ± 0.0	100.0	0
	75	5	2.6 ± 0.7	1.8 ± 0.4	95.6	4
	75	50	8.7 ± 0.4	0.4 ± 0.4	90.9	8
	75	500	8.9 ± 0.3	4.5 ± 1.2	86.6	12
	75	5000	53.7 ± 1.5	4.0 ± 0.4	45.9	41
G. mellonella	30	0	0.0 ± 0.0	0.0 ± 0.0	100.0	0
	30	5	6.7 ± 1.9	4.5 ± 1.1	88.8	5
	30	50	100.0 ± 0.0	0.0 ± 0.0	0.0	30
	30	500	100.0 ± 0.0	0.0 ± 0.0	0.0	30
	30	5000	100.0 ± 0.0	0.0 ± 0.0	0.0	30

[a] Mean ± SE.

Table 5. Relative susceptibility of tested insect species to *Steinernema carpocapsae* in Hawaii.

Common name	Species name	Stage	Susceptibility
Sweetpotato weevil	*Cylas formicarius elegantulus*	adult	high
Green garden looper	*Chrysodeixis chalcites*	sixth instar	high
Agromyzid leafminer	*Liriomyza trifolii*	third instar	moderate
Mediterranean fruitfly	*Ceratitis capitata*	third instar	low to moderate
Hawaiian *Drosophila*	*Drosophila grimshawi*	third instar	low
Chinese rose beetle	*Adoretus sinicus*	adult	low
Banana root borer	*Cosmopolites sordidus* (Germar)	adult	low

The potential of entomopathogenic nematodes as biological control agents against tropical insect pests shows considerable promise because: 1) various pest species are highly susceptible to the nematode; 2) the combined mortality by parasitoids and nematodes results in a higher mortality of the pest insect than parasitoid alone; 3) certain non-target organisms such as *D. grimshawi* will not be adversely affected by the nematode; and 4) environmental conditions in the Pacific Basin are optimal for these nematodes.

Further laboratory tests are needed with other *S. carpocapsae* strains and entomopathogenic nematode species to identify the most efficacious nematode for a target pest. Once the most efficacious nematode is identified, greenhouse and field tests should be conducted.

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APPLICATION OF A NEW STRAIN OF *METARHIZIUM ANISOPLIAE* (FUNGI IMPERFECTI) AS A MEANS OF BIOLOGICAL CONTROL AGAINST THE COCONUT LEAF HISPID, *BRONTISPA LONGISSIMA* (COLEOPTERA: HISPIDAE) IN SAMOA

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ABSTRACT *Brontispa longissima* (Gestro), coconut leaf hispid (CLH), is a serious pest of coconut palm, an important staple crop in Samoa. In 1980, a naturally occurring strain of *Metarhizium anisopliae* var. *anisopliae* was found by the senior author on field collected specimens of *B. longissima* at Vailoa-Tai in American Samoa. A laboratory strain of the pathogen was subsequently developed and spores were mass produced and packaged. In 1982, the spores were used successfully in Mulifanua, Western Samoa, to suppress *B. longissima* populations. In 1984, *M. anisopliae* spores were used in the Manua Islands of American Samoa to control *B. longissima* on 5 - 6 month old coconut trees. A follow-up survey in American Samoa in 1988 indicated that the CLH population was significantly lower in those areas where the fungal spores had been used as compared to untreated areas. In addition, observable *B. longissima* damage was negligible in treated areas. Survey of areas adjacent to initial *M. anisopliae* applications revealed the fungus was present on dead beetles in coconut trees up to 1 km from the initial source of application.

The coconut leaf hispid (CLH), *Brontispa longissima* (Gestro), is a small beetle native to Southeast Asia. It lives between the folded leaves of coconut palms and feeds on the surface layer of leaf tissue. In the early 1970's *B. longissima* was accidentally introduced to Tutuila, American Samoa, and to Upolu, Western Samoa in 1980. In contrast to its native home where CLH is of little economic significance, it became a devastating pest in the Pacific islands. CLH is particularly devastating as it destroys young palm trees. In November 1980, during a search for pathogens of *B. longissima* on Tutuila, a few CLH beetles were found with fungal infections in palm trees on the coast near Taputimu Farm, Vailoa-Tai, American Samoa. They were subsequently taken to the commercial laboratory of the senior author at Vaoala, Upolu, Western Samoa. The fungus was propagated and identified as *M. anisopliae* var. *anisopliae*, a cosmopolitan, entomopathogenic fungus with a wide insect host range. Strains affecting beetles tend to be rather host specific. Toxicological tests indicated that it had no detrimental effect on nontarget organisms. After the fungal spores contact the host's integument, they grow and penetrate the host's haemocoel, multiply, and kill the host. Eventually they grow through the cuticle to the outside, producing an abundance of conidiospores on the carcass, thus allowing for spread of the disease to surrounding beetle populations.

Laboratory trials were conducted to determine virulence, host range and potential of mass producing *M. anisopliae* under limited technical conditions in Samoa. The effect of this new strain was determined in the field and an efficacious rate of 0.045 g or 3 x 10^9 spores per palm tree was established. Spore weight was subject to variations of up to 20 percent due to drying and other environmentally determined variables.

This study evaluated the effects of spraying a naturally-occurring strain of *Metarhizium anisopliae* var. *anisopliae* in the control of *B. longissima* on a large scale coconut palm plantation in Western Samoa; and determined any differences between *M. anisopliae* treated and untreated sites on two islands of American Samoa.

Methods and Materials

Western Samoa. After suitable rearing methods had been developed and disease virulence verified under field conditions, a combined research and practical biological control program commenced in July 1982 at the 60-ha Mulifanua Plantations of Western Samoa Trust Estates Corporation, (WSTEC), on Upolu.

Conodiospores were reared on artificial media so that they could be separated from the medium and hyphae before weighing and counting. Small plastic bags were filled with 2.5 g of spores, which was the amount calibrated to fill a hand-operated 17 L capacity knapsack sprayer for application to 0.4 ha of 50 to 60 palms. Each palm crown was sprayed with an approximately 300 cc spore suspension. Spores were mixed with ordinary kitchen detergent and water, and then sprayed into the unopened leaflets of the central shoot with a single-jet nozzle.

Treatments were applied to survey plots in July, September, December 1982, and June 1983. In total, over 7,500 three to five-year-old trees were treated on the plantations. In the first treatment in July 1982, some of

the palm trees were treated with *M. anisopliae* and some with dicidex (trichlorfon). Dicidex was applied because it was desirable to compare its effect with the biological control agent, and because not enough spores were available at that time to treat all endangered palms. Dicidex was applied to ca. 250 trees each in concentrations of 0.2 and 2.0 percent in water with detergent.

Using a small ladder, checks for *M. anisopliae* infected beetles in palm trees were made immediately before the first fungus application and counts were made about 2 weeks or more after spraying to allow for the week-long incubation period of the disease. Palm trees were checked to determine the effect of the treatment. Folded palm leaflets were carefully opened so that *B. longissima* stages would not fall out. CLH larvae, pupae, and adult beetles found within were counted and diagnosed. Only dead insects with clear signs of *M. anisopliae* infection (i.e., either green spores or white hyphae) were recorded as dead.

Because beetle damage to the leaf surface is difficult to assess, trees surveyed were grouped into 3 categories: no damage (0 percent), medium damage (less than 50 percent of leaf surface affected), and heavy damage (greater than 50 percent of leaf surface affected).

American Samoa. In 1984, a CLH outbreak occurred in American Samoa on the Manua Islands of Ofu and Olosega. These islands have a combined area of 1270 ha and are about 100 km east of Tutuila, the main island of American Samoa. Ofu and Olosega are only 70 m apart and connected by a bridge. Fronds of 5 - 6 month old coconut palm trees in the Toaga area of Ofu were almost totally brown and wilted due to heavy CLH infestation. In the village of Olosega on the island of Olosega, 5 - 6 month old palm trees were similarly infested. Following the methods used in Western Samoa, all palm trees (approximately 50) were sprayed with spores of *Metarhizium anisopliae* var. *anisopliae*. At two similarly infested sites, the Ofu village and Ofu airport, 5 - 6 month old coconut trees were left as untreated controls. A follow-up survey was conducted in 1988 to assess the outcome of this single spraying and to compare the CLH population at the four sites.

Results and Discussion

Western Samoa. At the beginning of the trial in early 1982, the coconut replanting area under consideration was at the brink of destruction because of high *B. longissima* infestation. Trees were heavily damaged (most young leaves were brown and wilted), and it was thought that most would die. No *M. anisopliae* infection was detected in the pre-treatment counts in the Mulifanua area.

Counting *B. longissima* stages in palm crowns was a formidable task. Ninety-five crowns were checked, most of them 6 to 10 times each. A total of 17,965 individual insects were counted. Results from 36 crowns are presented here. In some trials the number of beetles became too low and too erratic after treatment to yield meaningful statistical data.

Because only dead beetles with clear signs of infection were recorded, our mortality estimates due to *M. anisopliae* infection were probably low. This was because both living CLH beetles and dead beetles without visible fungal infection were recorded as non-infected by the disease. In the dry months of July to November 1982, the number of dead *B. longissima* beetles without *M. anisopliae* symptoms was about one-third of the total number of dead beetles (Fig. 1). During the wet months of December 1982 to April 1983 most dead insects exhibited *M. anisopliae* symptoms. The infection process did not appear to be influenced by the humidity in contrast to the fungus growth outside the dead body which was humidity influenced.

In dicidex-treated trees, less than 40 percent CLH mortality was recorded using the 0.2 percent solution. Ninety-five percent mortality was found in the 2 percent dicidex concentration treatment. In the pathogen-treated trees, *M. anisopliae* caused between 15 to 40 percent mortality (Fig. 2).

However, one month post-treatment, the CLH population regained its previously high numbers in the dicidex-treated palms whereas in the *M. anisopliae* treatment, the population remained significantly below the pre-treatment figures. This phenomenon was consistently observed and corroborated by observations from other plantations where dicidex was applied. Additionally, this insecticide had a deleterious effect on honey bees and other pollinating insects whereas the fungus exclusively attacked the target pest. After the initial trials, dicidex was not used again.

After the initial application of *M. anisopliae*, the CLH population remained relatively low although only low levels of *Metarhizium* infection were observed (Fig. 2). In no case were numbers of the pests found in the treated trees in the range of the pre-treatment figures (Fig. 1). After each application, the beetle population dropped drastically and later slowly increased, possibly due to *B. longissima* beetles immigrating into the treated area from surrounding untreated palms. The palms recovered in 6 to 8 months with less than 10 percent lost with damage levels generally decreasing throughout the survey period after introduction of the pathogen (Fig. 2).

CLH counts were made within a block of untreated trees in the treated area. Two months after the initial microbial application, no *M. anisopliae* infected beetles were found in the untreated trees (Fig. 3). However, six months later (January 1983) *M. anisopliae* incidence in the untreated control block (22 percent) was similar to the treated blocks and remained about this level until observations were terminated.

Since 1983, replanting areas in Mulifanua have been regularly treated every 3 to 4 months with *M. anisopliae* spores. CLH is still present, but at low levels.

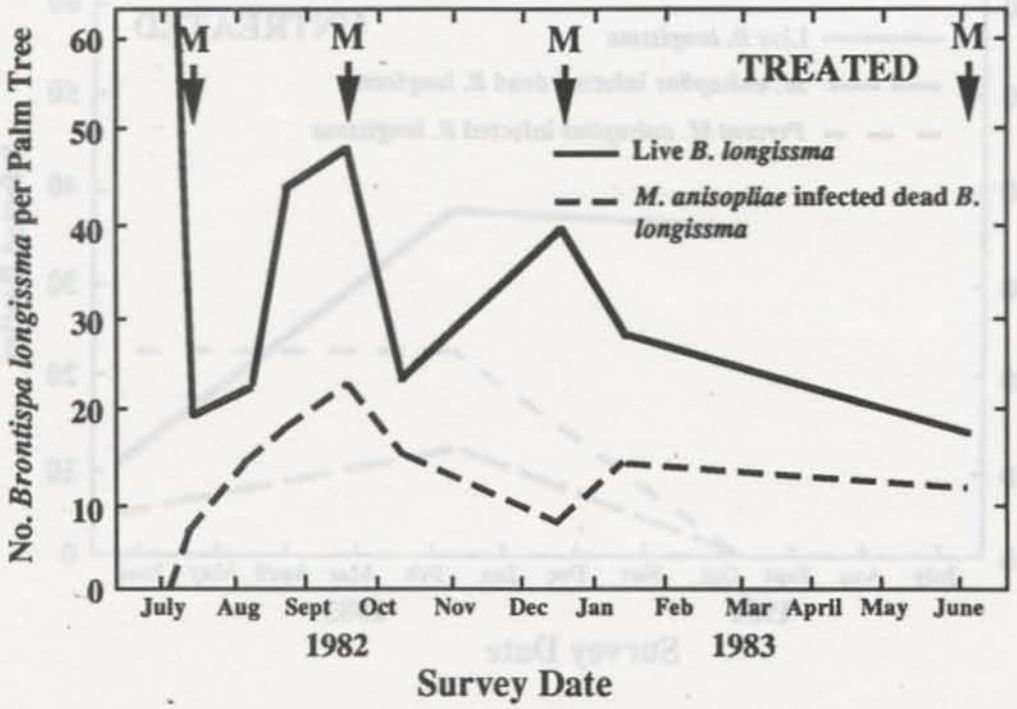

Fig. 1. Changes in mean numbers of *Brontispa longissima* larvae and adults per palm tree in Western Samoa after application of *Metarhizium anisopliae*, and the incidence of the pathogen at various times after microbial application. Arrows with "M" indicate spraying with spores.

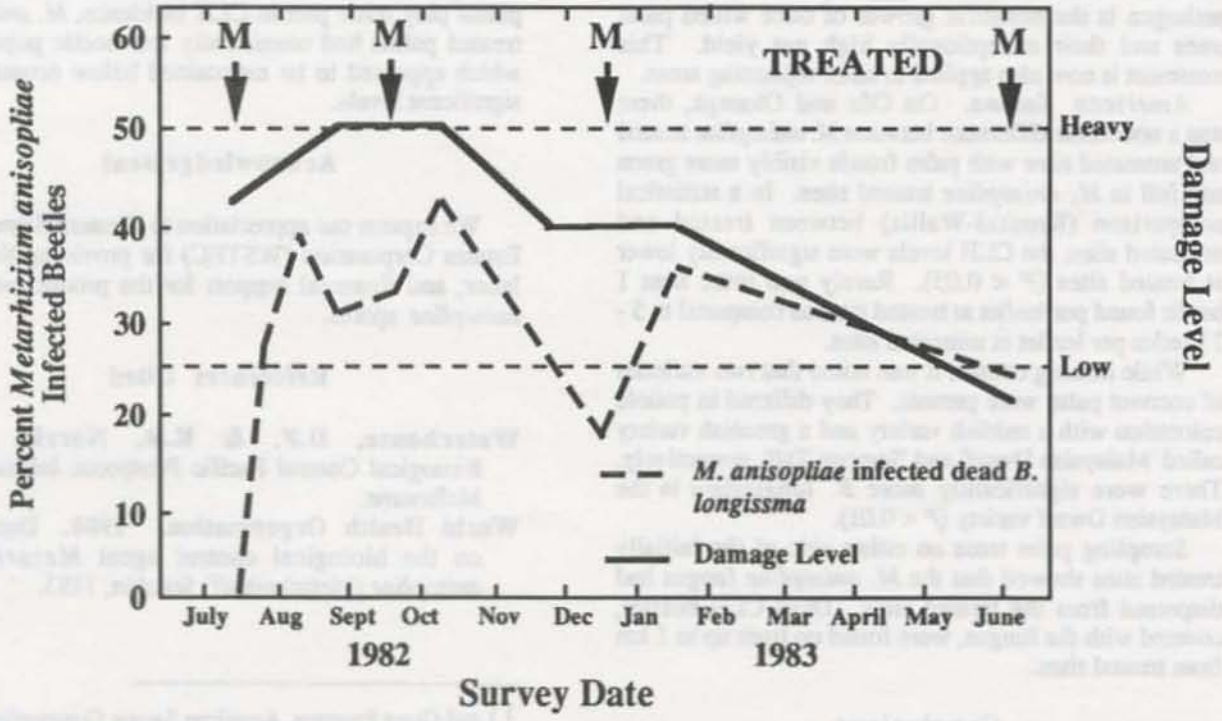

Fig. 2. Mean percentage of *Brontispa longissima* per palm tree which died from confirmed *Metarhizium anisopliae* infections, and palm damage level in relation to pathogen applications in Western Samoa. Arrows with "M" indicate spraying with spores.

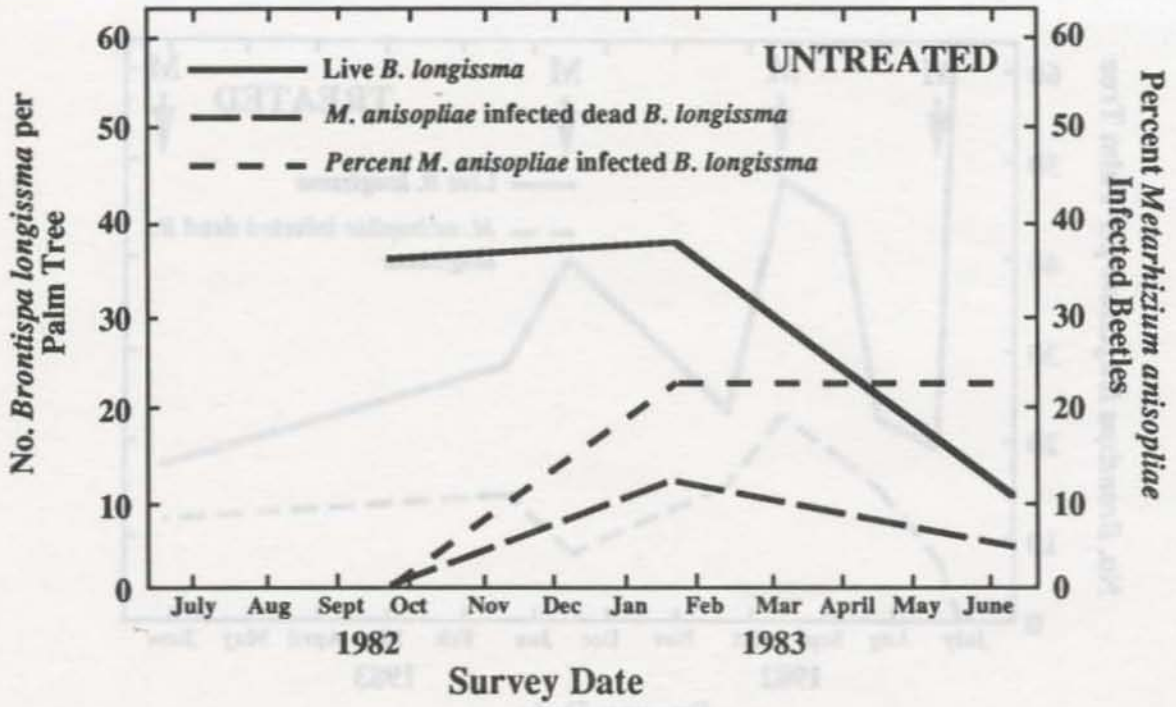

Fig. 3. Mean numbers of live and *Metarhizium anisopliae* infected dead *Brontispa longissima* larvae and adults per palm tree in untreated controls, and the percent *B. longissima* dead from *M. anisopliae* infection in Western Samoa. Data was obtained from 10 palm tres with a total of 950 *B. longissima* evaluated.

Proof of the effect of effective biological control by the pathogen is the beautiful growth of once wilted palm trees and their exceptionally high nut yield. This treatment is now also applied to other replanting areas.

