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Parasitoid Phenology, Ovicides, And Damage-Yield Relationships Of The Spotted Tentiform Leafminer (Lepidoptera: Gracillariidae) on Apples

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John Patrick Hayden

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PARASITOID PHENOLOGY, OVICIDES, AND DAMAGE-YIELD RELATIONSHIPS OF THE SPOTTED TENTIFORM LEAFMINER (LEPIDOPTERA: GRACILLARIIDAE) ON APPLES

By

John Patrick Hayden

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ABSTRACT

PARASITOID PHENOLOGY, OVICIDES, AND DAMAGE-YIELD RELATIONSHIPS OF THE SPOTTED TENTIFORM LEAFMINER, (LEPODOPTERA: GRACILLARIIDAE) ON APPLES

By

John Patrick Hayden

A study of the seasonal occurrence of the spotted tentiform leafminer (STLM) Phyllonorycter blancardella (F.), and its parasitoids was carried out in an unsprayed orchard in Michigan. There were seven parasitoid species recovered. Peak STLM adult emergence occurs before peak emergence of the braconid, Pholetesor ornigis, in all three generations.

In laboratory experiments testing ovicidal activity, fenvalerate, permethrin and methomyl were successful. In field applications, fenvalerate and diflubenzuron were effective ovicides (100.0 and 70.7% mortality, respectively).

In a study using punched holes to simulate leaf mines, no significant differences in apple weight gain were found between 0, 15 and 30% defoliation on 'Red Delicious' fruiting spurs in 1983. In 1984, girdled 'Golden Delicious' branches with 10:1, 15:1, and 20:1 leaf:fruit ratios were subjected to different levels of simulated damage with up to three second and five third generation simulated mines/leaf. The effect of leaf:fruit ratio on weight gain was highly significant, but the effect of different simulated infestation levels was not significant.

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INTRODUCTION

From an ecological point of view, the monocultures of modern agriculture are highly artificial. Their lack of diversity make pest outbreaks an inherent problem. Several general strategies have been used to protect crops from insects. The most important of these are chemical, biological and cultural control methods. In the past, and still to a large extent, chemical control of insects using broad spectrum insecticides is popular because of its ease, relative low cost, and short term effectiveness (Luckman and Metcalf 1975).

Traditionally, regular preventive pesticide applications, whether the pest is present or not, have been the mainstay of apple pest management programs. This is because apples have a low tolerance for damage due to high consumer appeal and expectations (Croft 1975). Heavy reliance on chemical control, however, has resulted in long term problems. Among these are resistance (Hough 1963), destruction of beneficial species resulting in secondary pest outbreaks (Huffaker et al. 1969), and environmental contamination (Luckman and Metcalf 1975).

Integrated Pest Management (IPM) is a concept that has gained popularity recently (Hoyt and Burts 1974). IPM emphasizes the use of biological and cultural pest management strategies in conjunction with chemical strategies, to maintain pests below economic injury levels. The main goal of IPM is to optimize the economic gain of the grower while minimizing the unfavorable consequences of broad spectrum insecticide use.

Three of the prerequisites to the successful development of an IPM program are an understanding of: the organisms and their interactions; how inputs will affect the agro-ecosystem; and damage-yield relationships necessary to set economic injury thresholds.

The following thesis is a set of three papers that are aimed at increasing understanding of the spotted tentiform leafminer (STLM) problem on apples and improving management strategies.

The first paper deals with the phenology of the pest and its parasitoids, and the impact of parasitoids on a population in an unsprayed system. The goal of this research was to study the interactions of the organisms throughout the season and to formulate hypotheses relative to the effect of timing and selection of chemical treatments.

The second paper investigates the ovicidal properties of certain insecticides and discusses the possibility of a new management strategy that could decrease the number of insecticide sprays used to control STLM, as well as decrease their impact on beneficial species in the orchard.

The third paper investigates the damage-yield relationships of second and third generation infestations. To achieve various levels of infestation, artificial defoliation was carried out using a hole punch to simulate leaf mines. Localized effects were studied by girdling specific parts of the trees. This type of study has implications for setting economic thresholds for foliage feeding insects.

While this research deals with specific aspects of a specific pest in the apple system, and represents only small portion of the apple ecosystem, these are the type of basic studies that need to be done when laying the groundwork for a total IPM program for apples.

I. SEASONAL OCCURRENCE OF THE SPOTTED TENTIFORM LEAFMINER (LEPIDOPTERA: GRACILLARIIDAE) AND ITS MAJOR PARASITOIDS IN MICHIGAN.