American Samoa. On Ofu and Olosega, there was a noticeable difference between *M. anisopliae* treated and untreated sites with palm fronds visibly more green and full in *M. anisopliae* treated sites. In a statistical comparison (Kruskal-Wallis) between treated and untreated sites, the CLH levels were significantly lower at treated sites ($P < 0.05$). Rarely was more than 1 beetle found per leaflet at treated sites as compared to 5 - 7 beetles per leaflet at untreated sites.

While making counts, it was noted that two varieties of coconut palm were present. They differed in petiole coloration with a reddish variety and a greenish variety called 'Malaysian Dwarf' and 'Samoan Tall', respectively. There were significantly more *B. longissima* in the Malaysian Dwarf variety ($P < 0.01$).

Sampling palm trees on either side of the initially treated sites showed that the *M. anisopliae* fungus had dispersed from the treated sites. Dead CLH beetles, covered with the fungus, were found on trees up to 1 km from treated sites.

Conclusions

Metarhizium anisopliae var. *anisopliae* was used effectively in Samoa in the control of *B. longissima* in both large-scale plantations (WSTEC, Western Samoa) and in isolated stands on smaller islands. (Ofu and Olosega, American Samoa) While varietal differences of palms play some part in CLH incidence, *M. anisopliae* treated palms had consistently low beetle populations which appeared to be maintained below economically significant levels.

Acknowledgement

We express our appreciation to Western Samoa Trust Estates Corporation (WSTEC) for providing the trees, labor, and financial support for the production of *M. anisopliae* spores.

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INSECTICIDE STUDIES ON THREE LEAFMINER PARASITOIDS IN HAWAII

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ABSTRACT *Diglyphus begini* (Ashmead) (Eulophidae), *Ganaspidium utilis* Beardsley (Eucoilidae) and *Chrysocharis oscinidis* (= *parksi*) (Ashmead) (Eulophidae) are common parasitoids of *Liriomyza* leafminers in Hawaii. Studies were conducted in 1989 to investigate the susceptibilities of these beneficial species to fenvalerate, permethrin, oxamyl, and methomyl. In addition, *G. utilis* and *C. oscinidis* were assayed for susceptibility to malathion. *D. begini* was less susceptible to all materials tested than *C. oscinidis* and *G. utilis*. *Diglyphus* females from a heavily sprayed location on the island of Oahu had LC_{50}'s 24 times above the field rate when tested with fenvalerate. Similiarly, the *C. oscinidis* colony tested had a LC_{50} approximately two-fold above the fenvalerate field rate. Resistant parasitoids may be useful for controlling leafminers in management programs that integrate biological and chemical controls.

Natural enemies purposely introduced into Hawaii for biological control of *Liriomyza* leafminers include *Ganaspidium utilis* Beardsley (Eucoilidae) and *Chrysocharis oscinidis* (= *parksi*) (Ashmead) (Eulophidae) (Funasaki et al. 1988). *Diglyphus begini* (Ashmead) (Eulophidae) has been present in Hawaii for many years, and was probably introduced accidently in *Liriomyza* infested foliage. Factors making Hawaii an ideal location for resistance studies include the geographic isolation of the Hawaiian Islands and those farms distributed among the islands; continuous cropping; lack of continuously implemented pest management programs; overuse of pesticides; and high levels of resistance in pest insects. During the last several years, studies of insecticide resistance in *Liriomyza* leafminers (Mason et al. 1987, 1989) and their hymenopterous parasitoids (Mason & Johnson 1988) were conducted in Hawaii. Mason & Johnson (1988) found that *D. begini* exhibited higher tolerance to permethrin and fenvalerate than those reported for the *Liriomyza trifolii* (Burgess) and *Liriomyza sativae* Blanchard. These results prompted further studies to examine variation in pesticide susceptibility in *D. begini*, *G. utilis*, and *C. oscinidis*.

Materials and Methods

Sources of parasitoids. Leaves containing both *L. sativae* and *L. trifolii* larvae were collected from three locations on the island of Oahu, Hawaii from February to August 1989. Two of the Oahu sites, the University of Hawaii Experiment Station, Poamoho, Oahu (PO), and a private commercial farm in Hawaii Kai, Oahu (HO), had a history of frequent pesticide use on the crops grown there. The third collection site was an isolated organic garden in the Manoa Valley near the University of Hawaii at Manoa (MO).

Long bean (HO and PO) and tomato (PO) foliage was sampled, taken to the laboratory, dried at 24°C for 2–3 days, and placed in emergence cages. Adult *D. begini* were aspirated from the cages into glass vials and held at 24°C with honey for 1–4 days before the bioassays were conducted. Because the MO site was a private backyard garden, it was difficult to collect *Liriomyza*-infested plant material. Therefore a different technique was used to obtain parasitoids for the bioassays. Twelve day-old 'Henderson Bush' bean plants (Burpee Seed, Warminster, PA) grown in vermiculite in a greenhouse and infested with second and third instar *L. trifolii* were placed at the MO site for 24 to 48 hours. After removal from the field, plants were kept in a holding cage in the laboratory for 7 to 10 days. Leaves were dried and placed in emergence cartons. Adult parasitoids were aspirated and handled in the same manner as parasitoids from the HO and PO sites.

Addditionally, *D. begini* individuals were acquired from the Salinas area of California (CA) through the assistance of M. P. Parrella and K. Heinz. These were assayed in the same manner as stated for the Oahu populations.

Adult *G. utilis* and *C. oscinidis* used in bioassays were obtained from laboratory cultures maintained on *L. trifolii* on Henderson bush bean. Colonies were initiated in June 1987 from parasitoids collected at the University of Hawaii Experiment Station, Poamoho, Oahu. Adult parasitoids were aspirated daily from emergence cartons into glass vials and kept at 24°C with honey for 1–4 days prior to conducting the bioassays.

Insecticides. Five formulated insecticides were used: methomyl (Lannate® 1.8 emulsifiable concentrate [EC]; E. I. Dupont de Nemours & Co., Inc.,

Wilmington, DE), oxamyl (Vydate® 2.0 EC; E. I. Dupont de Nemours & Co., Inc., Wilmington, DE), permethrin (Ambush® 2.0 water soluble liquid [L]; ICI Americas, Inc., Wilmington, DE), fenvalerate (Pydrin® 2.4 L; Shell, Houston, TX), and malathion (Malathion 57 percent emulsifiable liquid [EC]; Hopkins Agricultural Chemical Co., Madison, WI).

Bioassays. All adult parasitoids were anesthetized with CO_2 for 30 seconds and sorted approximately 24 hours before exposure to pesticide residue. *D. begini* males and females were tested separately. *G. utilis* and *C. oscinidis* were not separated by sex before conducting the bioassays. Parasitoids were placed in 36 ml clear plastic cups (Anchor Hocking, Minneapolis, MN.) with a camel's-hair brush. Cups were covered with organdy squares and ventilated plastic snap-top lids. All insects were kept in an environmental chamber at 24°C, 16:8 (L:D) photoperiod, and provided with honey before testing.

Serial dilutions of formulated insecticide were prepared in 50 ml of distilled water plus 1 ml of 0.2 percent Triton Ag-98®. (Rohm & Haas, Newark, NJ). Control treatments contained distilled water plus 0.2 percent Triton Ag-98. Dilutions were poured into 36 ml clear plastic cups (Anchor Hocking, Minneapolis, MN.) and poured back into the original beaker after 10 seconds. Treated cups were inverted on a wire rack inside a ventilated hood for 2 hours to dry. Unanesthetized insects set up in untreated cups 24 hours earlier were gently tapped into the treated cups. These cups were then covered with an untreated organdy and a ventilated plastic snap-top lid. A single drop of honey was placed in the center of the organdy, and the cup was inverted on a wire screen. This bioassay procedure is similar to a technique reported by Rathman et al. (1990). All tests were conducted in a temperature cabinet at 24°C with constant light. Mortality was recorded after 24 hours. Parasitoids not moving legs and antennae were scored as dead. On a given date, a series of five concentrations plus an untreated check were run. Each treatment or concentration was replicated four times with a total of five individuals per treatment. All experiments were run with a minimum of 120 individuals. Tests were repeated on at least two different dates, and data pooled for the analysis. Concentration-mortality data were analyzed with the probit option of **POLO PC** (LeOra Software 1987).

Results

The carbamates methomyl and oxamyl were more toxic to *D. begini* than the pyrethroids permethrin or fenvalerate. All *D. begini* populations tested had lower LC_{50}'s for methomyl than oxamyl and lower LC_{50}'s for permethrin than fenvalerate (Table 1). Malathion and methomyl were most toxic to *G. utilis* and *C. oscinidis*. Insecticides ranked in order of decreasing toxicity to *G. utilis* were malathion > methomyl > permethrin >oxamyl > fenvalerate. Insecticides ranked in order of decreasing toxicity to *C. oscinidis* were methomyl > malathion > permethrin > oxamyl > fenvalerate (Table 2).

Comparisons with field rates. *C. oscinidis* LC_{50}'s were below the field rate for permethrin (240 mg ai/l), oxamyl (1,200 mg ai/l), methomyl (1,080 mg ai/l), and malathion (78.5 mg ai/l). Methomyl LC_{50}'s for *C. oscinidis* were 45-fold below the field rate. The LC_{50} for fenvalerate was approximately two-fold above the field rate. The LC_{50}'s for *G. utilis* were all below the field rate. For example, the LC_{50}'s for fenvalerate and malathion were 0.5 and 0.1 times the field rate, respectively (Table 2).

All four *D. begini* populations had LC_{50}'s below the field rate of oxamyl and methomyl. *D. begini* females from HO had LC_{50}'s approximately 0.5 times the field rate for oxamyl. Female *D. begini* from PO and HO had LC_{50}'s approximately nine-fold below the field rate for methomyl. All populations tested with fenvalerate had LC_{50}'s greater than the field rate. For example PO and HO *D. begini* had LC_{50}'s approximately 24 and 13-fold above the field rate, respectively. For CA and MO populations, male *D. begini* had LC_{50}'s below the field rate, but female LC_{50}'s were above the field rate. Male *D. begini* from all locations had LC_{50}'s for permethrin below the field rate. Females from PO and HO had LC_{50}'s above the field rate (Table 1).

Susceptibility differences between populations - D. begini females. *D. begini* females from MO and CA had significantly lower LC_{50}'s than PO and HO females for methomyl, oxamyl, and fenvalerate. California *D. begini* were most susceptible to all insecticides tested (Table 1).

The maximum LC_{50} for oxamyl (HO) was 20 times higher than the LC_{50} for CA and eight times higher than the LC_{50} for MO. The maximum LC_{50} for methomyl was 16 times higher than the LC_{50} for CA and 8.5 times higher than the LC_{50} for MO. The maximum LC_{50} for fenvalerate (PO) was 14 times higher than the LC_{50} for the CA strain and four times higher than the LC_{50} for the MO strain. The maximum LC_{50} for permethrin (PO) was approximately 6 times greater than the LC_{50} for the CA strain.

D. begini males. Data for male *D. begini* showed similar trends, however males were significantly more susceptible to the pesticides than females. The CA and MO males had significantly lower LC_{50}'s than males from PO and HO for methomyl, oxamyl, and fenvalerate. The CA males were the most susceptible to all insecticides tested.

Comparisons between species. *D. begini* was significantly less susceptible to methomyl, oxamyl, fenvalerate, and permethrin than either *C. oscinidis or G. utilis*. *C. oscinidis* was significantly less susceptible to methomyl, oxamyl, malathion, fenvalerate, and permethrin than *G. utilis* (Table 2).

Table 1. Toxicity of fenvalerate, permethrin, oxamyl and methomyl to adult *Diglyphus begini* from various field populations in Hawaii and California.

Population	Sex	n	Slope ± SE	LC_{50}[a]	95% FL[a]	Resistance Ratios FO[b]	Resistance Ratios F:M[c]
				FENVALERATE[d]			
Poamoho, Oahu	F	193	1.9 ± 0.5	5,700	4,000 - 16,000	14.0	12.9
	M	598	1.1 ± 0.1	440	310 - 640		
Hawaii Kai, Oahu	F	340	2.8 ± 0.4	3,100	2,700 - 3,700	7.8	5.3
	M	240	2.9 ± 0.4	590	450 - 760		
Manoa, Oahu	F	298	1.7 ± 0.2	1,400	1,000 - 1,900	3.5	8.8
	M	226	1.5 ± 0.2	160	100 - 220		
Salinas, California	F	227	2.7 ± 0.6	400	240 - 580	1.0	3.3
	M	256	1.1 ± 0.2	120	31 - 210		
				PERMETHRIN[d]			
Poamoho, Oahu	F	239	2.9 ± 0.4	1100	850 - 1,300	5.8	15.7
	M	330	1.4 ± 0.1	70	50 - 100		
Hawaii Kai, Oahu	F	120	2.5 ± 0.4	620	200 - 2,300	3.3	10.3
	M	120	1.3 ± 0.2	60	30 - 140		
Salinas, California	F	290	1.6 ± 0.2	190	130 - 310	1.0	10.6
	M	370	1.1 ± 0.2	18	8 - 28		
				OXAMYL[d]			
Poamoho, Oahu	F	210	2.3 ± 0.3	280	210 - 400	10.0	3.1
	M	484	3.4 ± 0.3	91	77 - 110		
Hawaii Kai, Oahu	F	240	2.0 ± 0.3	570	430 - 830	20.0	5.2
	M	240	2.6 ± 0.3	110	82 - 150		
Manoa, Oahu	F	214	1.8 ± 0.3	68	46 - 96	2.4	3.4
	M	213	2.4 ± 0.4	20	14 - 25		
Salinas, California	F	332	3.1 ± 0.4	28	22 - 34	1.0	1.9
	M	240	2.7 ± 0.4	15	12 - 19		
				METHOMYL[d]			
Poamoho, Oahu	F	259	2.6 ± 0.4	130	110 - 170	16.0	3.2
	M	401	2.1 ± 0.3	40	33 - 54		
Hawaii Kai, Oahu	F	240	3.2 ± 0.4	120	95 - 150	15.0	4.0
	M	240	3.4 ± 0.4	30	25 - 37		
Manoa, Oahu	F	217	2.8 ± 0.4	15	11 - 20	1.9	1.9
	M	477	1.8 ± 0.2	8	7 - 10		
Salinas, California	F	246	2.3 ± 0.3	8	6 - 12	1.0	1.3
	M	246	2.9 ± 0.4	6	5 - 8		

[a] mg AI per liter

[b] Females only; LC_{50} of a population for a given pesticide divided by LC_{50} of the most susceptible population (Salinas, California).

[c] F:M: LC_{50} of females for a given population divided by LC_{50} of males for a given population.

[d] Field rates for methomyl and oxamyl were calculated as 1,080 and 1,200 mg ai per liter, respectively. Field rates for permethrin and fenvalerate were calculated as 240 mg ai per liter.

Discussion

Mason & Johnson (1988) tested technical fenvalerate and permethrin against different leafminer parasitoids in Hawaii. *Diglyphus begini* and *G. utilis* were significantly more tolerant of fenvalerate than permethrin. These results were in agreement with the data presented here.

Oatman & Kennedy (1976) reported that methomyl induced leafminer outbreaks due to adverse effects on parasitoids. Johnson et al. (1980a,b) found that all rates of methomyl applied to tomatoes caused an increase in *Liriomyza* densities and reduced populations of *D. begini*. Parasitization of *L. sativae* by *C. oscinidis* was reduced significantly in methomyl-treated plots. These results were supported by our laboratory bioassay data. *D. begini*, *G. utilis*, and *C. oscinidis* all exhibited a low tolerance for methomyl.

Comparisons With field rates. No hymenopterous parasitoids have been reported to survive

Table 2. Toxicity of various pesticides to adult *Chrysocharis oscinidis* and *Ganaspidium utilis* exposed for 24 hours.

Pesticide	n	Slope ± SE	LC_{50}[a]	95% FL[a]	LC_{90}[a]	95% FL[a]
			C. oscinidis			
Malathion	245	5.2 ± 0.7	74	63 - 86	130	107 - 179
Oxamyl	379	2.2 ± 0.2	311	244 - 417	1,181	782 - 2,307
Methomyl	240	2.5 ± 0.3	24	17 - 35	79	50 - 192
Fenvalerate	360	1.4 ± 0.2	506	353 - 744	4,146	2,232 - 12,807
Permethrin	240	1.2 ± 0.2	108	60 - 262	1,170	408 - 19,140
			G. utilis			
Malathion	364	7.0 ± 1.3	8	---	13	11 - 16
Oxamyl	330	3.5 ± 0.3	46	35 - 59	107	80 - 172
Methomyl	361	2.8 ± 0.3	19	16 - 109	55	42 - 84
Fenvalerate	480	1.8 ± 0.2	128	102 - 165	630	424 - 1,149
Permethrin	417	1.3 ± 0.1	38	23 - 62	395	192 - 1,523

[a]Field rates for malathion, methomyl , oxamyl were calculated as 78.5, 1,080 and 1,200 mg ai per liter, respectively. Field rates for permethrin and fenvalerate were calculated as 240 mg ai per liter.

field rates of the insecticides tested in this study. The data presented for *D. begini* from HO and PO and *C. oscinidis* from a laboratory colony are the first such examples. Low susceptibility to pyrethroids in the CA and MO populations of *D. begini* may be related to DDT cross-resistance. This has been demonstrated in *Microplitis croceipes* (Cresson) (Braconidae) (Bull et al. 1987) and other parasitoid species.

Susceptibility differences between populations. Our results indicate that *D. begini* exhibits considerable variability in susceptibility to both carbamates and pyrethroids. This variability is probably due to past selection from pesticides and most likely represents the development of pesticide resistance in *D. begini*. The two unsprayed populations of *D. begini* from MO and CA were in all cases significantly more susceptible to the pesticides tested than the two sprayed populations (PO and HO).

Comparisons between species. Because of its resistance to both the carbamates and pyrethroids, *D. begini* appears to be a better candidate for studies on the integration of biological and chemical control than either *G. utilis* or *C. oscinidis*. Comparisons between species are difficult to make, however, because *D. begini* were field-collected and *G. utilis* and *C. oscinidis* were laboratory-reared for several generations before conducting the bioassays.

Acknowledgments

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BIOLOGICAL CONTROL OF THE MANGO SHOOT CATERPILLAR ON GUAM

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ABSTRACT The mango shoot caterpillar (MSC), *Penicillaria jocosatrix* Guenée, is a serious pest of mango on Guam. It consumes the new leaves, flowers and fruit. In 1986 - 1987, four parasitoid species including the wasps *Trichogramma platneri* Nagarkatti, *Aleiodes* sp. nr *circumscriptus* (Nees), *Euplectrus* sp. and the fly *Blepharella lateralis* MacQuart, were released to control *P. jocosatrix*. Caterpillar populations were moderately high in early 1987, but fell to low levels after July 1987. In July 1987, 16.2 percent of the larvae were killed by parasitoids. By December 1987, mortality reached 39.8 percent and remained at approximately that level. *Euplectrus* sp. and *B. lateralis* were the dominant parasitoids. *Aleiodes* sp. was recovered in early samples but later disappeared. A 20 to 80-fold increase in fruit production was noted in 1988 compared to 1986 and 1987. Following the decline of *P. jocosatrix* populations, an increase in other herbivore populations associated with mango was observed.

In the early 1900's, mangoes were noted as beautiful trees, nearly pest free (Fullaway 1911). Insect surveys on mango revealed only a few pests including a root infesting mealybug, *Pseudococcus* sp.; a small geometrid foliage feeder (undoubtedly *Anisodes illepidaria* Guenée); and a phycitid moth feeding between fruit. Fullaway (1911) found no other serious pests present. Since then, the situation has changed dramatically with several new insect species emerging as pests on mango.

One of the more serious pests is the mango shoot caterpillar (MSC), *Penicillaria jocosatrix* Guenée (Lepidoptera: Noctuidae), whose larvae feed on the flowers, young leaves, buds and fruit. This pest is probably largely responsible for Guam's poor mango production. During 1983 and 1984, Ilse H. Schreiner and I (unpublished data) compared the growth parameters of infested trees to those of trees from which most *P. jocosatrix* larvae were removed with an insecticide treatment of carbaryl. Untreated mango trees flushed nearly twice as often as the treated ones and tended to flush asynchronously. Total leaf area produced was 5.9 m^2 per 25 shoots on treated trees and 3.3 m^2 on untreated trees. Shoot growth averaged 20 cm on treated trees compared to 11 cm on untreated trees. Flowers were produced on 35 percent of the branches on treated trees as compared to 13 percent of the untreated ones. Trees with leaf areas less than 4.5 m^2 per 25 shoots did not produce flowers, suggesting a relationship between leaf area and flowering.

In addition to consuming foliage, MSC also consumes flowers. Schreiner (1987) found that untreated trees or trees treated only with fungicide lost 47 percent of their flower stalks to *P. jocosatrix* with an additional 24 percent significantly damaged. In contrast, trees sprayed with *Bacillus thuringiensis* had 11 percent of the flowers stripped and 21 percent noticeably damaged. Most of the flowers (68 percent) had no noticeable damage.

Despite the wide distribution of MSC (Southeast Asia, China, India, Australia, and Hawaii), little has been published about its biology or impact on mango. Most publications deal with its distribution or taxonomy. Hill (1983) listed it as a minor mango pest and failed to mention its flower and fruit-feeding habits. The status of MSC as a minor pest in many places and lack of economic work on this caterpillar suggests that it is probably under good biological control elsewhere. The probable success of biological control measures prompted initiation of a biological control program on Guam in 1986.

Methods and Materials

Natural enemies present on Guam. In the Guam villages of Merizo, Yigo, Barrigada and Agat, monthly surveys of MSC densities on new shoots were started in 1986 and continued to 1989. In each village, four trees with new foliage were randomly selected. On each tree, twenty shoots were examined for MSC larvae. New and old shoot growth was examined because third through fifth instars often rest on old growth during the day. Samples were normally taken from the area of the tree between 2.4 and 4.8 m in height.

In Agat, recently flushed trees with newly matured leaves were randomly selected. The tree was divided into thirds. In the lower canopy, which often had the least foliage and was heavily shaded, five shoots were sampled. Ten shoots were sampled in the middle and upper canopies. On each shoot, the amount of leaf consumed was classified as 1 of 9 damage categories. Consumption categories were 1 = no damage; 2 = up to 10 percent; 3 = 11 - 20 percent; 4 = 21 - 35 percent; 5 =

36 to 50 percent; 6 = 51 - 70 percent; 7 = 71 - 90 percent; 8 = 91 - 99 percent; and 9 = entire leaf consumed. Leaf consumption estimates were taken in 1984 and 1989. Pre-release levels of damage were compared with post-release consumption using a Chi-squared contingency analysis.

To determine the natural enemy species present on Guam, new leaves, buds, twigs and flowers were examined for MSC eggs and larvae. All caterpillars collected were reared to detect any parasitoids present. The ground around the tree, debris among epiphyte roots, crevices in the bark, and depressions where branches forked and debris collected were searched for pupae. All pupae found were held for moth or parasitoid emergence. Surveys were conducted when there was sufficient new growth present in a village to provide a sample with greater than 100 MSC larvae.

Introduced natural enemies. In 1986 - 1987, four parasitoid species were introduced from California and India. These were *Trichogramma platneri* Nagarkatti (Hymenoptera: Trichogrammatidae), *Aleiodes* sp. nr. *circumscriptus* (Nees) (Hymenoptera: Braconidae), *Euplectrus* sp. nr. *parvulus* Ferriere (Hymenoptera: Eulophidae) and *Blepharella lateralis* Macquart (Diptera: Tachinidae). *T. platneri* was obtained from California and the latter three species came from India.

Two major types of field release were used: release into field cages and direct liberation. Release cages consisted of fine mesh, nylon organdy sleeves about 0.5 m long and 0.25 m wide. The sleeve was placed over a branch with numerous caterpillars on it. Two or three female parasitoids and an equal number of males were introduced into the cage. The cage was left on the branch for 24 hours and then removed. For directly released parasitoids, releases were made into the tree canopy and at the tree base. Mango trees with heavy infestations of MSC in the first three larval instars were selected. All releases were made on trees in yards or gardens in areas where numerous other mango trees were present. No trees selected were treated with insecticides. Parasitoids were allowed to crawl out of release containers onto leaves. Care was taken to avoid disturbing released parasitoids as not to invoke escape reactions or immediate dispersal flights.

T. platneri , an egg parasitoid, was released in 1986 in Mangilao and Baza Gardens. *Aleiodes* sp. was initially released in May 1986. Releases were made approximately every two weeks through February 1987. A total of 453 individuals were released. Part of these wasps were released in screen cages and part were directly liberated. Releases were made in Barrigada, Dededo, Mangilao, Piti and Toto.

B. lateralis was released in Dededo and Yigo in October 1986. A total of 45 flies were released in lots of 3 to 11 flies.

In late November 1986 and continuing through February 1987, *Euplectrus* sp. was released. A total of 858 individuals were released in seven villages in lots ranging from 9 to 128 individuals. Releases were made approximately every two weeks.

Results and Discussion

Natural enemies present on Guam. *Trichogramma chilonis* Ishii, *Trichogrammatoidea guamensis* Nagaraja, and *Trichogrammatoidea nana* (Zehntner) were reared from MSC eggs. These parasitoids were rare, parasitizing less than one percent of the eggs in an aggregate. No larval parasitoids were reared and only a single pupal parasitoid, *Brachymeria albotibilalis* (Ashmead) was reared. Three species of wasps, *Delta* sp., were observed collecting larvae. Few natural enemies were found attacking the MSC on Guam and those present were uncommon and appeared to have little impact on MSC populations.

Introduced Natural Enemies. *T. platneri* was not recovered and was presumed to have not established. *Aleiodes* sp., a solitary, internal parasitoid which attacks the first three larval instars, was recovered occasionally through July 1987 in the villages of Barrigada, Toto and Dededo. Near the release area, numerous pupal cases of *Aleiodes* were found in Toto several months after the final release. In July 1987, 7.6 percent of the second instar caterpillars collected in Barrigada were parasitized by *Aleiodes*. In other localities the wasp was uncommon. Since July 1987, *Aleiodes* has not been recovered and was assumed to have not established.

B. lateralis is an internal parasitoid. Tiny eggs are laid on the young leaves or flowers and ingested by the caterpillar. The parasitoid larvae emerge from fifth instar caterpillars or pupate inside the moth pupae. Most pupate in the moth pupae. In July 1987, the first recoveries of *B. lateralis* were made. Five flies were reared from caterpillars collected in Piti, which was several miles from either of the release points. By August, 15 of 225 (6.7 percent) caterpillars from several villages were parasitized by the tachinid suggesting a rapid spread of this species.

Euplectrus sp. is a gregarious ectoparasitoid which lays its eggs predominantly on the first three instars, although eggs have been found on all five instars. The wasp stings the caterpillar and arrests development. The wasp takes 8 - 10 days to develop from egg to adult emergence. Pupation takes place under the collapsed larval skin of the caterpillar, which is attached to the leaf by silken threads. In July 1987, *Euplectrus* were recovered from all release sites and from all survey villages.

All introduced parasitoids came from laboratory reared stocks except *B. lateralis*, which could not be reared in the laboratory. However, a relatively safe procedure exists for obtaining clean cultures of this fly. Eggs can be field-collected on young mango leaves. These leaves are then fed to laboratory-reared larvae. Pupae or identified adults can then be shipped and checked in quarantine before releasing. This minimizes the chances of transferring hyperparasitoids, diseases or other parasitoids.

Impact of the introduced parasitoids. MSC populations showed a noticeable decline beginning in July 1987 (Fig. 1). Heavy tree damage was observed prior to this period, but after July damage decreased.

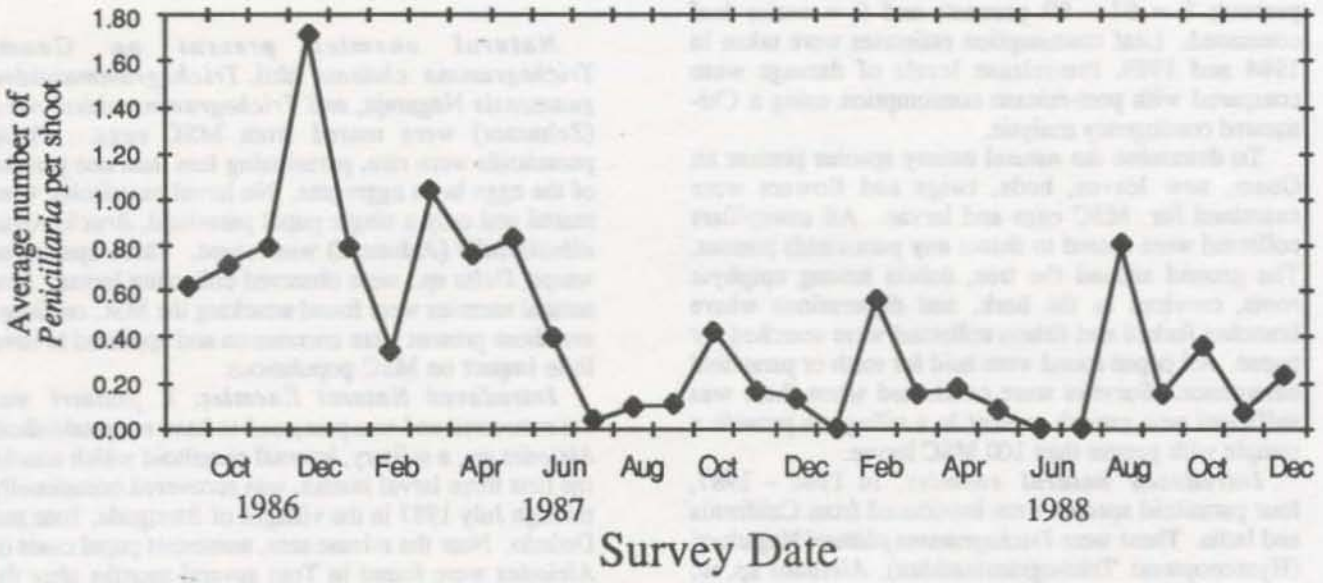

Fig. 1. Average monthly counts per shoot of mango shoot caterpillars on trees in Agat, Barrigada, Merizo and Yigo in 1986 through 1988.

Comparison of the estimated amounts of leaf tissue consumed in 1984 and 1989 showed a significant reduction in the latter year. In addition, much of the damage recorded in 1989 appeared to be caused by the geometrid *A. illepidaria* rather than MSC.

Prior to July 1987, MSC populations ranged between 0.3 and 1.8 and averaged 0.8 larvae per shoot (Fig. 1) and parasitoids were rare. In July, noticeable numbers of parasitoids were first found and MSC population levels declined. From July 1987 to December 1988, an average of 0.2 larvae per shoot was found. Peak populations have only exceeded 0.4 larvae per shoot in 2 of 23 months. In contrast, during the ten months before July 1987, populations were above 0.6 larvae per shoot for eight of the months. In July, 16.2 percent of the caterpillars were parasitized. By December 1987, the mortality had risen to 39.8 percent. Since then, the parasitization rate has fluctuated between 30 and 52 percent. Both *B. lateralis* and *Euplectrus* were common. Dominance of the two parasitoids appears to shift with season. *B. lateralis* was more common from August through November and *Euplectrus* from December through June.

From March to May 1986, an average of 0.11 fruit per branch were produced on monitored trees in Barrigada and Agat. In 1987, an average of only 0.03 fruits per branch were produced. In 1988, a dramatic increase in fruit production was observed. Fruit production averaged 2.3 fruit per branch in March 1988, a 20 to 80-fold increase over previous years.

The decline of the MSC had a pronounced effect on the herbivore community feeding on mango. Several species never collected in preliminary population surveys became common. *A. illepidaria* was present in surveys in 1984, but not common. On 100 monitored shoots on four trees, a total of 1326 Lepidoptera were found on new leaves from November through August. Of these, 17 were *A. illepidaria* and the rest were *P. jocosatrix*. No other species were found. In 1989, *P. jocosatrix* had declined significantly and several other species were found. *A.illepidaria* became so abundant that it defoliated several trees in Agat and Barrigada. An undescribed species of *Thalassodes* and two other undetermined species also become relatively common.

Mango flowers were heavily consumed by MSC before the natural enemy introduction. Since then, flowers have become more abundant, and several other insect species have become common on mango. *Thalassodes* sp., *A.illepidaria*, *Chloroclystis* sp. n., and two other unidentified species have been found. *A.illepidaria* was abundant enough to cause substantial damage.

The increase in the abundance of other lepidopterous herbivores on mango suggests that biocontrol agents can have a positive impact on native species in some cases. Many exotic herbivores reach extremely high populations and can have a severe effect on their host plants. The negative effects on the plant host (i.e., defoliation, death, induction of defensive chemicals) and other negative interactions between herbivores including interspecific competition, crowding, and increases in numbers of general predators, all can depress populations of other herbivores feeding on the affected hosts. Through these and other mechanisms, the presence of exotic, introduced herbivores may substantially contribute to the decline of native species resulting in decreased species diversity. Biological control can provide some correction by reducing the effects of exotic herbivores and restoring the environment to a more pre-introduction condition.

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BIOLOGY AND NATURAL ENEMIES OF THE FRUIT-PIERCING MOTH *OTHREIS FULLONIA* (LEPIDOPTERA: NOCTUIDAE) FROM GUAM

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Abstract The importance of *Othreis fullonia* (Clerck), as a major pest of fruit crops in Guam and other islands of Micronesia, prompted a study to examine the biology and natural enemies of this and related species in the American Pacific. The study was initiated in 1989 and is collaborative in nature involving scientists in Guam, Saipan, Pohnpei and American Samoa. Preliminary findings of some studies conducted in Guam are reported here.

The fruit-piercing moth, *Othreis fullonia* (Clerck), occurs in the sub-tropical and tropical regions of Africa, south and southeast Asia, Australia, and many islands in the Indian and Pacific Oceans. It is thought to be native to the Indo-Malayan region where its larval host plants are all vines in the family Menispermaceae (Waterhouse & Norris 1987). These vines are absent from most Pacific Islands. However, the noteworthy adaption of the larvae to species of *Erythrina*, a taxonomically unrelated group (Fabaceae) widely distributed throughout Oceania, and the adult moth's remarkable capacity for sustained flight over considerable distances, are key factors responsible for its proliferation and establishment in Micronesia.

Adult *O. fullonia* feed on a variety of fruit (Table 1) penetrating the skin with their barbed, highly sclerotized proboscis to obtain fruit juices and pulp. The resulting wound serves as an entry point for secondary pathogens which cause fruit rot. The destructive effects of this species were first observed in 1869 (Tryon 1898), and today it has achieved pest status in many areas throughout its range.

In 1987, a survey was initiated by one of us (R.M.) to determine the distribution and pest status of *O. fullonia* on Guam and other Micronesian Islands. Results of this investigation identified the need for a more intensive study. To examine the biology and natural enemies of *O. fullonia* in the American Pacific, a joint program of research was established in 1989 among the University of Guam, College of the Northern Marianas in Saipan, College of Tropical Agriculture and Science in Pohnpei, and Community College of American Samoa. The study was funded by the Agricultural Development in the Amercian Pacific (ADAP) program and has collaborative connections with the Council for Scientific & Industrial Research Organization (CSIRO), Brisbane, Australia. It was initiated with a view towards implementing effective biological control measures in areas of need at some future date. We report here on some preliminary investigations conducted in Guam.

Table 1. Fruit pierced by *Othreis fullonia*.[a]

Fruit Variety		
Apple	Grape	Orange
Apricot	Grapefruit	Papaya
Banana	Guava	Passion fruit
Bell pepper	Jackfruit	Peach
Breadfruit	Kiwifruit	Persimmon
Cactus	Lemon	Pineapple
Carambola	Litchi	Plum
Cashew nut	Longan	Pummelo
Coffee	Manderin	Soursop
Custard apple	Mango	Sweetsop
Eggplant	Melon	Tangerine
Fig	Nectarine	Tomato

[a] After Cochereau (1977), Maddison (1982), Kumar & Lal (1983), Vargo (personal communication, 1988).

Pest Status

There are no available records indicating when *O. fullonia* arrived in Guam. However, there can be little doubt that the island's abundance of *Erythrina* trees; plentiful supply of wild and cultivated fruit; generally high humidity; and equable tropical climate provided the invader with an ideal environment in which to establish.

Earliest reported sightings of *O. fullonia* in Guam were made by visiting Hawaiian entomologists in 1936 (Swezey 1946). However, it was not until 1985, almost half a century later, that *O. fullonia* was officially listed among Guam's top ten invertebrate pests causing widespread and important damage annually (Waterhouse & Norris 1987).

Several different types of locally grown fruit are attacked by *O. fullonia*, although the absence of a major fruit export industry in Guam means that the species

does not inflict the same degree of economic loss as experienced by some other Pacific islands (e.g., Kosrae). Nevertheless, local growers frequently experience heavy damage, at certain times of the year, to such fruit as banana, guava, carambola (starfruit), papaya, mango, pomegranate and various kinds of citrus.

Food Preferences

O. fullonia prefers sweet, aromatic types of fruit (e.g., banana, guava) over those with a low sugar content (e.g., tomato, bell pepper) (Sands & Schotz 1989). We quantified fruit preferences of *O. fullonia* using feeding experiments. Our data, though preliminary in nature, confirm that the moth prefers sweet, aromatic fruit and suggest that fruit ripeness can also be an important factor (Table 2). The preference index used to rank various fruit was calculated as:

$$\frac{\text{Mean No. penetrations in test fruit/moth/24 h}}{\text{Mean No. penetrations in most preferred fruit/moth/24 h}} \times 100$$

The rank order of preference for several local and market purchased fruit is currently being expanded. This may be useful in the selection of fruit for bait to lure moths away from lesser preferred produce grown on a commercial or large scale basis. Experiments continue toward assessment of potential age and sex-dependant variability in feeding preferences.

Table 2. Food preferences of *Othreis fullonia* from Guam.

Fruit	Acquisition Site	Fruit Condition	Preference Index[a]
Banana	market	ripe	100
Guava	local	ripe	89
Mango	local	green	54
Banana	local	ripe	45
Papaya	local	ripe	45
Tomato	market	ripe	31
Pear	market	ripe	30
Black Plum	market	ripe	13
Naval Orange	market	sweet	10
Red Apple	market	sweet	10
Calamansi	local	ripe	0
Eggplant	local	ripe	0
Papaya	local	unripe	0
Plum	market	red	0
Pomegranate	local	unripe	0

[a] See text for equation.

Life Cycle

Eggs obtained from outdoor caged *O. fullonia* colonies and incubated at 30 ±1°C require 2 - 4 days to hatch. Emergent larvae are about 0.5 cm in length and clear green colored with a black spot at the base of each body setae. There are five or occasionally six instars in contrast to previous reports of only five instars (Hargreaves 1936, Cochereau 1977, Kumar & Lal 1983). Whilst this phenomenon was not reported previously for *O. fullonia*, it was recorded in several other lepidopterans including related species of fruit piercing moths (Banziger 1987, Sands & Schotz 1989).

The duration of developmental stages of *O. fullonia* undergoing a total of either five or six molts was compared (Table 3). Final head capsule measurements and larval development times were similar in both cases. Also, the total number of molts were clearly not sex-dependant. Interestingly, head capsule measurements agree well with those reported for this species from Fiji (Kumar & Lal 1983).

During the course of development, larvae change in color; the variety and complexity of which increases with successive molts. Second instars are uniformly dark while later instars can range from a richly colored brown with black and white longitudinal bars to a striking combination of pale, primary colored spots, splashes and mottlings on either a black, olive brown, pale brown or pale green background. Consistent in all color variants are two conspicuous lateral "eye spots" on the second and third abdominal segments.