ABSTRACT

The seasonal development of the spotted tentiform leafminer (STLM), Phyllonorycter blancardella (F.) and its major parasitoids were studied in an unsprayed orchard in Michigan during 1983 and 1984. Mines from weekly leaf samples were dissected to observe parasitoid development. The contents of 100 cohort mines from each generation were reared to determine percent parasitism and composition of the parasitoid complex. STLM has three distinct generations in Michigan. Parasitoid development begins with the 'tissue-feeding' stage of each generation. Of the parasitoids successfully reared, 57% were Sympiesis marylandensis Girault, 37% were Pholetesor ornigis (Weed), 3% were Sympiesis sericeicornis (Nees) and 2% were Sympiesis bimaculatipennis (Girault). Pnigalio maculipes (Crawford), Horismenus fraternus (Fitch) and a Hypopteromalus sp. were also recovered from STLM mines. Parasitism within generations ranged from 30 to 65%. STLM populations were kept well below action threshold levels by natural mortality factors over the 2 year study period.

Studies using adult emergence traps and tagged mines show that for all three generations peak STLM emergence occurs before peak P. ornigis emergence (20, 7, and 4 days)

for spring brood, first generation and second generation emergence, respectively). *P. ornigis* is a larval parasitoid whose emergence is synchronized with the development of STLM larvae. These occurrences could be exploited by correctly timed short residual sprays targeted at STLM adults and eggs.

INTRODUCTION

The spotted tentiform leafminer (STLM), Phyllonorycter blancardella (F.) has become a sporadic, yet important pest in Michigan apple orchards (Dutcher and Howitt 1978). It was first reported in Michigan by Hutson (1938). Damage to the leaves is caused by the mining of the larval stages. This feeding reduces chlorophyll content and the photosynthetic rate of the leaves (Proctor et al. 1982). Heavy infestations can lead to early leaf abscission (Maeir 1983), a reduction in terminal growth, fruit growth stunting, premature ripening and fruit drop, and a reduction of fruit set the year following infestation (Kremer 1963, Pottinger and LeRoux 1971, Reissig et al. 1982).

STLM has three generations per year in Michigan. The third-generation overwinters as pupae in the leaf litter. In April, the spring brood of adults emerges and lays eggs on the underside of the unfolding leaves. There are five larval instars (Pottinger and LeRoux 1971). The first three are passed as sap-feeding larvae, which are dorso-ventrally compressed and feed by shearing cells and ingesting the cell contents. After the third instar, larvae undergo a hypermetamorphosis, becoming more cylindrical and developing thoracic legs and prolegs. Their feeding habit changes to chewing out irregular patches of mesophyll cells on the upper inside surface of the mine. Silken threads are spun and attached to both sides of the mine. As these threads dry they cause an arching of the mine that results in a tentiform appearance (Pottinger and LeRoux 1971).

STLM has a rich parasitoid complex that is usually dominated by the braconid *Pholetesor ornigis* (Weed) and/or the eulophid *Sympiesis marylandensis* Girault (Pottinger and LeRoux 1971, Maier 1984). Species previously found in Michigan by Dutcher and Howitt (1978) are *P. ornigis*, *S. marylandensis*, *Sympiesis sericeicornis* (Nees) (=*Sympiesis conica* (Provancher)), and the eulophid *Pnigalio flavipes* (Girault).

Parasitoids are more prevalent and play a more important role in regulating populations of leafminers in unsprayed orchards than in sprayed orchards (Pottinger and LeRoux 1971, Johnson et al. 1976, Van Driesch 1983, Maier 1984). Their ineffectiveness in controlling STLM populations in some commercial orchards may be due to the timing of insecticide applications (during parasitoid emergence and oviposition periods) (Maier 1984), or differences in susceptibility of parasitoids and adult STLM to certain cover sprays (Weires 1977, Dutcher and Howitt 1978, Pree et al. 1980, Hagley et al. 1981).

The purpose of this research is to further explore the relationships between STLM and its parasitoids in Michigan, and to look for possible means of enhancing the effectiveness of the natural enemies by selective timing of insecticide applications or other conservation methods.

MATERIALS AND METHODS

The seasonal development of leafminers and parasitoids was monitored in an unsprayed apple orchard near Fennville, MI that was taken out of production in 1982. Leaf samples were taken from April to October in 1983 and 1984. In 1983, six leaves from heights of 1.5 m and 2.5 m at each of the four compass points (N, E, S, W), for a total of 48 leaves per tree, were sampled weekly from each of 16 'Red Delicious' trees. In 1984, leaves were sampled by pruning 10 clusters from each of five apple trees every seven days. The sampling procedure was changed from 1983 to 1984 to increase the sample size (number of leaves) and to better correlate data with other research that uses the cluster as the basic sampling unit (Pottinger and LeRoux 1971, Dutcher and Howitt 1978, Johnson et al. 1976, Maier 1984). Samples were stored in a refrigerator at $4^{o}C$ in sealed plastic bags, for up to seven days, until they were processed. Each leaf was examined under a dissecting microscope for all life stages of STLM. Mines were opened to search for parasitoid eggs, larvae or pupae. STLM 'tissue-feeding' larvae were dissected in a droplet of water against a black background to determine the presence of endoparasitoids.

To determine the species composition of the parasitoid complex, as well as percent parasitism, 100 mines were collected from each generation during 1983 and 1984, when STLM pupae were first observed. The mines were excised from the leaves and placed in groups of five in disposable plastic petri dishes with moistened filter paper and a Parafilm seal. They were held for 14-21 days at 21-27°C and natural photoperiod to encourage emergence. Emerged specimens were collected and all mines were opened to match emerged adults with the mine contents. This was done to account for dead specimens that had not emerged and to become familiar with the characteristic pupal exuviae, cocoons (in the case of *P. ornigis*), meconia, frass and emergence holes of each species.

Emergence of STLM and parasitoid adults from the overwintering 3rd generation and first generation was monitored by the use of emergence traps in a commercial orchard near Fennville, MI and in a commercial orchard near Pullman, MI, respectively in 1984. The pyramidal traps were .3 m high with .24 m^2 open bases, supported by a wooden frame and covered with nylon netting. The traps were placed over piles of infested leaves on the orchard floor and were checked every 2-3 days. Traps were covered during pesticide application. Emerged specimens were aspirated through an opening in the side of the trap. The emergence of second generation adult STLM and parasitoids was monitored in the unsprayed orchard near Fennville, MI, by tagging and observing mines. On July 25, 250 late sap-feeding or early tissue-feeding mines that appeared not to have been preyed upon (1/leaf) were tagged.

At 2-3 day intervals each mine was examined for evidence of emergence (protruding STLM pupal cases, or circular parasitoid emergence holes), or predation (host feeding by parasitoids as described by Van Driesche and Taub (1983)). Mines that showed evidence of emergence or predation were brought back to the lab and opened under a dissecting microscope. Previous inhabitants were determined by their pupal exuviae, cocoons, frass, meconia, or cadavers (in the case of predation). STLM adult emergence was also monitored by weekly pheromone trap counts in the unsprayed orchard in 1983 and 1984.

RESULTS

The three generations of STLM in Michigan were clearly represented by three distinct peaks of abundance for each life stage on the leaf (Figure 1) and by the three distinct peaks of pheromone trap catches (Figure 2), during 1983 and 1984. The impact of the major parasitoids, as seen by the peaks of abundance for their life stages within the mine, (Figure 1), coincides with the appearance of 'tissue-feeding' mines over the three STLM generations. Parasitism of 'sap-feeders' was extremely rare. When parasitoid development by life stages within the mine is examined (Figures 3 and 4), the three generations that develop on the leafminer host become more distinct.

Of the species recovered from STLM mines (Table 1), *Pholetesor ornigis*, *S. marylandensis* and *Pnigalio maculipes* (Crawford), were observed as primary parasitoids of STLM. *Sympiesis sericeicornis* and *S. bimaculatipennis* (Girault) were observed to be parasitoids of STLM or hyperparasitoids on *P. ornigis*. *Horismenus fraternus* (Fitch) and a *Hypopteromalus sp.* were observed only as hyperparasitoids on *P. ornigis*. Maier (1984) reported *H. fraternus* to parasitize STLM as well as *P. ornigis* and a *Sympiesis sp.* As far as the author knows, *S. bimaculatipennis*, *P. maculipes* and *H. fraternus* are new records for Michigan.