Color variants reported here are more or less consistent with observations made in other regions of the world (Tryon 1898, Hargreaves 1936, Comstock 1963). However, the significance of such variation remains unclear. It has been suggested that population density is an influential factor with the dark colored larvae being typical of mass aggregations, and the lighter ones of isolation (Cochereau 1977). This may be true, in part, although we believe there are other, as yet unknown, considerations. Such speculation is based on the fact that we have frequently observed all color variants together in the same *Erythrina* tree, although the darker forms were unquestionably more common. Moreover, field collected, pale green larvae have molted to the dark brown form in the laboratory, even though kept in total isolation.

Pupation occurs 14 - 19 days after larval emergence and does not appear to be influenced by total instar number (Table 3). Adults emerge some 10 - 11 days later. Prior to oviposition, adult females undergo a pre-oviposition period of 4 - 10 days giving a total developmental time of 28 - 40 days for the species. This is close to the development times reported by others (Hargreaves 1936, Baptist 1944, Cochereau 1977, Kumar & Lal 1983).

Natural Enemies

There are a number of known natural enemies of *O. fullonia* (Waterhouse & Norris 1987) although not all are present in Guam. Of those present, only the micro-hymenopteran egg parasitoids are discussed here because they play the greatest role in regulating moth populations on the island.

Table 3. Biological parameters of *Othreis fullonia* larvae reared on *Erythrina* leaves at 30 ± 1°C (n=10).

Biological	Total larval molts: Five[a]		Six[b]	
Parameter	Days	HCW[c] (mm)	Days	HCW[c] (mm)
Egg	2-4		2-4	
Larval period				
First instar	2-3	0.56-0.60	2-3	0.58-0.60
Second instar	1	1.00-1.04	1-2	0.96-1.04
Third instar	2-3	1.68-1.88	2-3	1.68-1.84
Fourth instar	2-4	2.72-2.88	1-2	2.56-2.80
Fifth instar	6-11	4.40-5.47	3-4	3.44-3.88
Sixth instar			4-6	4.53-4.53
Total larval period	14-19		15-17	
Pupal period	10-11		10-11	
Development Time	28-40		33-38	
Pre-oviposition period	4-10		4-10	

[a] Sex ratio (M:F) = 4:3

[b] Sex ratio (M:F) = 2:1

[c] HCW = Head capsule width

Biweekly collections of *O. fullonia* eggs from six sites, island wide, have revealed at least ten species of hymenopterous parasitoids. However, seven of these have only been isolated once from several thousand eggs collected to date and their identity remains to be determined. The remaining three wasps, on the other hand, are very common and have been identified as *Telenomus* sp., *Ooencyrtus* sp. and *Trichogramma* sp..

All three genera have been cited as important egg parasitoids of *O. fullonia* in other regions of the world, although their relative effectiveness, one to the other, seems to vary, both on a temporal and spatial basis (Waterhouse & Norris 1987).

In Guam, *Telenomus* sp. is the dominant egg parasitoid of both single eggs and egg masses, especially during the dry season. At this time of year, it frequently accounts for 95 - 100 percent of all parasitized eggs collected. During the wetter months, however, the incidence of egg parasitization by *Ooencyrtus* sp. increases markedly to levels which are similar, and occasionally greater, than the former species. Data collected thus far suggests that both parasites are marginally more effective on egg clusters than single eggs (Table 4).

The incidence of parasitization by *Trichogramma* sp. is normally very low in eggs from tall, established *Erythrina* trees (Table 4). Surprisingly, however, we have found them to dominate egg masses laid approximately 1 m above ground level, on outdoor potted *Erythrina* plants. This observation suggests that their effectiveness is limited, at least in part, by their low foraging level. Work is continuing to further evaluate this hypothesis.

Table 4. Fate of non-parasitized and parasitized *Othreis fullonia* eggs collected from foliage of established *Erythrina* trees at six sights, island wide from March to August 1989.

Condition	Percentage of total collected[a]: Single Egg[b]	Egg Mass[c]
Non-parasitized	28.2	12.5
Hatched	1.6	0.3
Dead	0.1	0.2
Infertile/undeveloped	21.6	6.3
Attacked by fungi	1.8	4.5
Attacked by predatory bug	3.1	1.2
Parasitized	71.8	87.5
Telenomus sp.	47.6	54.6
Ooencyrtus sp.	15.5	23.9
Trichogramma sp.	0.6	<0.1
Unidentified sp.	<0.1	<0.1
Dead	8.1	8.9

[a] All empty eggs found during the collection were not included in analysis.

[b] 2,170 single eggs collected.

[c] 7,508 eggs collected from 235 egg masses.

Competitive interactions between *Trichogramma* sp. and *Telenomus* sp. were also considered as a possible reason for the above observations, although subsequent investigations have shown that, in the laboratory at least, both are mutually non-aggressive and tolerate one anothers' presence to the point of simultaneously parasitizing the same egg. Furthermore, the species that initially parasitizes an egg would, in most cases, appear to be the one that establishes and subsequently develops within it (Table 5).

All three parasitoids required a developmental time of 10 - 12 days at 30 ±1°C. All develop in both fertile and infertile eggs. Usually, only one individual of *Telenomus* sp. will emerge from a single egg whereas 2 - 3 *Ooencyrtus* sp. individuals per egg are common and as many as 18 *Trichogramma* sp. individuals per egg have been encountered. It is possible for more than one species to develop in the same egg although such occurrences are rare and usually only one successfully emerges.

The emergence hole made by each parasite is characteristic, permitting parsitoid identification long after it has left the egg. That made by *Telenomus* sp., for example, is a clean cut, circular hole of diameter 0.39 - 0.45 mm. In contrast, the emergence hole of *Ooencyrtus* sp. is ragged-edged and roughly circular measuring 0.32 - 0.37 mm in diameter. Frequently there may be more than one emergence hole per egg and more than one wasp may use the same hole to escape. *Trichogramma* sp. makes a small, circular, finely ragged-edged hole of 0.20 - 0.26 mm in diameter. Usually only one hole is cut, although two or more have been observed occasionally.

Table 5. Test for competitive interactions between *Trichogramma* and *Telenomus* for *Othreis fullonia* eggs

Exp. No.	No. Eggs	Order of Parasitization		Emergent Spp.	Egg Fate
		First	Second		
1	7	*Trichogramma*	*Trichogramma*	*Trichogramma*	6
				Undeveloped	1
2	7	*Telenomus*	*Telenomus*	*Telenomus*	5
				Undeveloped	2
3	8	*Trichogramma*	*Telenomus*	*Trichogramma*	7
				Undeveloped	1
4	8	*Telenomus*	*Trichogramma*	*Telenomus*	4
				Trichogramma	1
				Undeveloped	3
5	14	*Trichogramma* *Telenomus*	none	*Trichogramma*	6
				Telenomus	5
				Undeveloped	3

Typically, eggs parasitized by *Trichogramma* sp. turn grey to black during the course of the parasite's development, whilst those containing *Telenomus* sp. usually remain white and are decorated with many small purplish rings. These rather attractive markings may or may not be present on eggs parasitized by *Ooencyrtus* sp.

Population Dynamics

Our observations, based on *O. fullonia* larval activity on local *Erythrina* trees, indicate that populations undergo seasonal fluctuations which generally coincide with the appearance of tender new growth on the host plant during the wet season and its corresponding absence during the dry season. The fact that local *Erythrina* trees also shed most of their leaves between January and March, in addition to the notable absence of alternative host species, places additional survival pressures on the larvae at this time of the year.

High moth and/or larval populations of *O. fullonia* have also been found in Australia (Sands & Schotz 1989), New Caladonia (Cochereau 1972) and Thailand (Banziger 1982) during the rainy season. However, the exact opposite situation has been reported from Sierra Leonne (Hargreaves 1936) and Fiji (Kumar & Lal 1983).

Related Fruit-Piercing Species

Several other fruit-piercing species have been collected in Guam (Table 6). All are noctuids, but do not have the same pest-status as *O. fullonia*. They have been classified as either 'primary' or 'secondary' fruit-piercing species according to their ability to pierce fruit which, in turn, largely reflects the degree of sclerotization and armature of the proboscis tip (Banziger 1982).

For the purpose of this discussion, primary fruit piercers are regarded as those capable of penetrating the skin and pulp of a wide variety of fruit. Secondary fruit-piercers, on the other hand, are generally unable to penetrate the skin of firm fruit and may use existing holes made by primary fruit-piercing moths (or other such breaks in the skin) to reach the pulp beneath. A third catagory of moth, that imbibe surficial sap from the cells of damaged fruit (fruit-sucking moths) but are incapable of penetrating either the skin or the pulp, are not considered here.

To date, *Platyja umminia* (Cram.) is the only other primary fruit-piercing moth species found in Guam. The proboscis of this species, though lacking the barbs, hooks and spines which characterize *O. fullonia*, is heavily sclerotized with an extremely sharp, double edged, spear-like tip. Interestingly, this species had not previously been recorded in Guam, although it occurs in Thailand, where it is a primary fruit-piercer of several fruits including guava and mandarin (Banziger1982).

All other species listed (Table 6) are classified as secondary fruit-piercing moths, on the basis that their mouth parts are only lightly sclerotized, the proboscis tip being typically spatulate with numerous projecting bristle-like structures and clearly incapable of penetrating the skin of all but the softest fruit. One of these species, *Achaea janata* (L.) is very common and described by Banziger (1982) as an established secondary fruit-piercer of longan and a probable secondary fruit-piercer of mandarin, ripe guava, mango and papaya (among others). He also found this species to be a primary fruit-piercer of the soft-skinned Panama berry, and pointed out that 'the status of a primary or secondary fruit-piercer is not a fixed characteristic of the moth species but varies according to the fruit type it feeds upon'.

Table 6. Species of fruit-piercing moths in Guam listed according to fruit-piercing ability.

Species	Fruit-piercing Status
Othreis fullonia (Clerck)	Primary
Platyja umminia (Cram.)	Primary
Achaea janata (L.)	Secondary
Anua coronata (F.)	Secondary
Anua tongaensis Hampson	Secondary
Thyas regia Lucas	Secondary

With this in mind, a more detailed evaluation of the fruit piercing status of all species listed (Table 6) is currently underway.

Conclusions

Notwithstanding the fact that about 98 percent of all *O. fullonia* eggs laid annually in Guam never develop, the species still attains populations that are troublesome at certain times of the year. Additional biological control measures are, therefore, recommended to augment and improve the effectiveness of existing

natural enemies already present in Guam. In this regard, the larval parasites of *O. fullonia* are worthy of consideration because none are currently found in Guam and some of them (e.g., *Winthemia caledoniae* Mesnil. (Diptera: Tachinidae) and certain *Euplectrus* spp. (Hymenoptera: Eulophidae)) have yielded varying though nonetheless encouraging degrees of success elsewhere in the world (Waterhouse & Norris 1987).

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PROSPECTS FOR BIOLOGICAL CONTROL OF THE FRUIT PIERCING MOTH, *OTHREIS FULLONIA* (CLERCK) (LEPIDOPTERA: NOCTUIDAE)

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ABSTRACT The fruit piercing moth, *Othreis fullonia* (Clerck), is a frequent pest in several countries of the Pacific Basin and eastern Australia. However, on some islands, including Papua New Guinea, it is neither abundant nor a pest. The Division of Entomology, Commonwealth Scientific and Industrial Research Organization (CSIRO), has investigated the ecology and control of fruit piercing moth and with particular attention directed to finding biological control agents. Parasitic fauna have been shown to differ between geographic areas.

Techniques were developed to assess the effectiveness of egg parasitoids, and these methods were used to compare the endemic parasitoids of Papua New Guinea with those in Western Samoa. In Papua New Guinea, two undescribed species in the genera *Ooencyrtus* and *Telenomus* are believed to act as natural biological control agents (> 66 percent parasitization), whereas in Western Samoa the dominant endemic species, *Ooencyrtus crassulus* Prinsloo & Annecke, is less effective (ca. 29 percent parasitization). Based on these findings, both species from Papua New Guinea were first studied in quarantine to test their potential as biological control agents and these have now been released in Western Samoa. To date only the *Telenomus* sp. has established.

Prospects for biological control of *O. fullonia* in the Pacific appear promising and parasitoids are currently being assessed for introduction into other countries including Tonga, Fiji, Guam and American Samoa.

Fruit piercing moths (Noctuidae : Catocalinae) occur in many sub-tropical and tropical countries, particularly Africa, India, Southeast Asia, the Americas, Australia, and the Pacific Islands. Adult moths damage ripening fruit when they pierce the skin with their powerful, modified proboscis, to feed on the juice. One of the most widely distributed species, *Othreis fullonia* (Clerck), is a serious pest, especially in eastern Australia and parts of the Pacific region (Mosse-Robinson 1968). Its distribution, biology and natural enemies were recently reviewed by Waterhouse & Norris (1987). In Australia, three other species, *Othreis materna* (Linnaeus), *Othreis jordani* (Holland) and *Eudocima salaminia* (Cramer) are also serious pests on a range of commercially grown fruit species (Sands & Schotz 1989).

In Australia and the Pacific, many other Noctuidae have been associated with fruit damage, including *Phyllodes imperialis* Druce, *Thyas miniacea* (Felder), *Serrodes campana* Guenée, *Parallelia* spp., *Anomis* spp., *Ophiusa* spp. and *Achaea* spp. (unpublished). The proboscis in these genera is not sufficiently developed to penetrate firm-skinned fruit, and these "secondary," fruit-sucking species are usually observed on fruit previously damaged by primary species or other agents. However, some of these species as well as others are capable of damaging soft-skinned stone fruit, berries, guavas and carambolas (Fay 1987, personal communication).

The life-history of *O. fullonia* was studied in New Caledonia by Cochereau (1977) and in Thailand by Banziger (1982). Larvae feed on vines in the family Menispermaceae and in the Pacific region, on trees of the unrelated genus *Erythrina* (Waterhouse & Norris 1987), but they are not regarded as pests. Larvae of *E. salaminia* feed on several varieties of the forest vine *Stephania japonica* (Thumb.) Miers, including var. *forsteri* (DC.) on the Pacific islands.

The natural enemies of *O. fullonia* were listed by Waterhouse & Norris (1987). In New Caledonia, Cochereau (1973, 1977) found that egg parasitoids, particularly an *Ooencyrtus* sp. (*O. cochereaui* Prinsloo and Annecke) contributed to *O. fullonia* egg mortality (ca. 30 percent parasitization) and the tachnid fly *Winthemia caledoniae* Mesnil was an important larval parasitoid (ca. 25 - 46 percent parasitization). In some Pacific countries, including Papua New Guinea, egg parasitization levels are thought to contribute to biological control of the moths (Sands & Liebregts 1988).

The Division of Entomology, Commonwealth Scientific and Industrial Research Organization (CSIRO) has investigated the ecology and control of fruit piercing moths in Australia and several Pacific countries. We

discuss here prospects for biological control of the moths using natural enemies occuring in the Pacific and methods to monitor their activity.

Methods and Materials

At each locality in the Pacific region (currently Western Samoa, Tonga and Guam), the following data were collected to assess which natural enemies were present and their impact on the immature stages of fruit piercing moths.

Egg Parasitization. This was assessed by i) collection of naturally deposited eggs; and ii) exposure of laboratory culture produced eggs in the field. On each sampling occasion, 30 single eggs or 30 egg masses were collected when available or exposed.

Eggs and egg masses with developing stages of moth larvae or parasitoids were held separately in plastic tubes (50 x 10 mm), closed with a firm cotton wool plug and incubated at ca 25°C. After 21 days incubation, the following information was recorded for the respective egg types. With respect to 1) unparasitized eggs: numbers of eggs that produced moth larvae (empty eggs or egg shell remnants) or did not hatch (infertile or with dead larvae); 2) parasitized eggs: numbers that i) produced parasitoids; ii) contained dead parasitoids; iii) had emergence holes/egg; iv) numbers of emerged parasitoids; and 3) numbers of eggs dead or damaged by predators, fungus, etc. Parasitoids which emerged were identified and their respective parasitization rates were determined.

Larval and Pupal Parasitization. On each occasion, up to 30 pupae and 30 larvae, representing as many instars as possible, were collected from the field and taken to the laboratory where they were maintained at ca. 25°C with fresh host plants until pupation. Pupae were incubated until moths or parasitoids emerged or the pupae died.

Predators. Natural enemy species present on immature stages in the field and the number attacking fruit moth life stages were recorded each month. Specimens were collected for identification on each sampling occasion and damage attributed to predators was recorded.

Results

Egg Parasitoids and Predators. Species of parasitic Hymenoptera recorded from eggs of fruit piercing moths during this study from the Pacific region were summarized (Table 1). They include seven *Ooencyrtus* species (Encyrtidae), ca. three *Telenomus* species (Scelionidae), several *Trichogramma* species (Trichogrammatidae) and one *Anastatus* species (Eupelmidae). *Ooencyrtus* species appear to differ for each country except that *O. crassulus* Prinsloo & Annecke, is present in both Western and American Samoa. Only one other species, *O. cochereaui* Prinsloo & Annecke, from New Caledonia is named while the remainder appear to belong to the *O. malayensis* Ferriere species complex. All *Ooencyrtus* species were gregarious, averaging 3 individuals per host egg, and biparental, except one (LPL551) which was uniparental. *Ooencyrtus* sp. (LPL531) from Papua New Guinea achieved higher levels of parasitization than other species from the genus occurring elsewhere including Western Samoa. This species was released in Western Samoa but has not yet established (W. Liebregts, personal communication).At least three *Telenomus* species attacked eggs of fruit piercing moths in the Pacific region. All were biparental, solitary parasitoids. One species (LPL530), contributed to high parasitization levels (66%) in Papua New Guinea. It was recently established in Western Samoa following assessment as an effective biological control agent for *O. fullonia* (W. Liebregts, personal communication). In the laboratory, egg parasitoids from Papua New Guinea and Australia completed development in both *O. fullonia* and *E. salaminia.*

Estimates of percentage parasitism do not reflect the actual proportion of host mortality (Van Driesche 1983). Methods for assessing parasitoid effectiveness need to consider searching ability, reproductive potential, seasonality, and competition between species for hosts. In the methods developed for assessing egg parasitoids, we calculated parasitization levels separately for each species. By regular sampling over a 12 month period, profiles for activity in moth egg masses (percent egg masses attacked) and overall parasitization (percent parasitization in parasitized egg masses) can be contrasted with parasitization of single eggs. To date, we have not seen evidence of superparasitism. *Ooencyrtus* spp. and *Telenomus* spp. do compete for available hosts in Papua New Guinea when parasitization levels are relatively high. We expect that introduced exotic parasitoids will increase the levels of egg mortality caused by endemic parasitiods.

The following egg predators were identified: the lygaeid *Germalus samoanus* (China), and the ants *Pheidole megacephala* (Fabricius) and *Tetramorium insoleus* (Fr Smith) attack *O. fullonia* in Western Samoa, while *P. megacephala* and *Iridomyrmex glaber* (Mayr) attack *E. salaminia* in Australia. Larvae of unidentified Neuroptera also prey on *E. salaminia* eggs in Australia.

Larval and Pupal Parasitoids and Predators. Most larval and pupal predators and parasitoids of *O. fullonia* were listed by Waterhouse & Norris (1987). To these we added an ichneumonid larval/pupal parasitoid, *Echthromorpha agrestoria* (Swederus) and a tachinid larval parasitoid *Exorista sorbillans* (Wiedmann) of *E. salaminia* in Australia. There were two hemipterous predators of larvae: *Oechalia schellenbergi* (Guerin) (Pentatomidae) attacked third instar *O. fullonia* in Western Samoa and this has a wide prey range including other Lepidoptera in Australia and elsewhere in the Pacific Basin (G. F. Gross, personal communication). *Gminatus wallengreni* (Stal) (Reduviidae) attacked and completed development on *E. salaminia* larvae in Australia.

Table 1. Hymenoptera parasitic on eggs of fruit piercing moths in the Pacific region.

Country	Moth Spp.	Parasitoids[a]	References
New Caledonia	*O. fullonia*	*Ooencyrtus cochereaui* Prinsloo & Annecke	Prinsloo & Annecke 1978,
		Trichogramma chilonus Ishii	Cochereau 1974, 1977,
		Telenomus sp.	Waterhouse & Norris 1987,
			Maddison 1982.
Papua New Guinea	*O. fullonia*	*Ooencyrtus* sp. (LPL531)	Sands & Liebregts 1988.
		Telenomus sp. (LPL530)	
Vanuatu	*O. fullonia*	*Ooencyrtus* sp. (LPL515)	CSIRO unpubl.
	E. salaminia	*Telenomus* sp. (LPL519)	CSIRO unpubl.
Fiji	*O. fullonia*	*Trichogramma* sp. nr. *papilionis* Nagarkatti	Kumar & Lal 1983.
Hawaii	*O. fullonia*	*Trichogramma chilonis*	Heu et al. 1985.
		Trichogramma ostriniae Pang & Chen	
Western Samoa	*O. fullonia*	*Ooencyrtus crassulus*	Sands & Liebregts 1988.
		Trichogramma sp. (LPL522)	CSIRO unpubl.
American Samoa	*O. fullonia*	*Ooencyrtus crassulus*	Prinsloo & Annecke 1978.
Guam	*O. fullonia*	*Ooencyrtus* sp. (LPL528)	CSIRO unpubl.
		Telenomus sp. (LPL527)	
		Trichogramma sp. (LPL565)	
		Trichogramma sp. (LPL566)	
Tonga	*O. fullonia*	*Telenomus* sp.	Crooker 1979,
		Trichogramma sp. (LPL581)	CSIRO unpubl.
Australia	*Othreis* spp.	*Trichogramma* sp. (LPL513)	
	O. materna	*Telenomus* sp.	H. Fay pers. comm.
	O. fullonia	*Telenomus* sp. (LPL535)	CSIRO unpubl.
	E. salaminia	*Telenomus* sp. (LPL535)	CSIRO unpubl.
		Ooencyrtus sp. (LPL588)	
		Ooencyrtus sp. (LPL551)	
		Trichogramma sp. (LPL599)	

[a] LPL Numbers represent CSIRO registrations for unidentified species.

Unidentified midges, *Forcipomyia* spp. (Ceratopogonidae), were observed sucking juices from larvae of *O. fullonia* in the field in Vanuatu and Western Samoa and *E. salaminia* in Australia.

Discussion

Data were collected on fruit piercing moth egg parasitization in several countries using the methods described for Papua New Guinea and Western Samoa. This information is necessary before the introduction of exotic natural enemies. Data for natural enemies of other immature stages of fruit piercing moths was scarce and none have shown potential as biological control agents. No natural enemies of the larval and pupal stages from the Pacific region were considered to be useful biological control agents except possibly *Winthemia caledoniae* (Cochereau 1977). However, following its introduction from New Caledonia to Fiji (Kumar & Lal 1983), this species did not effectively control *O. fullonia*. Other *Winthemia* spp. parasitic on *O. fullonia* in Vanuatu, Western and American Samoa were not effective agents and had a wide host range.

Our data allowed measurements of the efficacy of endemic parasitoids in each country and enabled us to select the most active exotic species for introduction. The methods also allowed us to monitor changes in parasitization levels following establishment of exotic species. We are comparing the biology of some of the parasitoid species under controlled conditions (e.g., intrinsic rates of increase) to determine if these parameters reflect performance as measured by the methods described above.

In the CSIRO program, we are coordinating a biosystematic approach to the biological control of fruit piercing moths in Australia and the Pacific region. We are first concentrating on egg parasitoids as suggested by Waterhouse & Norris (1987) and have made progress towards distinguishing the various species. We expect eventually to revise the taxonomy of those species attacking eggs of fruit piercing moths in the Pacific. To date, two parasitoids from Papua New Guinea appear to be valuable biological control agents. These are now being evaluated in Western Samoa. If these parasitoids prove effective, they will be considered for introduction to other Pacific countries incuding Tonga, Fiji, Guam and American Samoa. If biological control of fruit piercing moths is not achieved with egg parasitoids, we

expect to extend our search for parasitoids of more advanced pest stages from the Asian region.

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BIOLOGICAL CONTROL OF THE SPIRALING WHITEFLY, *ALEURODICUS DISPERSUS* RUSSELL (HOMOPTERA: ALEYRODIDAE), ON POHNPEI, FEDERATED STATES OF MICRONESIA

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ABSTRACT The spiraling whitefly became a serious insect pest on many crops after it was accidentally introduced to Pohnpei in early 1986. The hymenopterous parasite *Encarsia ?haitiensis* Dozier was released and established in Kolonia in early 1987, and reduced the spiraling whitefly population in 6 months. Whitefly nymphs killed by the parasite were easily identified by the round holes created by adult parasite emergence. The parasite was aggressive and had a high host-searching capacity. It was recovered on spiraling whitefly-infested beef steak plants about 6.4 km from the release site. Recent observations also revealed that parasite populations have established in other Pohnpei municipalities and were responsible for reducing spiraling whitefly populations.

On Pohnpei, the spiraling whitefly, *Aleurodicus dispersus* Russell, feeds on the leaf undersurfaces of guava, banana, bell and hot pepper, mango, coconut, citrus, papaya, plumeria, sweet potato, taro, cassava, eggplant, ground orchid, bittermelon, beans, and a red-leafed ornamental plant locally called "beef steak" plant. Although polyphagous, the spiraling whitefly does considerable damage only to guava, plumeria, bell pepper, beans, bittermelon and beef steak plant. It inflicts damage mostly by sucking sap from leaves, thereby causing foliage to turn yellow and eventually drop to the ground. Infested leaves also show a blackened appearance due to the presence of sooty mold growing on the whitefly produced honeydew.

The spiraling whitefly was first recorded on Guam in 1981 on plants around the home and nursery of an individual who imported ornamentals from Hawaii (Schreiner & Nafus 1986). Two natural enemies, a coccinellid, *Nephasis amnicola* Wingo, and an aphelinid parasite, *Encarsia ?haitiensis* Dozier, were imported and released in Guam. They established and provided control of the pest (Schreiner, 1985). However, the spiraling whitefly spread to Saipan and finally reached Pohnpei in early 1986, leaving its natural enemies in Guam. That same year, the spiraling whitefly population increased rapidly on Pohnpei, spreading to the five municipalities and causing considerable damage to crops by year's end.

This paper reports on the effectiveness of *E. ?haitiensis* introduced for spiraling whitefly control on Pohnpei.

Materials and Methods

The first *E. ?haitiensis* shipment from Guam was received in February 1987. The shipment consisted of 4 test tubes with 5, 10, 8 and 3 adults in the respective tubes. Using the following method, parasites were released immediately on 4 whitefly-infested guava trees growing in different sections of Kolonia. On each guava tree, a twig with whitefly-infested leaves was selected, enclosed with muslin cloth, and the parasites from one test tube were released inside the enclosure. When enclosing a twig with muslin cloth, adequate space was provided for the parasites to move freely and search for the host. The ends of the cloth were tied to the twig with twine to prevent parasite escape. Selected twigs were on shaded tree parts to protect parasites from direct sunlight. Muslin cloth was removed 3 days after parasite introduction.

A second parasite shipment consisted of four test tubes with 14, 22, 15 and 17 adult *E. ?haitiensis* in respective tubes. Parasites were released on whitefly-infested beef steak plants growing near the College of Tropical Agriculture & Science (CTAS) office. The colonization procedure used on guava was followed in releasing parasites on beef steak plants.

One day prior to *E. ?haitiensis* releases, ten randomly selected leaves from each guava tree and ornamental plant were sampled to determine the whitefly density on each infested leaf. Each leaf was placed in a bottle with 70 percent ethyl alcohol to kill the insects and facilitate counting. Three to six months after releasing *E. ?haitiensis*, ten leaves were randomly selected from each tree and ornamental plant. These infested leaves were placed in individual plastic bags and observed under a stereoscopic microscope. Parasite exit holes in the whitefly pupae were small, smooth, and round. Healthy adult whiteflies emerged from "T" shaped slits on the dorsum of pupae. The number of parasite exit holes were recorded.

After counting, parasitized whitefly pupae on foliage were held in Dixie® Cups with plastic covers for two

Table 1. Parasitization of the spiraling whitefly by *Encarsia ?haitiensis* at Kolonia, Pohnpei, Federated States of Micronesia, 1987.

	Mean No. Per Leaf								
	Spiraling whiteflies			Parasite exit holes		Whitefly exit holes		% Parasitized whiteflies	
	Before	Months After Release							
Plant No.[a]	parasite release	3	6	3	6	3	6	3	6
				Guava					
1	15.6	16.1	8.5	10.7	7.3	3.3	0.1	66.5	85.9
2	19.1	22.4	4.0	14.1	3.3	7.0	0.2	63.0	82.5
3	25.3	37.0	1.7	12.3	1.2	23.4	0.4	33.2	70.6
4	50.2	48.0	7.1	7.0	4.4	37.7	1.6	14.6	62.0
				Beef steak plant					
1	72.2	107.3	14.5	33.9	11.6	64.0	2.1	31.6	80.0
2	20.4	87.1	2.7	21.4	2.2	59.7	0.4	24.6	81.5
3	23.1	10.2	11.1	4.5	9.3	4.6	1.1	44.1	83.8
4	60.0	15.1	2.4	8.3	1.7	6.1	0.3	55.0	70.8

[a] Ten leaves sampled per plant

weeks for parasite emergence. After emergence, parasites were transferred to test tubes, plugged with cotton soaked in sugar solution to provide nourishment, and transported to other Pohnpei municipalities. Additionally, adult parasites were collected on guava and ornamental plants growing near release sites, and subsequently released on infested crops in other municipalities to further facilitate parasite dispersal.

Results and Discussion

Although considered a more serious crop pest during dry months, the spiraling whitefly persisted in large numbers throughout the year on Pohnpei, a wet island with an evenly distributed annual rainfall of almost 500 cm. At the release site, the spiraling whitefly density averaged 15.6 to 50.2 per infested guava leaf, and 20.4 to 72.2 per infested leaf of the beef steak plant (Table 1). No parasite exit holes were observed. Furthermore, on heavily infested leaves, most whiteflies counted were in the nymphal stage. Adult spiraling whiteflies fly readily and disperse to uninfested leaves when whitefly densities on infested leaves become high.

Three months after *E. ?haitiensis* was introduced, there was a slight increase in the spiraling whitefly population: 16.1 to 48.0 individuals per infested guava leaf and 10.2 to 107.3 individuals per infested beef steak plant leaf (Table 1). On guava, 14.6 to 66.5 percent of the nymphs were parasitized, while on beef steak plant 24.6 to 55.0 percent of the nymphs were parasitized.

Six months after *E. ?haitiensis* was introduced, the spiraling whitefly population was reduced to low levels at release sites as a result of high parasitization. Only 1.7 to 8.5 whiteflies and 2.4 to 14.5 whiteflies per leaf were recovered from guava and beef steak plant, respectivelty (Table 1). Parasitization ranged from 62.0 to 85.9 percent on guava and 70.8 to 83.8 percent on beef steak plant. Old leaves encrusted with sooty mold were almost rendered whitefly-free. New shoots and leaves appeared and in the case of guava, the trees began producing new fruit buds.

The few parasites released on spiraling whitefly-infested guava leaves in each municipality reproduced rapidly and dispersed readily to other whitefly-infested trees growing near the release sites. As a result, the whitefly population declined and in some cases could hardly be found on those trees where parasites were released. Furthermore, parasites were recovered from beef steak plants growing about 6.4 km from release sites.

Conclusions

Successful biological control of the spiraling whitefly occurred on a wet island such as Pohnpei. The parasite imported from Guam, *E. ?haitiensis*, established on guava and ornamental plants and reduced spiraling whitefly population to a low level. The parasite also reduced whitefly infestations on other crops. This is an example of good biological control being achieved with very few individuals in the original release. It is likely that biological control will work on other exposed major pests present in Pohnpei such as the orange spiny whitefly, red coconut scale and coconut transparent scale.

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INSECT PESTS OF TARO (*COLOCASIA ESCULENTA*) AND THEIR BIOLOGICAL CONTROLS IN AMERICAN SAMOA

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ABSTRACT Taro, *Colocasia esculenta* (L.) Schott, a staple crop in American Samoa, was found to serve as a plant host to several potentially devastating insect pests: the taro armyworm, *Spodoptera litura* (F.); the taro hornworm, *Hippotion celerio* (L.); the taro aphid (= melon aphid), *Aphis gossypii* Glover; and the taro planthopper, *Tarophagus proserpina* (Kirkaldy). Sixty taro plants were observed weekly over a seven month period in 1985 - 1986. *Apanteles* sp., *Euplectrus* sp., and *Chelonus* sp. were found parasitizing *S. litura* on these plants. A hymenopteran parasite, a ladybird beetle, and a syrphid fly larva were biological control agents found in association with the taro aphid. *Cyrtorhinus fulvus* Knight preyed on eggs of the taro planthopper. A population study of the taro planthopper yielded a negative binomial distribution. An extract of diseased *S. litura* larvae was as effective as Dipel® (*Bacillus thuringiensis*) in causing taro armyworm mortality in a laboratory trial. Intercropping taro with pate, *Coleus blumei* Benth, had no measurable effect on taro armyworm incidence.

Taro, *Colocasia esculenta* (L.) Schott, a member of the Araceae, is an ancient crop grown throughout the tropics and subtropics for its edible corm. It is the major staple crop in American Samoa. Little is known regarding insect pest species on this crop or related biological controls in American Samoa. Planting pate, *Coleus blumei* Benth, with taro is a local practice which farmers believe decreases numbers of taro armyworms (= taro anufe 'ai Taro; cluster caterpillar; tropical armyworm; rice cutworm), *Spodoptera litura* (F.), in intercropped fields.

This study was conducted to determine which insect species were present on taro, assess their associations with the crop, and determine the effectiveness of intercropping pate, *Coleus blumei* Benth, with taro to control the taro armyworm.

Materials and Methods

Intercropping study. A 550 m^2 plot was laid out in a completely randomized design with four treatment combinations: Niue and Manua taro cultivars planted in the presence and absence of *C. blumei*. Each treatment combination was replicated two times. There were between 81 to 99 plants per treatment combination. Once or twice each week, beginning four days after planting, eight plants were randomly selected from each treatment combination and the type and number of insects on each plant were recorded. In all, 33 such samples were taken over a 22 week survey period. Counts or careful estimates (of highly mobile insects) were tabulated for four specific pests: taro armyworm; taro planthopper (= saga *or* gao gao), *Tarophagus proserpina* (Kirkaldy); taro hornworm, *Hippotion celerio* (L.); and taro aphid (= melon aphid, cotton aphid), *Aphis gossypii* Glover. Because taro planthopper numbers could exceed an estimated 1000 insects per plant, their populations were grouped into blocks of 50 and an integer assigned for each block. For example, a sample having 0 to 49 planthoppers per plant was assigned the value of 0; 50 to 99 planthoppers per plant was 1; and so forth up to 20 which represented 1000 or more planthoppers per plant. Counts of *Cyrtorhinus fulvus* Knight, an egg-piercing mirid predator of the planthopper were also recorded. To detect parasites of the taro armyworm, *S. litura* larvae were randomly removed from the field, isolated in vials, and closely monitored for parasite emergence.

Insect pathogen study. To study what appeared to be a naturally occurring taro armyworm disease, an experiment was undertaken when several diseased armyworms, characterized by their bloated and discolored appearance, were noted in the field. Ten to twelve containers holding 10 - 15 first and second instar larvae were set up to receive each of the following treatments: Dipel® (*Bacillus thuringiensis* var. *kurstaki*); diseased insect spray; and a water control. For the diseased insect spray, two infected armyworms were ground in a blender with 70 ml of water. The liquid was decanted off and about 0.5 ml of this solution was sprayed on the larvae in each container. Mortality data was collected for four days.

Results and Discussion

Intercropping study. Parasite species in three genera emerged from *S. litura* larvae: *Apanteles* sp., *Euplectrus* sp. and *Chelonus* sp. The taro armyworm has been reported as an occasional serious pest of taro in American Samoa. In our case, however, we did not find this to be so. Possibly, environmental conditions were not conducive to the reproductive cycle of the armyworm or

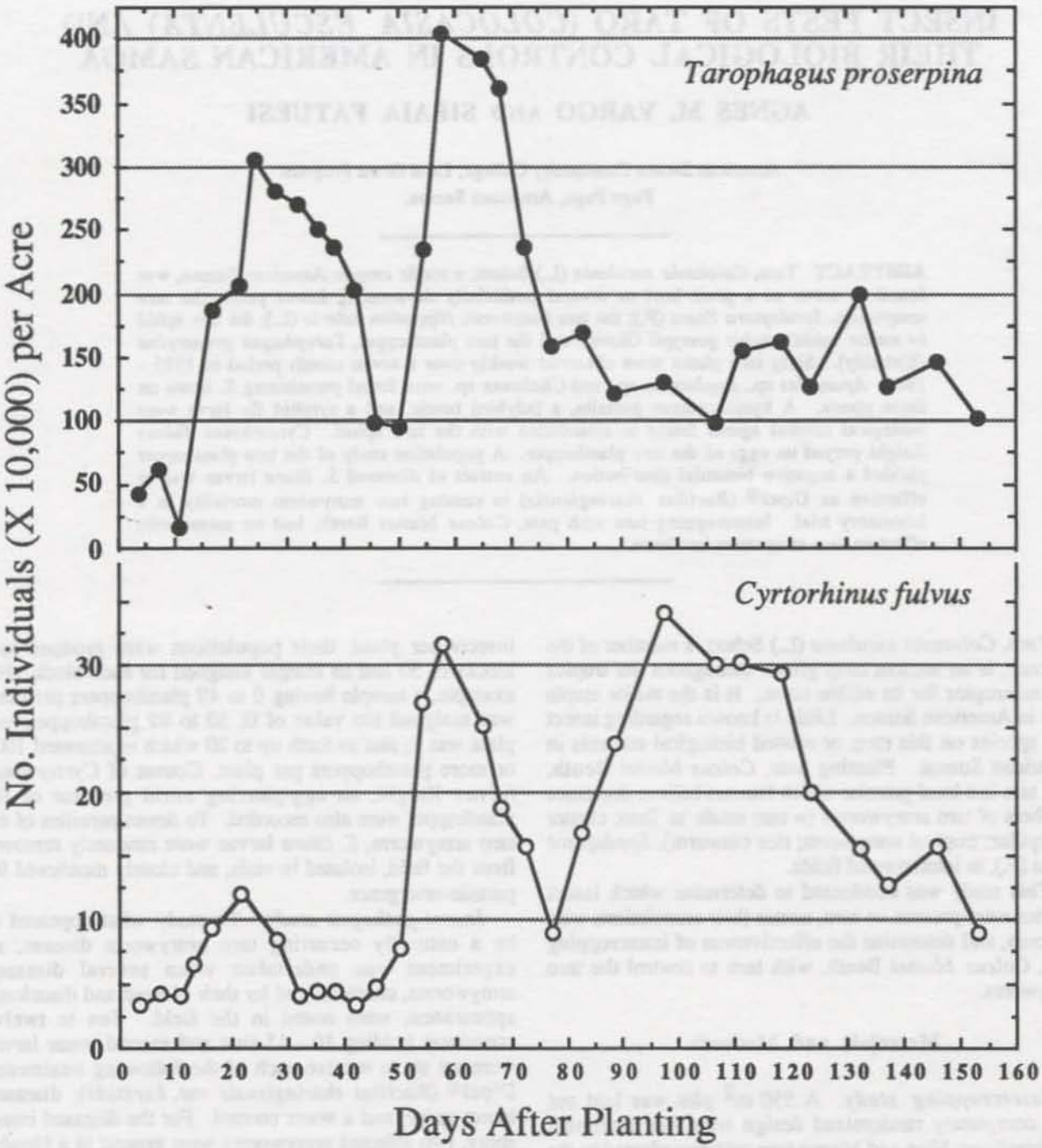

Fig. 1. Comparison of densities of the taro planthopper, *Tarophagus proserpina*, and the egg-piercing mirid predator, *Cytorhinus fulvus*, in a taro field.

perhaps the biological control complex present in this area, where no pesticides had been used, was sufficient to hold pest populations in check.