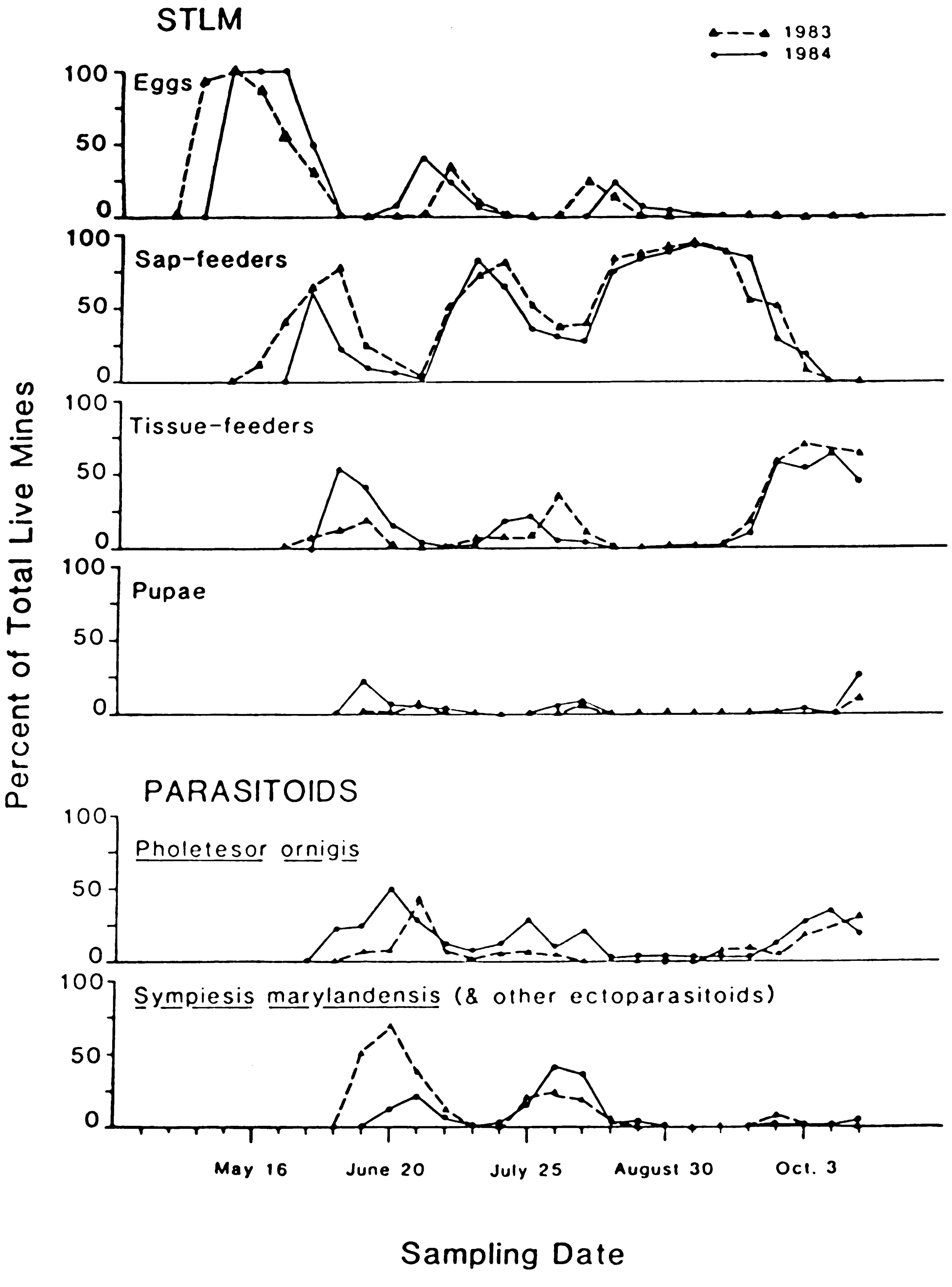

Figure 1: Seasonal occurrence of STLM and parasitoid life stages within the leaf mines, 1983-1984.