Analysis of variance indicated no significant differences in taro armyworm populations among those plots which contained pate and those which did not. As indicated above, armyworms were not considered a serious problem at this time. In 66 percent of the 2012 sample counts, no armyworms were found. Although leaf damage was not measured quantitatively, overall observations and local opinion indicated that damage was negligible.

The taro planthopper was often found in large numbers on taro along with the mirid predator *C. fulvus* (Fig. 1). Both insects were found together in young, unfolded taro leaves and all leaf petioles. Leaves with high planthopper infestations (1000/per leaf) turned yellow, often with the entire petiole rotting. However, there was no evidence of alomae and bobone, two viral diseases transmitted by the planthopper.

Fluctuations in the taro planthopper and predator populations appeared to follow a typical biological control

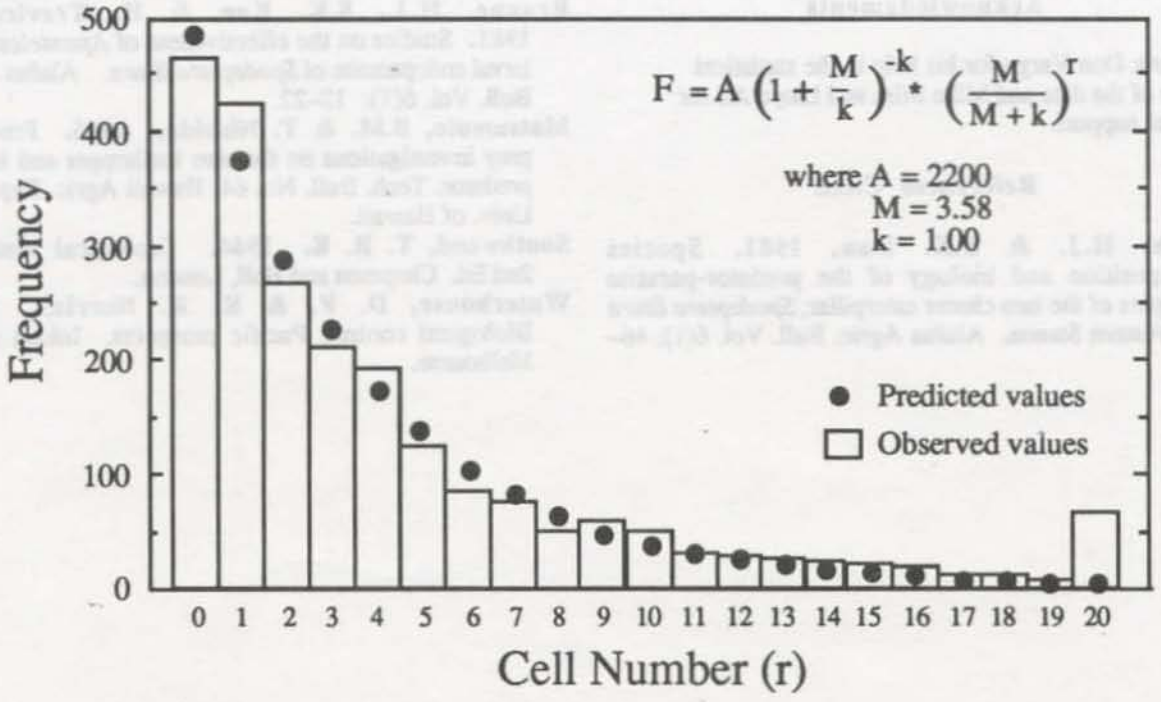

Fig. 2. Frequency distribution of taro planthopper from 0 to 22 weeks after planting using grouped and transformed data. Counts were partitioned into cells of 50 insects, with 0 representing 0 to 49 planthoppers, 1 representing 50 to 99 planthoppers, etc. Bars indicate actual counts and the smooth curve is a theoretical best fit of the negative binominal distribution. M = mean; k = dispersion parameter; A = measure of amount of clumping.

scenario where an increase in the prey population is followed by an increase in the predator population (Fig. 1). After day 75, the increase in the planthopper population corresponded to a decrease and leveling off of the planthopper population. The population dynamics of this complex suggests that *C. fulvus* is actively suppressing the taro planthopper.

One step in the integrated pest management approach to controlling pests is devising a sampling method which will allow farmers to determine when to apply pesticides. The population distribution of the pest must first be determined. The model that best fitted our grouped and transformed data with better than 99 percent confidence was the negative binomial distribution (Southwood 1966). (Fig. 2). This implied that our methods of sampling and estimation were accurate and reliable. The deviation from the curve in cell 20 suggests that errors in estimation are more likely to occur when large numbers of planthoppers are present. In the future, this mathematical model will be used, along with yet to be determined economic thresholds in the development of a sequential sampling method to assist in taro planthopper control.

The taro hornworm and the taro aphid were occasional pests. Ladybird beetles, syrphid fly larvae, and parasitic wasps appeared to keep the aphid population in check. Species identification of these natural enemies is underway.

Insect pathogen study. An evaluation of the insect disease experiment showed that mortality in the Dipel and dead-insect spray group was significantly different ($P = 0.01$ level) from the control group. There were no significant differences between the Dipel and insect spray group. Mean percent mortalities after four days were 75, 83, and 46 percent in the Dipel treatment, diseased-insect spray, and control, respectively. The occurrence of this disease may be another factor in the low incidence of armyworms observed.

Conclusions

In American Samoa, taro appears to be an ideal crop in consideration of the pest and biological control complexes present. Additionally, a naturally-occurring taro armyworm disease appears to suppress the *S. litura* population. Pate, *C. blumei*, intercropped with taro did not significantly reduce taro armyworm numbers in our plots. However, its true effects may be masked because the armyworm population was low during the experiment. Additional studies are necessary to determine the role of pate as well as the influence of seasonality, rainfall, and other abiotic factors.

Taro planthopper can occur in large numbers, causing mechanical damage. It's mirid predator, *C. fulvus*, appears to be an effective biological control. Study of the population dynamics of the planthopper yielded a negative binomial distribution. Additional studies are necessary to determine economic thresholds for this pest.

Acknowledgments

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THE LEUCAENA PSYLLID: A CASE HISTORY OF AN EPIDEMIC AGROFORESTRY PEST

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ABSTRACT The Leucaena psyllid, *Heteropsylla cubana* Crawford, is native to the Caribbean region where its principal host, *Leucaena leucophylla* (Lam) de Wit, originated. It appeared suddenly in Hawaii in 1984 where it underwent explosive population growth and caused severe defoliation of Leucaena throughout the state. It spread rapidly from Hawaii throughout the south and western Pacific, and now occurs almost everywhere Leucaena grows, as far west as India. Long distance dispersal has been primarily by adults carried in aircraft, and its likely that circumglobal distribution will be achieved within a few years.
Leucaena is one of several rapidly growing tropical trees now being widely planted for biomass production, reforestation, etc. When planted in exotic locations such trees generally are devoid of the phytophagous pests which occur in their native homes. Large plantings are vulnerable to pest epidemics when their native pests are spread accidently into new areas, as in the case of the Leucaena psyllid. Classical biological control, utilizing pest natural enemies from the tree's native home, has a high likelihood of success in such cases, but lack of taxonomic knowledge about pests of tropical forest trees and their natural enemies has hampered this work.

Leucaena leucocephala (Lam.) de Wit, commonly called Koa haole or ekoa in Hawaii, is a fast growing, leguminous tree which apparently orginated in Central Mexico or the Yucatan Peninsula of Central America, but is now widely distributed throughout tropical America, and, since 1600, has spread pantropically (Brewbaker 1987). Although considered by some people in Hawaii to be an undesirable weed, *L. leucocephala* has proven to be a highly useful plant in most areas where it now grows. In addition to its rapid growth rate, *L. leucocephala* fixes nitrogen, resists drought, is easily propagated and can be harvested repeatedly. It is extensively utilized for human food, animal fodder, firewood, light construction, windbreaks, erosion control, reforestation, wood pulp, and as a shade tree for plantation crops such as coffee and cacao (Brewbaker 1987).

Until quite recently *L. leucocephala* had relatively few serious insect pests in most areas where it grew. Because distribution was usually by seed dispersal, phytophagous insects associated with *L. leucocephala* in its native home had not spread outside of the Caribbean region. However, in April 1984, a narrowly oligophagous psyllid, *Heteropsylla cubana* Crawford, was discovered heavily infesting uncultivated leucaena plants in Hawaii. Explosive psyllid population growth there was followed by widespread defoliation and dieback of *L. leucocephala*, a dominant element of wild vegetation in many lowland areas of the islands. Despite dramatic increases in populations of predaceous coccinellid beetles, principally *Curinus coeruleus* (Mulsant) and *Olla v-nigrum* (Mulsant), both of which were already present, and the successful introduction of an encyrtid parasite, *Psyllaephagus yaseeni* Noyes, from Trinidad, *H. cubana* has continued to cause sporadic damage to leucaena in Hawaii. It is presently considered to be under partial biological control.

H. cubana spread extremely rapidly from Hawaii, throughout the south and western Pacific islands, northern Australia, Indonesia and southeast Asia, as far west as Sri Lanka and India (Mitchell & Waterhouse 1986, Waterhouse & Norris 1987, Napompeth 1989). It seems inevitable that within a very few years the distribution of this pest will be circumglobal, wherever *Leucaena* is grown. Although the economic impact of repeated defoliation and dieback of *L. leucocephala* caused by *H. cubana* has been relatively minor in Hawaii, the pest has caused devastating economic losses in places where leucaena is a major source of animal fodder, firewood, and the like, as in Indonesia, the Philippines and south Asia.

The increasing use of rapidly growing exotic trees such as *Leucaena* and *Eucalyptus* in agroforestry for biomass production, firewood, animal fodder, and reforestation, particularly in the developing countries of the tropics, may be creating extensive, essentially monoculture plantings. These are highly vulnerable to epidemics of introduced pests such as the leucaena psyllid. One reason for planting such trees is their rapid growth, which, in turn, is often related to the absence of serious pests. The spread of the leucaena psyllid is believed to have been largely by means of adults on aircraft. Adults of *H. cubana* are attracted to light, and *L. leucophylla* is commonly found growing in the vicinity of airports throughout the Pacific and south Asia. Night-loading aircraft are probably often invaded by these psyllids, thereby facilitating the rapid spread of this pest.

Pests of some other widely planted tree species have spread from their native homes in a similar, if somewhat less spectacular, manner. For example, the acacia psyllid, *Psylla uncatoides* (Ferris and Klyver), a pest of pyllodenous *Acacia* species, has spread from Australia to New Zealand, California, Hawaii and Europe. The blue gum psyllid, *Ctenarytaina eucalypti* Maskell, is another Australian native that has become a serious pest of biomass plantings of *Eucalyptus globulus* in Portugal, South Africa and South America.

Although the potential for serious new insect pest problems in agroforestry plantings is great, in many cases, with insect pests at least, the possibilities are also good that successful biological control can be achieved. The classical method of returning to the pest's homeland to seek natural enemies has worked well with such introduced forest insects as the eucalyptus snout beetle in South Africa (Tooke 1955) and acacia psyllid in California and Hawaii (Leeper & Beardsley 1976). A major hurdle to rapid biological control solutions in such cases has often been a lack of taxonomic knowledge concerning both the pests of tropical trees and the natural enemies of those pests. The leucaena psyllid is a case in point. The taxonomy of the genus *Heteropsylla* is presently in a confused state. As a result, the proper identification of the pest species required several months. Additional problems occurred in attempting to identify the parasites associated with *H. cubana* in the Caribbean region. The parasite which has been released in Hawaii and other parts of the Pacific, *Psyllaephagus yaseeni*, was undescribed until recently. A second parasite, recently described as *Taxarixia leucaenae* Boucek (Eulophidae), was discarded from insectary cultures in Hawaii. It was at first identified as *Tetrastichus triozae* Burks, a supposedly widespread species with a wide host range, which, in reality, is probably a complex (now placed in *Taxarixia*), the individual species of which may be relatively host specific. According to McClay (1989), *T. leucaenae* is the dominant parasite associated with *H. cubana* in Mexico.

The possibility of future catastrophic outbreaks of new insect pests, similar to the leucaena psyllid epidemic, threatens large scale agroforestry planting of fast-growing tree species throughout the tropics. The creation of extensive monospecific plantings of exotic trees such as *Leucaena leucocephala*, for reforestation, biomass production, and the like, is inherently dangerous for that reason. Sooner or later, pests associated with such trees in their native homes will span the ocean gaps which separate them from these exotic plantings. We need to do the basic research now to identify those native pests of important agroforestry trees which have the most potential to cause future problems. Also we need to determine what natural enemies are available that are potentially useful for future biological control programs which may need to be implemented to control these pests.

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PRELIMINARY SURVEY OF POSSIBLE APHID VECTORS OF A CUCURBIT VIRUS COMPLEX ON THE ISLAND OF MAUI, HAWAII

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ABSTRACT A complex of plant viruses including Zucchini Yellow Mosaic Virus, Watermelon Mosaic Virus I & II, and Cucumber Mosaic Virus causes major crop loses in the cucurbit growing areas of the Hawaiian Islands. Several aphid species are known to transmit these non-persistent viruses to zucchini and other cucurbits. To gain an understanding of how aphid populations influence virus epidemiology, a preliminary survey of aphid species was conducted at three elevations on the island of Maui using yellow pan traps to capture alate aphids.

Seasonal abundance data provided by alate aphid trapping indicated relatively high aphid vector populations throughout the year. Preliminary data indicate higher aphid numbers during January and February in the sampled areas. Throughout the year the greatest number of aphids were collected at the highest elevation (930 m, Kula Research Center) monitored.

Methods of preparing aphids for identification by morphological characterization were used instead of time-consuming slide mounting of individual aphids. Development of an identification key of collected aphids is in progress.

A virus complex including Cucumber Mosaic Virus (CMV), Watermelon Mosaic Virus 1 and 2 (WMV-1 and WMV-2, respectively) and Zucchini Yellow Mosaic Virus (ZYMV) has been previously reported in Hawaii. A recent cucurbit virus survey indicated the predominance of ZYMV and WMV-1, (Cho et al. 1991, Ullman et al. 1991). However, CMV and WMV-2 have been prevalent in the past. All these viruses are transmitted non-persistently by aphids. In recent years, zucchini production on the island of Maui has been severely affected by ZYMV. Frequently, commercial plantings are 100 percent infected before first harvest, thereby limiting the harvest duration period.

A survey of the alate stage of aphid species present in the zucchini growing areas was conducted to 1) determine which aphid species were present in the area and their seasonal abundance; and 2) determine the abundance of known vector species of the cucurbit virus complex.

Materials and Methods

Alate aphids were captured in yellow pan traps 30.5 cm diam. and 10.2 cm deep. Several holes were made in the top 2.5 cm of the trap rim and screened to prevent specimen loss in case of water overflow due to rainfall. Ten traps were placed 3.04 m apart on the outside of zucchini fields and filled with soapy water.

Traps were placed at three sites at different elevations: Agriculture Park (AGP) = 335 m, Pulehu (PUL) = 640 m and Kula Research Center (KRC) = 930 m.

Aphids were removed from traps approximately every three days and preserved in 70 percent ethyl alcohol. Collected aphids were processed with 10 percent potassium hydroxide and a modified Essig's clearing solution (Kono & Papp 1977). Treated aphids were identified using a binocular dissecting microscope.

Results and Discussion

Aphid counts in the first and second half of each month were compiled and plotted. Using this method, seasonal abundance of the total aphids captured from November 1987 to June 1988 at the three survey sites was illustrated (Fig. 1). The pattern of abundance was similar at all sites. Aphid numbers increased in January 1988, peaked in February, decreased sharply, and was then followed by a moderate increase in April and May. The highest elevation surveyed, KRC, consistently had the highest aphid numbers while lower elevations, AGP and PUL, had fewer aphids, but similar distributions.

Aphid species in Hawaii reported in the literature as vectors of the respective cucurbit viruses are listed (Table 1). The proportion of reported vectors of the cucurbit virus complex was similar at all sites surveyed (Fig. 2). The mean proportion of reported vectors versus non-vectors was 80 percent over the duration of the sample period.

The percentage of cucurbit virus complex vectors found in this study which are reported vectors of ZYMV or WMV-1 is presented (Table 2). Reported vectors of the two predominant viruses make up approximately 60 percent of the total vector species captured throughout

Table 1. Reported aphid vectors of cucurbit virus diseases.

Species	CMV	WMV I	WMV II	ZYMV
Acyrthosiphon pisum	1[a]	1?[b]	6	7
Aphis citricola		3	3	7
Aphis craccivora	1	3	3	8
Aphis fabae	1			
Aphis gossypii	1	1?	3	5
Aphis middletonii			6	7
Aulacorthum solani	1		6	
Brachycaudus helichrysi	1			
Brevicoryne brassicae	1		4?	
Cavariella aegopodii	2			
Hyperomyzus lactucae	1			
Lipaphis erysimi	1		4?	7
Macrosiphum euphorbiae	1		6	
Myzus ornatus	1			
Myzus persicae	1	1?	3	7
Rhopalosiphoninus latysiphon	1			
Rhopalosiphum maidis	1		4?	
Rhopalosiphum nymphaeae	1			
Rhopalosiphum padi	1		6	
Toxoptera citricidus			6	

[a] Numbers indicate source of reference.

[b] ? = no strains of WMV indicated in the source.

1 Kennedy et al. (1962)
2 Carter (1973)
3 Adlerz (1974)
4 Sako et al. (1977)
5 LeCoq et al. (1981)
6 Yamamoto et al. (1982)
7 Adlerz (1987)
8 Ullman D.E. & J.Cho (unpublished data)

Table 2. Percentage of reported vectors of ZYMV and WMV-1

Species	KRC[a]	PUL[a]	AGP[a]
Aphis gossypii	26	16	22
Myzus persicae	17	35	26
Aphis craccivora	9	14	9
Aphis middletonii	3	<1	1
Aphis citricola	1	<1	<1
Lipaphis erysimi	1	<1	<1
Acyrthosiphon pisum	<1	<1	<1
Total	57	66	59

[a] KRC = Kula Research Center; PUL = Pulehu; AGP = Agriculture Park

the survey period. The majority of vectors captured were *Aphis gossypii* Glover, *Aphis craccivora* Koch and *Myzus persicae* Sulzer.

The preliminary seasonal abundance survey of aphids indicated a high number of alate aphids present at the three elevations. Populations were greatest at the highest elevation, KRC. This may be due to the greater diversity of vegetation in the surrounding area given the site is a research facility with various plant types. The number of aphids in the two lower elevation sites were consistently lower than at KRC and similar throughout the survey period. These areas were primarily small farms with less diverse vegetation than in the KRC area.

The proportion of reported vectors of the cucurbit virus complex, however, was similar for all three locations. Over one half of the total aphids captured were potential vectors of the cucurbit virus complex, providing strong pressure for potential disease outbreaks. Moreover, the majority of vectors were able to transmit the ZYMV and WMV-1 viruses known to be present in the zucchini growing areas. With such large numbers of aphid vectors present, control of the non-persistent

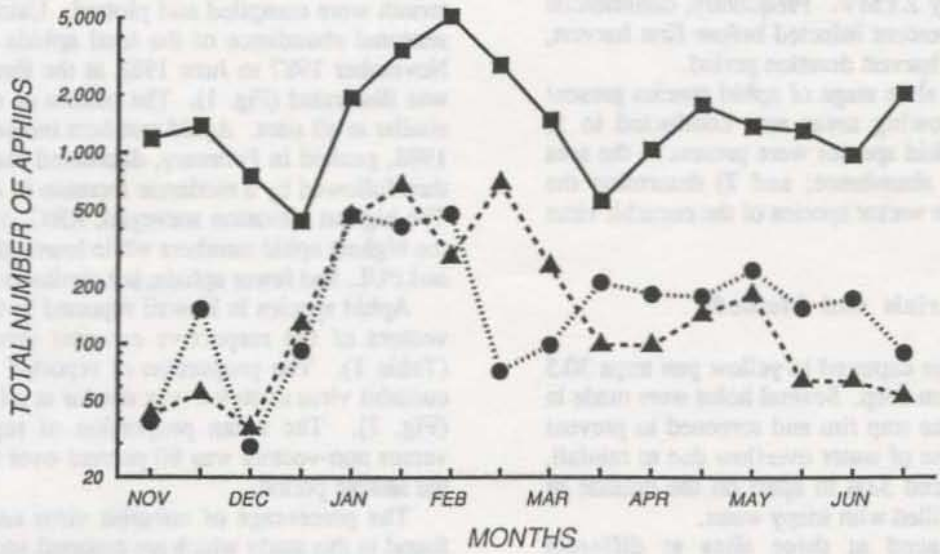

Fig. 1. Total number of aphids captured per two week period at three elevations.

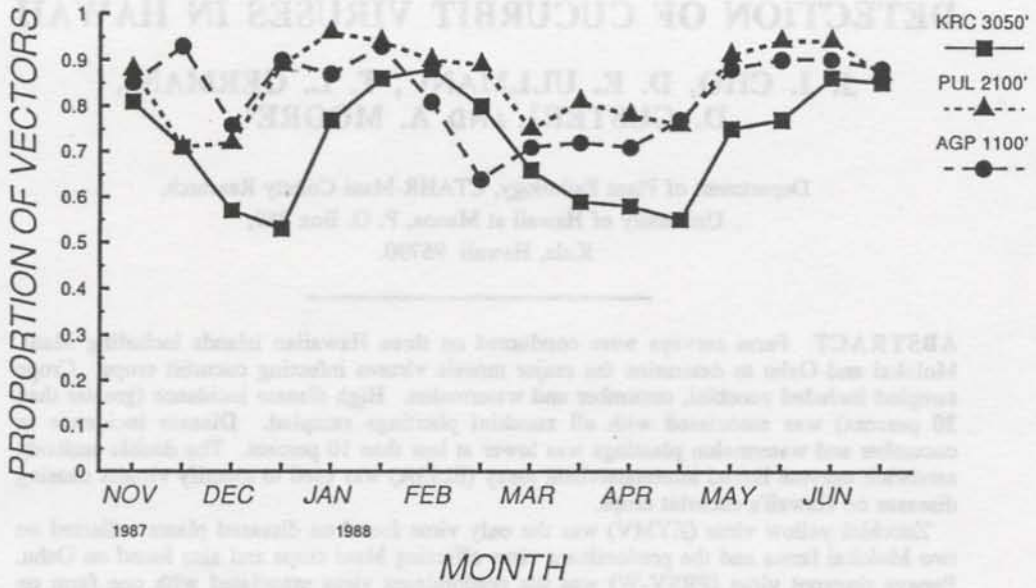

Fig. 2. Proportion of reported aphid vectors of the cucurbit virus complex.

diseases cannot be accomplished by controlling aphid populations alone. Alternative management strategies such as cultural controls, aphid repellents, and use of resistant varieties must be implemented.

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DETECTION OF CUCURBIT VIRUSES IN HAWAII

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ABSTRACT Farm surveys were conducted on three Hawaiian islands including Maui, Molokai and Oahu to determine the major mosaic viruses infecting cucurbit crops. Crops sampled included zucchini, cucumber and watermelon. High disease incidence (greater than 30 percent) was associated with all zucchini plantings sampled. Disease incidence in cucumber and watermelon plantings was lower at less than 10 percent. The double antibody sandwich enzyme linked immunosorbent assay (ELISA) was used to identify viruses causing diseases on Hawaii's cucurbit crops.

Zucchini yellow virus (ZYMV) was the only virus found on diseased plants collected on two Molokai farms and the predominant virus affecting Maui crops and also found on Oahu. Papaya ringspot virus (PRSV-W) was the predominant virus associated with one farm on Oahu; and accounted for 3, 29 and 49 percent of infected plants on Maui farms. Cucumber mosaic virus (CMV) and watermelon mosaic virus (WMV2) were not detected on any of the surveyed farms.

Two wild cucurbits on Maui were found to harbor mosaic viruses. *Momordica balsamina* plants (wild bittermelon) were infected with ZYMV and *Lagenaria siceraria* (togan squash) was found infected with ZYMV and PRSV-W.

Cucurbit crops grown in Hawaii include cucumber, watermelon and zucchini. Major production areas for cucumbers are located on three islands including Maui, Hawaii and Oahu; for watermelon are Oahu and Molokai; and for zucchini are Maui and Hawaii.

Cucurbit mosaic virus diseases are major limiting factors for efficient cucurbit production in the State. Mosaic viruses typically account for losses of 10 to 30 percent in cucumber and watermelon and account for severe losses in zucchinis where 100 percent losses have frequently been observed after 1 to 2 fruit harvests.

Several viruses have been reported in the literature to infect cucurbit crops of which five are known to cause important crop losses. These include cucumber mosaic virus (CMV), squash mosaic virus (SQMV), papaya ringspot virus (PRSV-W), watermelon mosaic virus 2 (WMV2), and zucchini yellow mosaic virus.

Disease symptoms exhibited by affected cucurbits show typical veinclearing, mosaic patterns and leaf distortion particularly early on in infection. Later stages of infection by papaya ringspot virus and zucchini yellow mosaic virus can be easily distinguished from other mosaic viruses in that plants exhibit typical leaf distortion, strapping and inward cupping of the leaves. Another typical symptom of PRSV-W and ZYMV is fruit distortion and malformation. Because of the similarities in disease symptoms among the different viruses and possible mixed infections, diagnosis by symptomatology is inadequate.

Materials and Methods

To facilitate detection and identification of the major mosaic viruses, we obtained polyclonal antisera from Drs. Dennis Gonsalves of Cornell University, and Howard Schott of University of Arkansas. Using these antisera, we developed a direct double antibody sandwich enzyme linked immunosorbent assay (ELISA) method for detection and diagnosis of the five major mosaic viruses previously mentioned. Our studies have shown that the ELISA method is quick, reliable, can readily distinguish between viruses in mixed infections, and can be readily used to process large numbers of plant samples in a short period of time.

In this test we simply grind up plant samples being tested separately using a mortar and pestle; load the expressed sap material into ELISA plates previously coated with antisera; and can separate positive virus containing plants from non-infected plants based upon a yellow color reaction. Color intensity is indicative of virus titer.

Results and Discussion

Preliminary studies showed that the antisera used in ELISA could easily differentiate between infected and healthy plant tissues as well as being able to detect mixed infections.

We also determined that infected plant samples could be stored frozen for a month at -20°C and still be serologically active. This has been quite useful since we

can accumulate samples and do all our ELISAs when time permits.

ELISA was used in farm surveys of four islands in the state during the winter of 1988 to 1989. Crops sampled included cucumber, watermelon, and mainly zucchini. CMV and WMV2 were not detected on any of the farms surveyed. We found PRSV-W to be the predominant virus on Oahu at 80 percent. On the other hand, ZYMV was the predominant virus found on Maui at 81 percent and accounted for 100 percent of the infections on Molokai.

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INFLUENCE OF VIRUS INFECTION ON THE YIELD OF BELL PEPPER, *CAPSICUM FRUTESCENS* L., IN THE NORTHERN MARIANA ISLANDS

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ABSTRACT One month old seedlings of bell pepper (variety Emerald Giant) were transplanted into a farmer's field on 5 December 1988. Ten rows were planted with a total plant population of four hundred. On December 13 natural virus infection was observed on some young transplants. Twenty infected and twenty seemingly healthy plants were tagged randomly in the field and their development up to fruiting were monitored. On 8 January 1989, twenty-four seedlings were transplanted in 30.5 cm dia. plastic pots with one seedling per pot. Seedlings were then inoculated with the virus mechanically at various stages of growth.

Infected plants were stunted with their leaves heavily puckered, curled and showing mosaic pattern. Seventy-five percent of the flowers were aborted. Fruit from infected plants were small and many misshapen. Infected plants showed a yield reduction of 52 and 70 percent with respect to fruit number and fruit weight, respectively, as compared to non-infected plants.

Innoculated plants in the pot experiment showed similar trend of results with highly significant differences ($P<0.01$) among treatments.

Bell pepper, *Capsicum frutescens* L., is an important crop in Saipan. It is produced by local farmers to supply the needs of institutional markets such as hotels, restaurants and garment factories. In 1986 - 87, Saipan farmers produced a total of 6,351 kilograms of bell peppers valued at $13,720.00 (Anon. 1986). Farm visits, however, revealed that many bell pepper plants were infected with a virus disease with different degrees of severity.

No work has been conducted on virus diseases affecting bell pepper in Saipan. According to Milbrath & Cook (1971), there are four viruses attacking bell peppers in Hawaii. These are Potato Y Virus, Spotted Wilt Virus, Tobacco Mosaic Virus and Tobacco Etch Virus. Cucumber virus has also been reported to attack bell pepper (MacNab et al. 1983).

With the increasing acreage devoted to this crop on Saipan, control of virus diseases will become increasingly important.

Materials and Methods

Field Study. One month-old bell pepper seedlings (variety Emerald Giant) were transplanted into a farmer's field on 5 December 1988 with 25 cm between plants along a row and 50 cm between rows. Ten rows were planted with a total plant population of four hundred. On 13 December, a natural virus infection was observed on some young transplants. Twenty infected and twenty seemingly healthy plants were randomly tagged in the field and monitored until plants fruited.

Innoculation Study. On 8 January 1989, a single month-old bell pepper seedling was transplanted into each of 24 pots (12 in. dia.) filled with sterilized soil. To determine the effect of innoculation time on the impact of the virus on test plants, two plants were mechanically innoculated with sap from naturally infected pepper leaves at the following times in the plants' phenology: one week post seedling transplant; the vegetative stage; and the flowering stage. An untreated control (2 plants) was also included. Treatments were replicated three times. Plants were fertilized twice with complete fertilizer (16-16-16 NPK), watered regularly, and sprayed biweekly with a combination of carbaryl (Sevin®) insecticide and Tribasic copper fungicide.

Results and Discussion

Field study. Initial symptoms observed were on the emerging young leaves which showed yellowish-green to light and dark green mosaic patterns. As leaves matured they became curled, puckered and deformed. Leaf size was also reduced. Older leaves defoliated prematurely. Affected plants were stunted and bushy with reduced fruit set. Fruit were reduced in size, number and many were misshapen.

At the first harvest on 23 January 1989, the 20 infected plants sampled yielded a mean of 1.70 fruit per plant with a mean weight of 56.8 grams in comparison to non-infected or healthy plants which had a mean of 2.40 fruit per plant with a mean weight of 139.1 grams.

Table 1. Comparative yield of infected and healthy bell pepper plants during 1989 study.

Plant Condition	Survey Date	No. fruit	Fruit wt.
Healthy	23 Jan	48	2,782.8
	2 Feb	40	1,916.5
	13 Feb	49	1,489.8
	All dates	137	6,189.1
Infected	23 Jan	34	1,136.0
	2 Feb	9	213.0
	13 Feb	22	539.6
	All dates	65	1,888.6

In the second and third harvests, fruit numbers and weights further declined in the infected plants (Table 1). Of the non-infected plants, some produced as much as 5 fruit per harvest weighing more than 0.5 kilogram. Comparison of yields of infected to non-infected plants showed that yields of infected plants were reduced 52 and 70 percent in terms of fruit and loss in monetary value, respectively. Monetary loss was $9.00 per plant based on the current price of $0.94 per pound.

Innoculation study. First symptoms of virus infection appeared one week after innoculation. The symptoms were similar to those observed in the field study. Flower abortion was recorded 21 days after the appearance of symptoms. As much as 75 percent flower abortion occurred on plants innoculated in the seedling stage. Plant height was also affected. Infected fruits were severely misshapen and exhibited brown streaks. All were non-marketable. Plants innoculated at vegetative and flowering stages showed severe virus infection, but their heights were not much affected. There were fewer aborted flowers as compared to plants innoculated in the seedling stage. Fruit from these treatments were larger and heavier with fewer misshapen fruit. Analysis of variance showed highly significant differences ($P > 0.01$) among treatments (Tables 2).

Table 2. Bell pepper yield as a result of virus innoculation at various host plant developmental stages.

Treatment	Rep I	Rep II	Rep III	Mean
		Fruit no.[a]		
T_1 Seedling	21	25	18	21.33
T_2 Vegetative	38	34	36	36.00
T_3 Flowering	40	38	37	38.33
T_4 Control	49	42	39	43.33
		Fruit wt. (kg)[b]		
T_1 Seedling	0.87	0.98	0.75	0.86
T_2 Vegetative	1.14	1.08	1.13	1.11
T_3 Flowering	1.17	1.14	1.12	1.14
T_4 Control	1.28	1.23	1.19	1.23

[a] $F = 32.5$, $P < 0.01$, C.V. = 8.26%
[b] $F = 24.2$, $P < 0.01$, C.V. = 7.17%

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EFFECT OF PLASTIC MULCH AND OVERHEAD COVER ON BELL PEPPER PRODUCTION

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ABSTRACT Among the most important diseases of bell peppers on Guam are bacterial wilt, bacterial leaf spot, and soilborne diseases caused by several fungi. Various cultural practices were compared in field tests to find ways of reducing disease losses. Soil amendments (chicken manure, *Casuarina* sp. needles, shredded *Leucaena* sp. clippings) and black plastic mulch were compared with an untreated control in a randomized complete block experiment. Plastic mulch reduced soilborne disease incidence and also increased fruit weight per plant. In a separate experiment, raised beds, plastic mulch, and overhead polyethylene cover were analyzed for their effect on bacterial wilt and bacterial leaf spot. Plastic mulch reduced bacterial wilt incidence while overhead cover reduced leaf spot severity. Highest yields were recorded in raised beds with plastic mulch and overhead cover.

Bell pepper is a popular vegetable on Guam. Market prices range from $1.50 to $2.00 per pound. However, not every farmer profits from growing this crop. Bell pepper has serious disease problems of which bacterial wilt, *Pseudomonas solanacearum*, is the most important followed by bacterial leaf spot, *Xanthomonas campestris* pv. *vesicatoria*. Soilborne pathogens, principally *Sclerotium rolfsii* and *Rhizoctonia solani* are also important (Russo et al. 1985).

Traditionally, if there was an incidence of bacterial wilt in a field, solanaceous crops were not planted there any more. For bacterial leaf spot, copper sprays with or without maneb mixes are used. Preventive treatments of PCNB are recommended at time of transplanting for the control of soilborne fungi control (USDA 1986, Bjork 1986). However, pesticide use increases production costs, may or may not increase yields, and may represent an environmental hazard. Various cultural practices were compared in this study to look for ways of reducing crop losses and production costs, and to simultaneously minimize the need for pesticide applications.

Use of plastic mulch in vegetable production is not new (Emmert 1956). Its advantages for weed control (Porter & Etzel 1982) have long been known. On Guam, the use of plastic mulch was shown to be economically advantageous in bell pepper production (Khamoui & Russo 1985). Biological properties of soils have been shown to be responsible for suppressiveness of soilborne plant pathogens (Alabouvette et al. 1979), and these properties can sometimes be transferred. Where drainage or excessive rain is a problem for growing vegetables in the Orient, raised beds are recommended (Knott & Deanon 1967). Overhead polyethylene cover for vegetable production has proved advantageous in other countries (Brun 1980). This study included tests to evaluate the effect of plastic mulch, soil amendments, and raised beds on soilborne diseases of bell pepper under Guam's particular conditions, as well as the effect of overhead cover on foliar diseases.

Materials and Methods

Soil amendments and mulch test. In a field experiment conducted at Barrigada during the dry season of 1987, various cultural practices were tested for controlling soilborne pathogens on bell pepper, primarily *Sclerotium rolfsii* and *Rhizoctonia solani*. Treatments were as follows: 1) plastic mulch; 2) soil amended with shredded foliage and twigs from *Leucaena* sp. (1 kg/m^2); 3) soil amended with *Casuarina* sp. needles (1 kg/m^2); 4) soil amended with chicken manure (1 kg/m^2); and 5) an untreated control with no mulch or amendments. Treatments were replicated four times. Plots consisted of five 3.6 m long rows with 1.25 m between rows and 0.45 m between plants. Bell pepper seedlings (cv 'Blue Star') were started in trays and transplanted after six weeks. Fertilizer (16-16-16) was administered in two applications with the first at transplant (50 g/plant), and a second side-dressing one month later (23 g/plant). Thereafter, a monthly application of 15 g KNO_3/plant was administered through the drip system. Arthropod pests were controlled as needed with blanket sprays. Irrigation was provided by drip lines.

The experiment was re-planted after six weeks. The plant population, however, was doubled in this second experiment by planting double rows 25 cm apart.

Covered and uncovered plots. A separate experiment conducted in planting beds outside the University of Guam Plant Pathology Laboratory at Mangilao consisted of a 5 m uncovered plot, and a 5 m plot covered with clear polyethylene sheet stretched over arches of PVC pipe 1.5 m tall by 1.5 m wide. Two

rows were planted 0.75 m apart with 0.45 m between plants. Irrigation was provided by drip lines.

Raised and flat beds, with and without mulch and cover. In a split-plot experiment conducted during the rainy season in 1987 at Mangilao, various cultural practices were tested to evaluate their effect on bacterial leaf spot and wilt. Comparisons were made between raised (50 cm) and flat planting beds, with and without plastic mulch, and with and without overhead polyethylene cover. Sub-plots were 4.55 m x 2.75 m, with three rows of plants on 0.5 m centers with 0.35 m between plants. Irrigation was provided as necessary by drip lines. Fertilizer was applied as above. Leaf spot severity was estimated by using standard area diagrams developed from live samples by computer (Wall & Wall 1989).

Results and Discussion

Soil amendments and mulch test. The first experiment planted had no statistically significant differences in soilborne disease incidence between treatments (Fig. 1). However, because some promising trends were evident in the data, a second experiment with a larger plant population was planted. The second experiment was harvested only twice because of its later planting time. The following results pertain to data collected up to the second harvest.

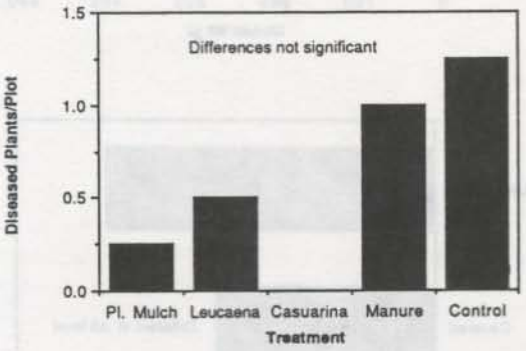

Fig. 1. Effect of various soil amendments and plastic mulch on soilborne plant disease incidence in bell pepper (Experiment I).

In the second experiment, plastic mulch plots had the highest yields (Fig. 2). A multiple regression model based on fruit weight per plant and plant count was able to explain 99.9 percent of the yield variation. The major source of variation was the incidence of soilborne diseases. A regression of yield on plant count (Fig. 3), although statistically significant, was low ($r^2 = 0.308$). However, when plant count data in plastic mulch treatments was analyzed separately from all other treatments, two effects of plant count on yield were apparent. First, where plant populations were low, as in all treatments except plastic mulch, plant count was

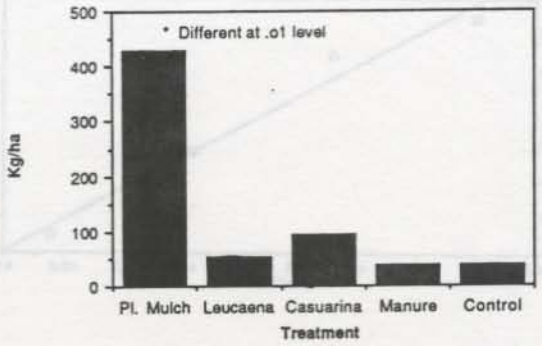

Fig. 2. Effect of various soil amendments and plastic mulch on soilborne plant disease incidence in bell pepper (Experiment II).