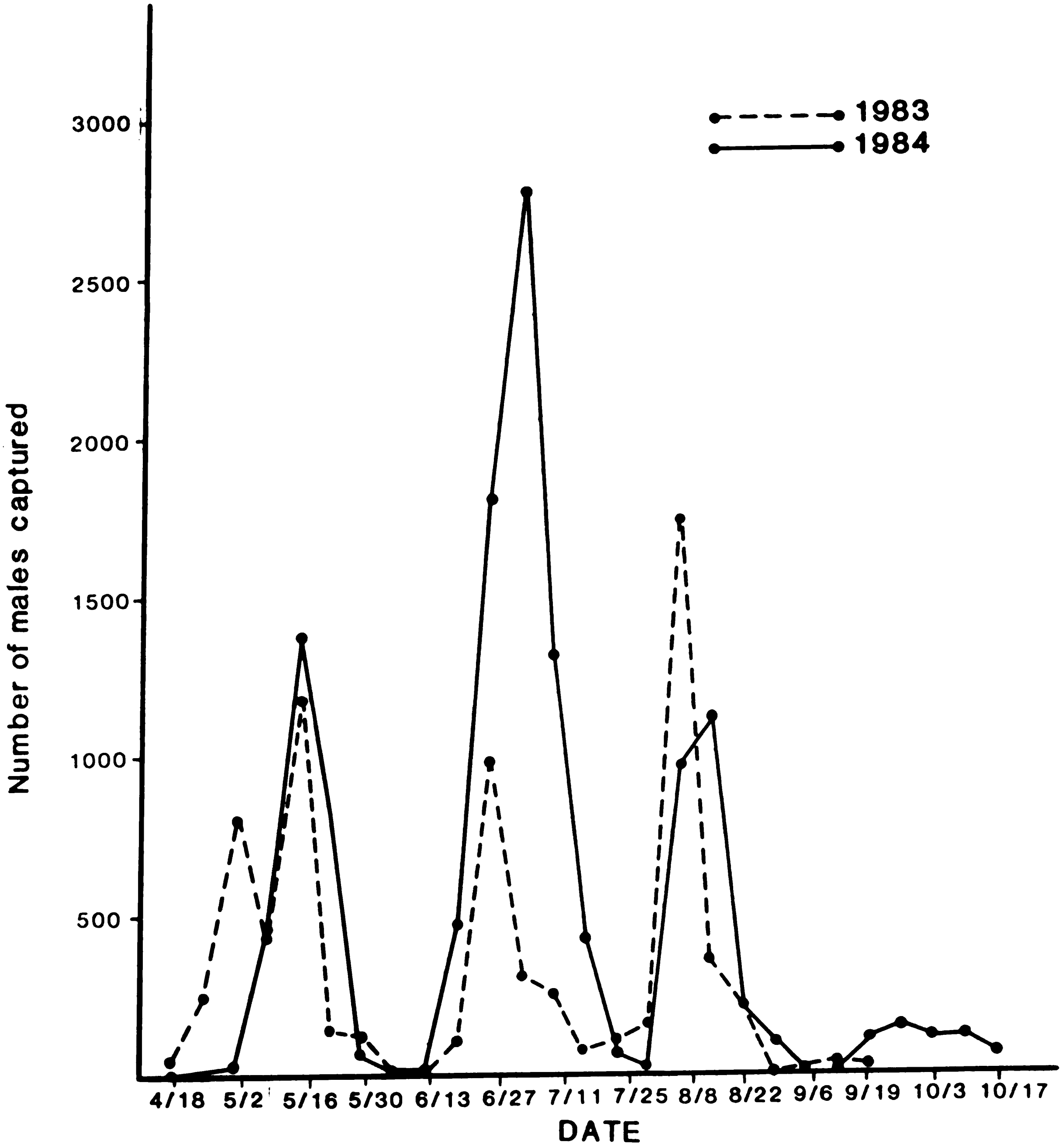

Figure 2: Average weekly pheromone trap counts, 1983 and 1984.