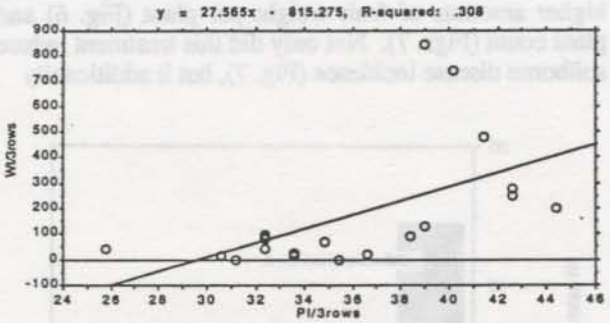

Fig. 3. Relationship of bell pepper yield to plant number in Experiment II ($P<0.05$).

directly correlated to yield (Fig. 4). With reduced disease incidence resulting in higher plant populations, as in the case of the plastic mulch treatment (Fig. 5), plant count and yield were inversely correlated. This suggests that there was a higher than optimum plant density. When analyzed together, therefore, the plant count data showed a low correlation to yield (Fig. 3).

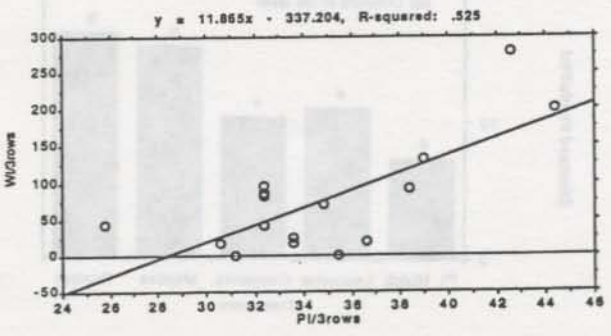

Fig. 4. Relationship of bell pepper yield (g) to plant number in all treatments except the plastic mulch in Experiment II ($P<0.05$).

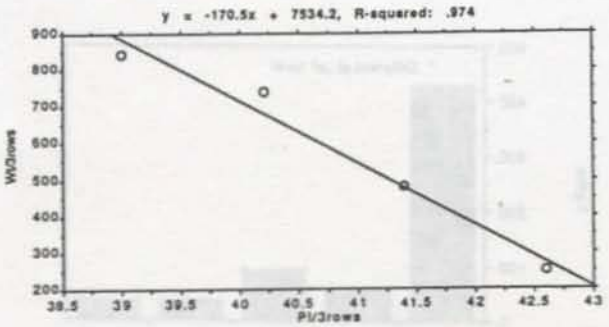

Fig. 5. Relationship of bell pepper yield (g) to plant number in the plastic mulch treatment of Experiment II ($P<0.05$).

The plastic mulch treatment resulted in significantly higher amounts of fruit weight per plant (Fig. 6) and plant count (Figs. 7). Not only did this treatment reduce soilborne disease incidence (Fig. 7), but it additionally

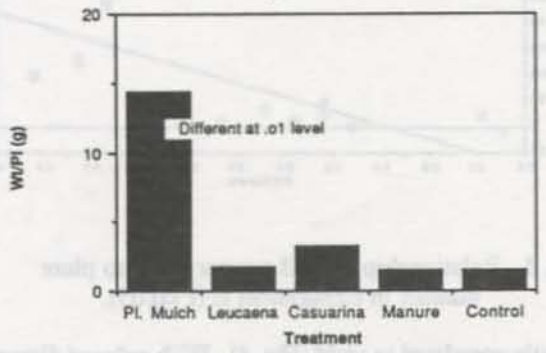

Fig. 6. Effect of various soil amendments and plastic mulch on bell pepper fruit weight per plant.

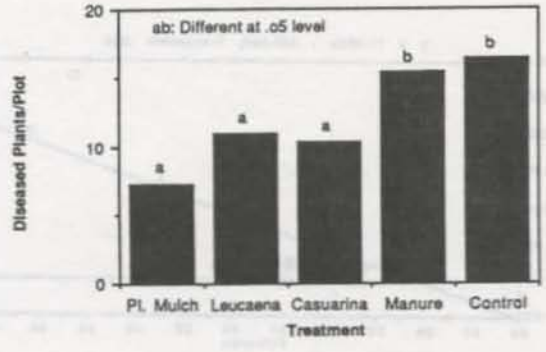

Fig. 7. Effect of various soil amendments and plastic mulch on the number of diseased bell pepper plants.

(and primarily) increased fruit weight per plant through other effects it had on crop development (less weed competition, more soil moisture, lower soil temperature, etc.). It is also quite possible that plant death due to root rot was reduced. Improved root health would contribute to an increase in fruit weight per plant. These effects, however, were not tested.

Together with the findings from experiments in this area (Khamoui & Russo 1985), plastic mulch has been shown to be advantageous in reducing weed problems and control costs as well as plant death due to soilborne pathogens. It increases fruit weight per plant, and has an overall effect that results in higher yields at lower costs.

Covered and uncovered plots. Results of over 20 harvests showed differences in the number of unmarketable fruit (Fig. 8). Overhead polyethylene cover protected the fruit from various types of damage that subsequently resulted in unmarketable fruit.

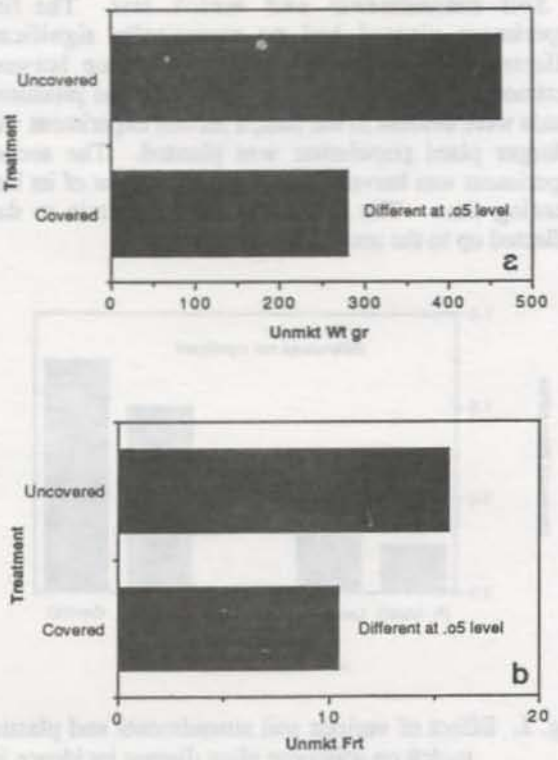

Fig. 8. Effect of polyethylene cover on unmarketable fruit weight (a) and number (b).

Raised and flat beds, with and without mulch and cover. Raised beds reduced bacterial wilt incidence in this test (Fig. 9a). Raised beds also showed a tendency to reduce bacterial leaf spot severity (Figs. 10a). The use of plastic mulch resulted in reduced bacterial wilt incidence (Fig. 9a); however, it showed a tendency to increase bacterial leaf spot severity (Fig. 10a). Overhead cover reduced bacterial leaf spot severity (Fig. 10b) and increased fruit weight per plant (Fig. 11b), which in turn resulted in higher yield.

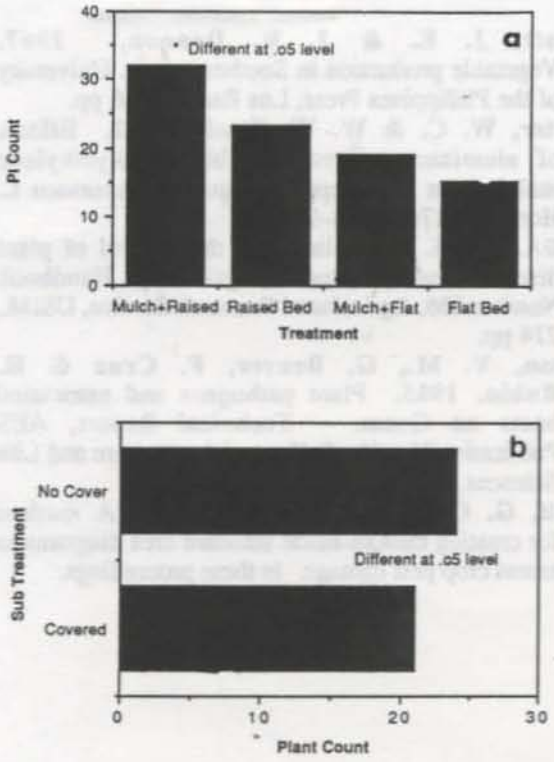

Fig. 9. Numbers of bell pepper plants not infected with bacterial wilt in plots where various cultural practices (a); and polyethylene cover (b) were employed.

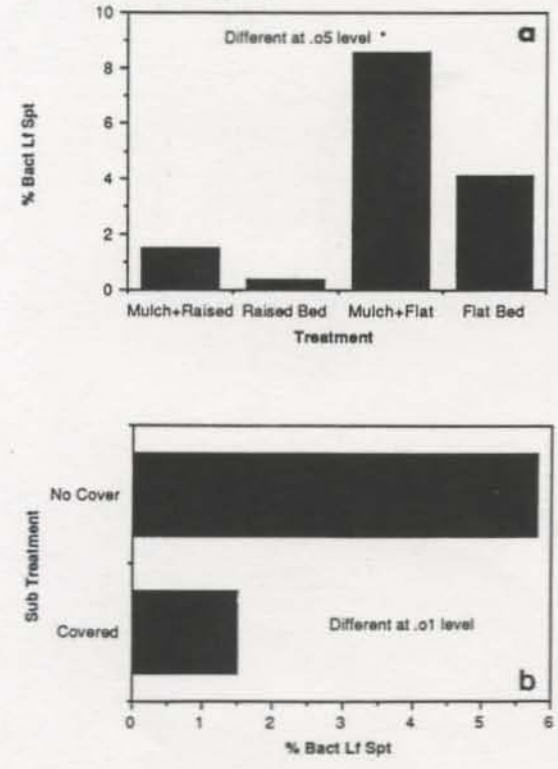

Fig. 10. Effects of various cultural practices (a); and polyethylene cover (b) on percent bacterial leaf spot infection of bell pepper plants.

This was in spite of slightly higher wilt incidence (Fig. 9b). In the previous experiment, overhead cover reduced the number of unmarketable fruit as well. Leaf spot severity was estimated by using the standard area diagrams shown (Fig. 12).

The best overall yields in this test were obtained in raised beds with plastic mulch and overhead cover (Fig. 11).

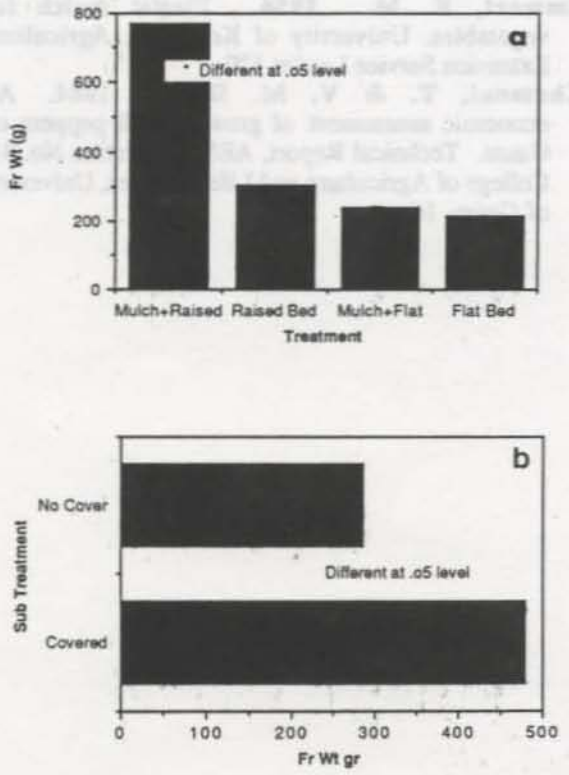

Fig. 11. Effects of various cultural practices (a); and polyethylene cover (b) on bell pepper yield.

Use of overhead cover reduces, although it may not eliminate, the need for spraying pesticides to control bacterial leaf spot. Used together with plastic mulch, it can compensate for the tendency of the latter to increase leaf spot severity, and still have the advantages of plastic mulch. Combining these practices with raising the planting beds reduces leaf spot severity even further.

Acknowledgments

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ADAP CROP PROTECTION CONFERENCE: CLOSING REMARKS

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The paper sessions were well attended and everyone should be commended for participating in the first ADAP Crop Protection Conference. My brief remarks are not to be construed as preferences for any particular subject, but to give a general consensus of points brought out by the participants reporting on crop protection studies on their Pacific island(s).

Studies of aphid transmitted non-persistant viruses in cucurbits showed that stylet oil applications do not negatively impact on other control measures. Destruction of virus sources (e.g., abandoned crops, etc.) is critical to controlling and limiting spread of the vectors. Spatial distribution of the pest and biological control agents needs to be determined. Trellising cucumbers reduced aphids, but had higher numbers of melon thrips. Ladybird beetle populations were higher on cucumber vines on trellises than those grown on the ground.

Commercial markets for fresh fruit and vegetables for export and tourism are developing. Pesticide selection in most of the Pacific islands is limited and participants expressed a need for help and guidance in registration, proper use, and disposal of pesticides. They were also interested in developing biological control programs in combination with effective use of pesticides (i.e., Integrated Pest Management training).

The problem of pesticide resistance in the Diamondback moth (DBM) was discussed. Pesticide resistance has been found in 447 arthropod species. Resistance in the DBM can develop in a short time. The migration rate of the pest is important in retarding development of resistance.

Methods to evaluate or assess crop damage were discussed. Direct measurements of insect or disease damage need to be developed and investigated. Such information is important for researchers and agriculturists to use as a basis for funding research and extension programs.

Concerns were expressed by a number of participants on the problems of herbicides and other pesticides and residues moving into ground water and contaminating the soil. Information on the biodegradation of pesticides is needed for registration in many of the Pacific island countries.

Reports were made on the progress of Integrated Pest Management (IPM) programs which are being initiated in a number of Pacific countries. One of the major problems has been determining the **action** or **economic thresholds** for their pests. All agreed that they were thinking and seeking alternatives to the "pesticide treadmill". Other problems discussed were sampling techniques for the myriad of pests. A simple system, presence or absence of the pest, has been effective for some pests. Knowledge of distribution of a pest species may aide in the understanding the problem it causes. *Thrips palmi* Karny in cucumber preferred the leaves while *Frankliniella occidentalis* (Pergande) preferred the blossoms. Such information is important in determining key pest status. The greatest need is the development of practical sampling techniques and the establishment of valid **economic thresholds (action levels)** for major pests.

Methods of rearing various biological control (BC) agents were discussed. The use of artificial substrates showed promise in specific cases. The rearing of biocontrol agents on a small scale is most promising for island conditions. One of the major problems has been in securing a supply of containers (plastic bottles, boxes, bags etc.). Before establishing a rearing facility, one should determine what BC agents are present in the area attacking the pest species. If the BC agents are to be introduced, a quarantine facility is necessary for rearing and holding an imported species prior to release. This is to insure that no hyperparasites are accidentally introduced with the beneficial species. Rearing efficiency increases as production increases.

The South Pacific Commission (SPC) emphasized the need for regional cooperation among the many countries in the South Pacific. They cautioned that one should not field collect BC agents in one country and ship them to another country for direct field use. Precautions and requirements for introduction were discussed. SPC guidelines should be distributed to agencies in the Pacific for review and information.

One participant discussed the use of insect specific nematodes (Family: Steinernematidae and Heterorhabitidae) in a BC program. This concept has a bright future. Pests with cryptic habitats in the soil or plant tissue plus the environmental conditions in the Pacific are favorable for nematode survival and infectivity. Preliminary studies showed *Steinernema feltiae* Filipjev was pathogenic to agromyzid leafminers (*Liriomyza* spp.), sweet potato weevil (*Cylas formicarius elegantulus* (Summers), and Mediterranean fruit fly (*Ceratitis capitata* (Wiedemann).

A pathogenic fungus, *Metarhizium anisopliae*, was reported showing promise for biocontrol of *Brontispa longissima*, a pest of coconuts in several areas of the Pacific.

Insecticide residues are detrimental to the parasitoids of the dipterous leaf miners, *Liriomyza sativae* Blanchard. Results of investigations on the development of insecticide resistance by the parasitoid *Diglyphus begini* (Ashmead) were reported. Another species,

Ganaspidium utilis Beardsley was the least tolerant. Effective selection of parasitoids for resistance to commonly used pesticides may be possible in the near future.

Biological control of the fruit piercing moth, *Othreis fullonia* (Clerck), looks promising. Biologies of several parasitoids are being studied by Australian entomologists, in the laboratory and field, for future liberation and introduction into Pacific countries.

Information on the progress of biocontrol programs on coconut scale, *Aspidiotus destructor* Sign.; spiralling whitefly, *Aleurodicus dispersus* Russell; citrus snow scale, *Uaspis citri* Comstock; mango shoot caterpillar, *Penicillaria jocosatrix*; pests of taro, stalk boring lepidoptera on sugarcane, and phytophagous agents attacking the weed *Chromolaena odorata* were presented. It is great to get first hand information on BC programs and to learn of their success.

The leucaena psyllid, *Heteropsylla cubana* Crawford, has spread across the Pacific. Biological control of the psyllid is an alternative worthy of investigation. The lack of taxonomic status of BC agents and pests of leucaena in the tropical forests is a major deterrent in the development of a biological control program. Caution is advised on the importation and release of general coccinellid predators such as *Curinus coeruleus* (Mulsant) into new areas without having basic information on the activity of other BC agents in the areas.

Many islands reported problems with ants in the field as well as their home. Baits containing either corn grits, soybean oil and a toxicant have been effective in controlling the bigheaded ant , *Pheidole megacephala* (Fabr.). The toxicants tested were hydramethylnon (Amdro®) and fenoxycarb (Logic®) at 0.88 and 1.0% active ingredient, respectively. Reinfestation occurred between 11 and 16 weeks after treatment with 1.5 pounds of prepared bait per acre.

A lively discussion on plant disease/insect vector management was held. Surveys of aphids and other vectors of viral plant diseases were discussed. Techniques for sampling and determination of vector status was presented for some species. In the studies, the percentage of vector species in the area was higher than all other species. It was emphasized that better and standard techniques are needed to preserve field collections and to aide in species identification. An enzyme linked immunosorbent assay (ELISA) has been developed to separate the virus complex in cucurbits.

Information on yam dieback, *Colletotrichum gloeosporioides*, in Samoa was discussed. The timing of fungicide applications were important in its control. Resistant varieties show some promise.

One interesting report was on the biology and ecology of a new mango pest in Guam that had been mistakenly identified as anthracnose. It was an undescribed midge, *Procontarinia* sp. It caused a blotch mine on the mango leaves. The cecidomyiid deposits its eggs in the leaf, mines the leaf for 3-5 days and pupates in the soil. Fungi invade the mine, causing the mine to drop out leaving holes surrounded by fungal spores. Care should be taken to examine new growth flushes on mango trees for presence of the pest.

Everyone believed the meeting was a success and the interaction between researchers stimulated them and their programs. A majority of participants thought fewer papers should be presented and more time given to scientific interaction and discussion of problems of common interest. Some wanted time to utilize the library facilities and meet colleagues on campus during the conference schedule.

The conference coordinators, Agnes M. Vargo and Marshall W. Johnson, are to be commended for organization and operation of the conference.