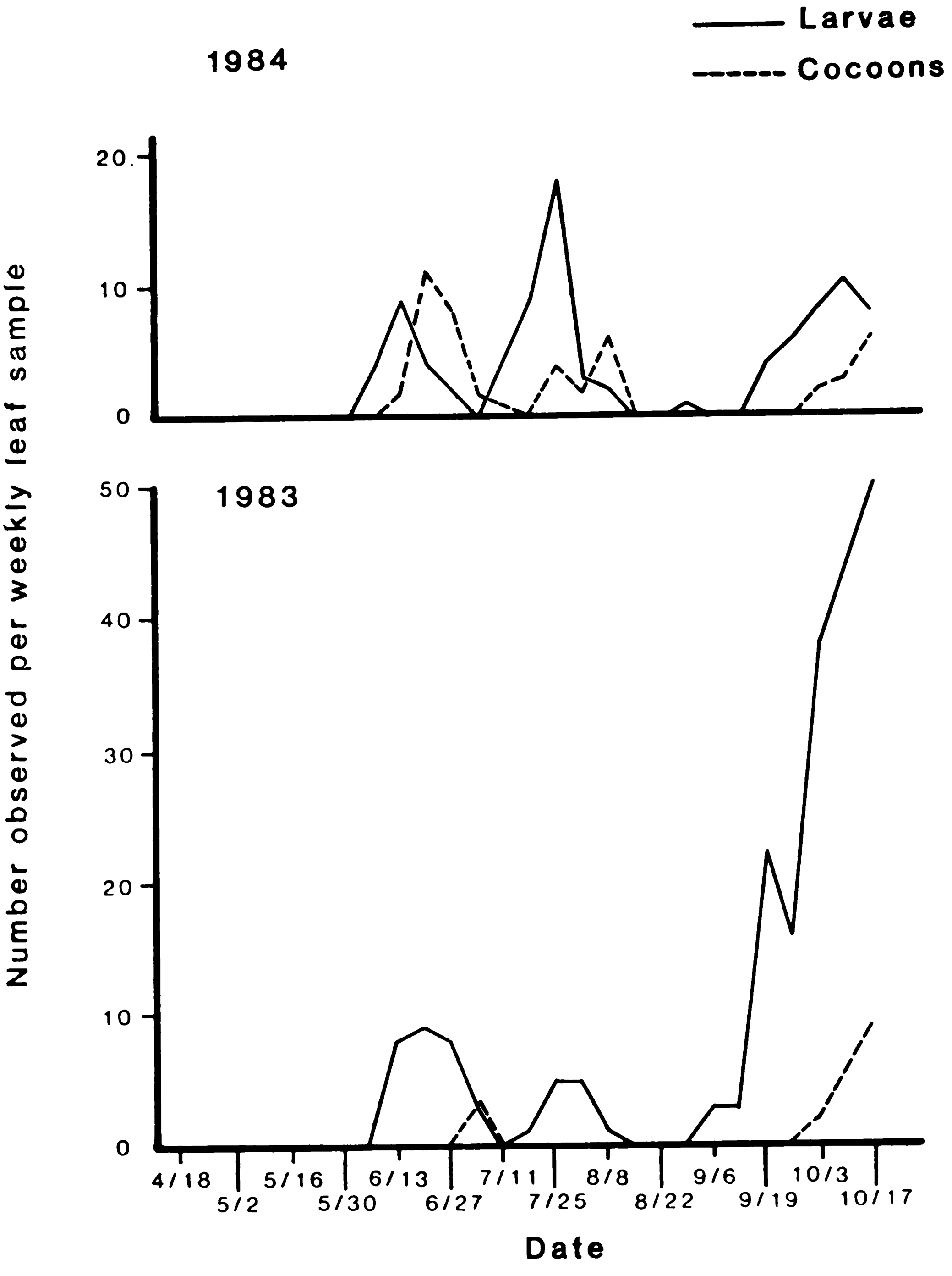

Figure 3: Seasonal Occurrence of P. ornigis life stages within the mine.

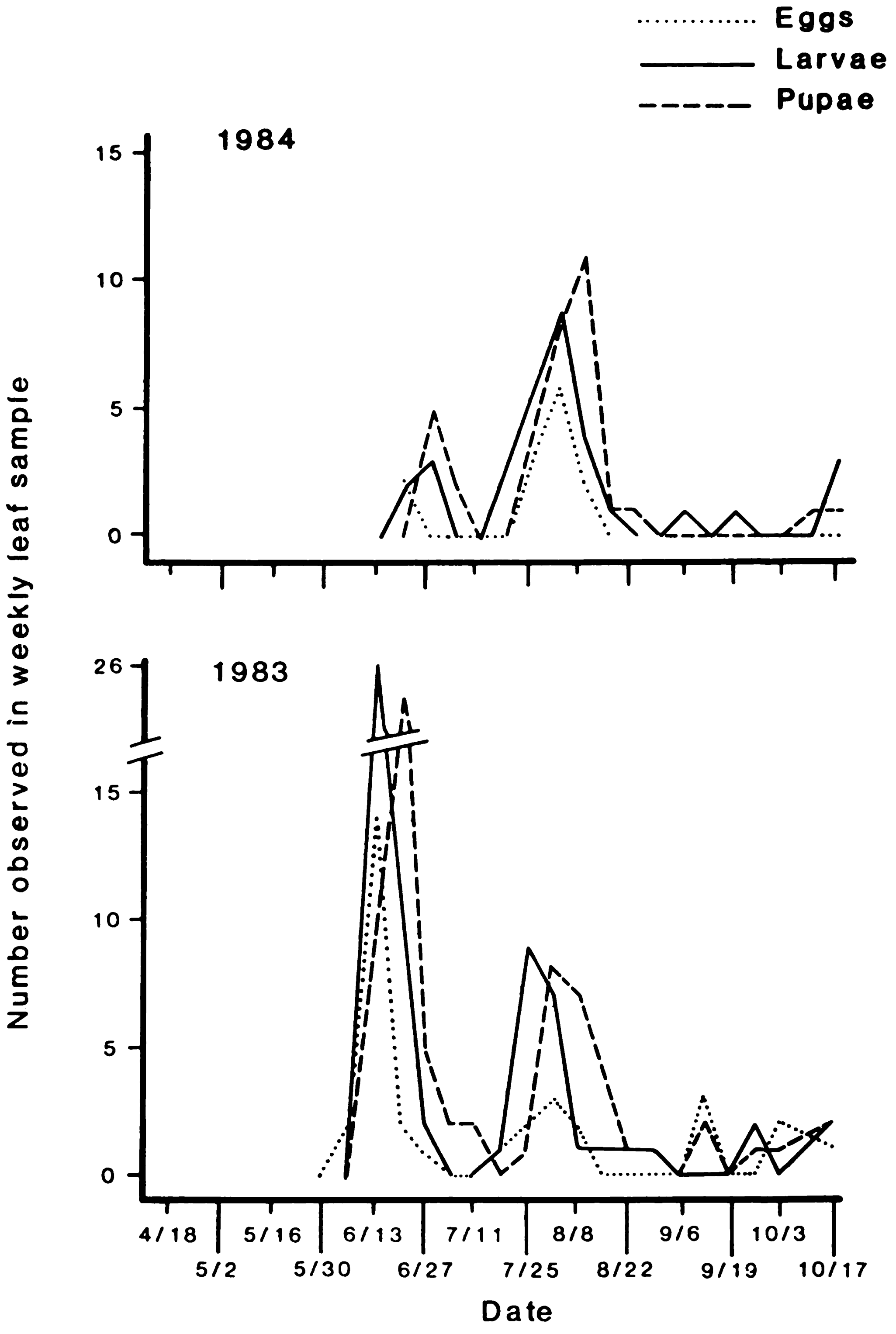

Figure 4: Seasonal occurences of S. marylandensis life stages within the mine.

Table 1: Parasitoid and hyperparasitoid species recovered from STLM mines in Southwest Michigan, 1983-1984.

Pholetesor ornigis (Weed)
Sympiesis marylandensis Girault
Sympiesis sericeicornis (Nees)
Sympiesis bimaculatipennis (Girault)
Pnigalio maculipes (Crawford)
Horismenus fraternus (Fitch)
Hypopteromalus sp.

Table 2: Contents reared from 100 cohort mines/generation from an unsprayed orchard, 1983-1984.

	1983			1984		
	Gen 1	Gen 2	Gen 3[b]	Gen 1	Gen 2	Gen 3[a]
STLM	4	8	50	32	8	54
Parasitoids						
P. ornigis	7	6	24	31	16	27
S. marylandensis	48	39	8	22	49	3
Hyperparasitoids						
S. sericeicornis	1	1	0	0	5	3
S. bimaculatipennis	2	0	0	1	4	0
other	1	0	0	0	1	3
Mortality other than apparent parasitism	37	46	18	14	17	10

[a] Overwintering generation mines collected from leaf litter in November 1983 and 1984

[b] Samples partially destroyed by fungi (numbers are estimates from remains).

Table 3: Average number of mines/leaf for each generation in an unsprayed orchard during 1983-1984.

1983			1984		
Gen 1	Gen 2	Gen 3	Gen 1	Gen 2	Gen 3
.07	.27	.51	.05	.10	.30

Of the parasitoids successfully reared out in 1983 and 1984, 57% were S. marylandensis, 37% were P. ornigis, 3% were S. sericeicornis, and 2% were S. bimaculatipennis. Total percent parasitism (measured by successfully reared parasitoids) on a generational basis ranged from 30 - 65%, with an average of 47%. Mortality by causes other than successful parasitism (host feeding, predation, disease, etc.) ranged from 10 - 46%, with an average of 25% (Table 2). In both years the second generation had the highest percent mortality, and the third generation had the largest numbers of successful adult STLM. Overwintering third generations were collected and reared in the fall and do not reflect overwintering mortality.

P. ornigis were the more abundant parasitoids of STLM 'tissue-feeders' in the first and third leafminer generations except for the first generation in 1983, while S. marylandensis were more abundant in the second generation (Table 2). This is consistent with Dutcher and Howitt's (1978) work and with reports from Massachusets (Van Driesche and Taub 1983) and Connecticut (Maier 1984).

Throughout the six generations that were studied over this two year period, STLM populations were always kept low by parasitism and other natural mortality factors. In both years there was an increase in density (measured by mines/leaf) from the first generation to the third generation (Table 3), but they never approached the recommended action thresholds of one mine/leaf for first generation or two

mines/leaf for second generation (Weires 1981, Reissig et al. 1982).

The results from the adult emergence studies showed that for all three generations studied in 1984, peak adult STLM emergence occurred earlier than peak emergence for either parasitoid species (Figures 5, 6, and 7). The time differences were the greatest for spring brood emergence (20 days between peak STLM and peak *P. ornigis* emergence), and the smallest for second generation emergence (4 days between peak STLM and peak *P. ornigis* emergence). *P. ornigis* emergence is more synchronous with the occurrence of 'tissue-feeding' hosts than is *S. marylandensis* emergence. The peak emergence trap catches of STLM match up well with peak pheromone trap catches for the same generations.

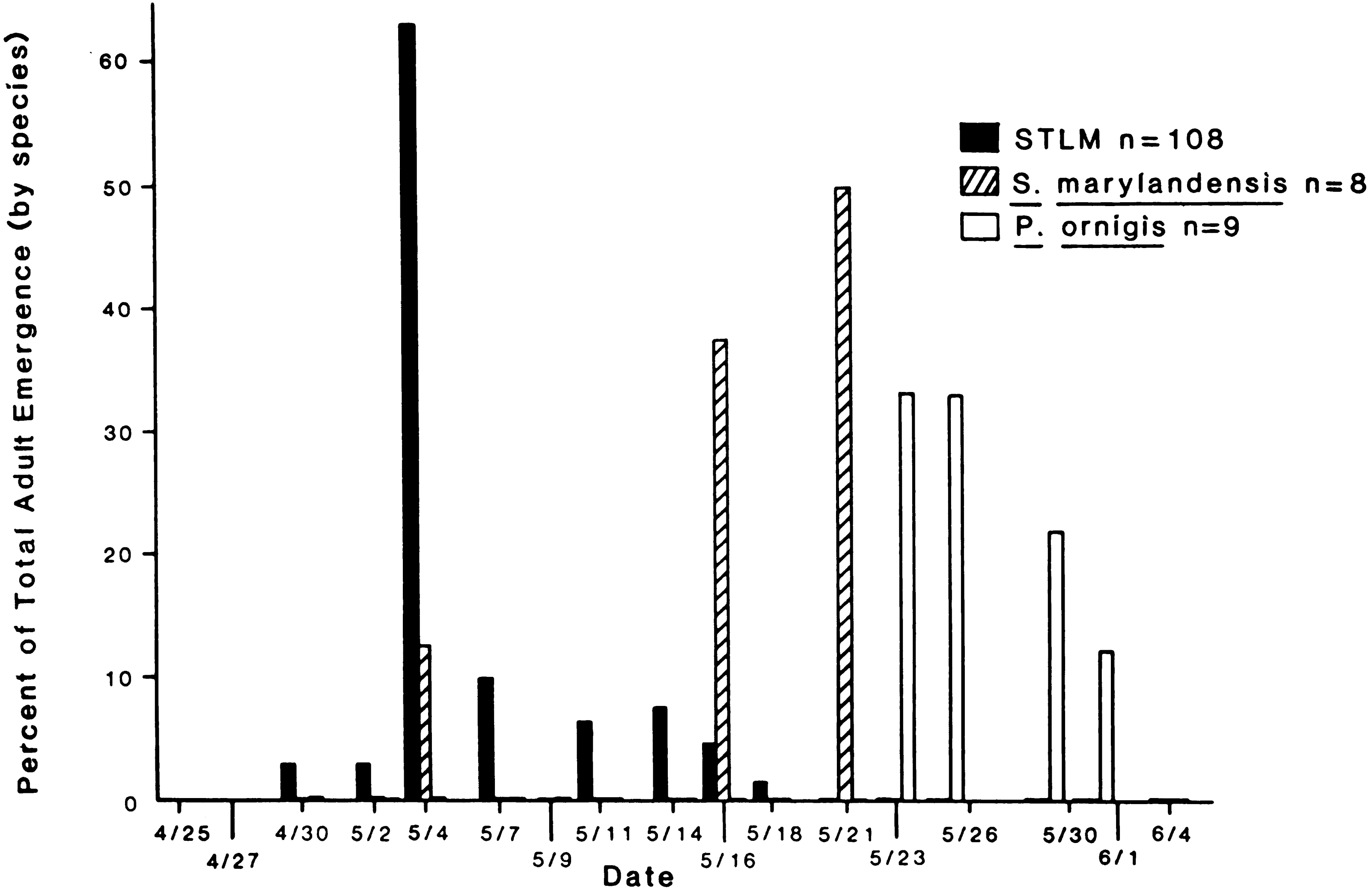

Figure 5: Spring brood emergence of STLM and major parasitoids from emergence trap.

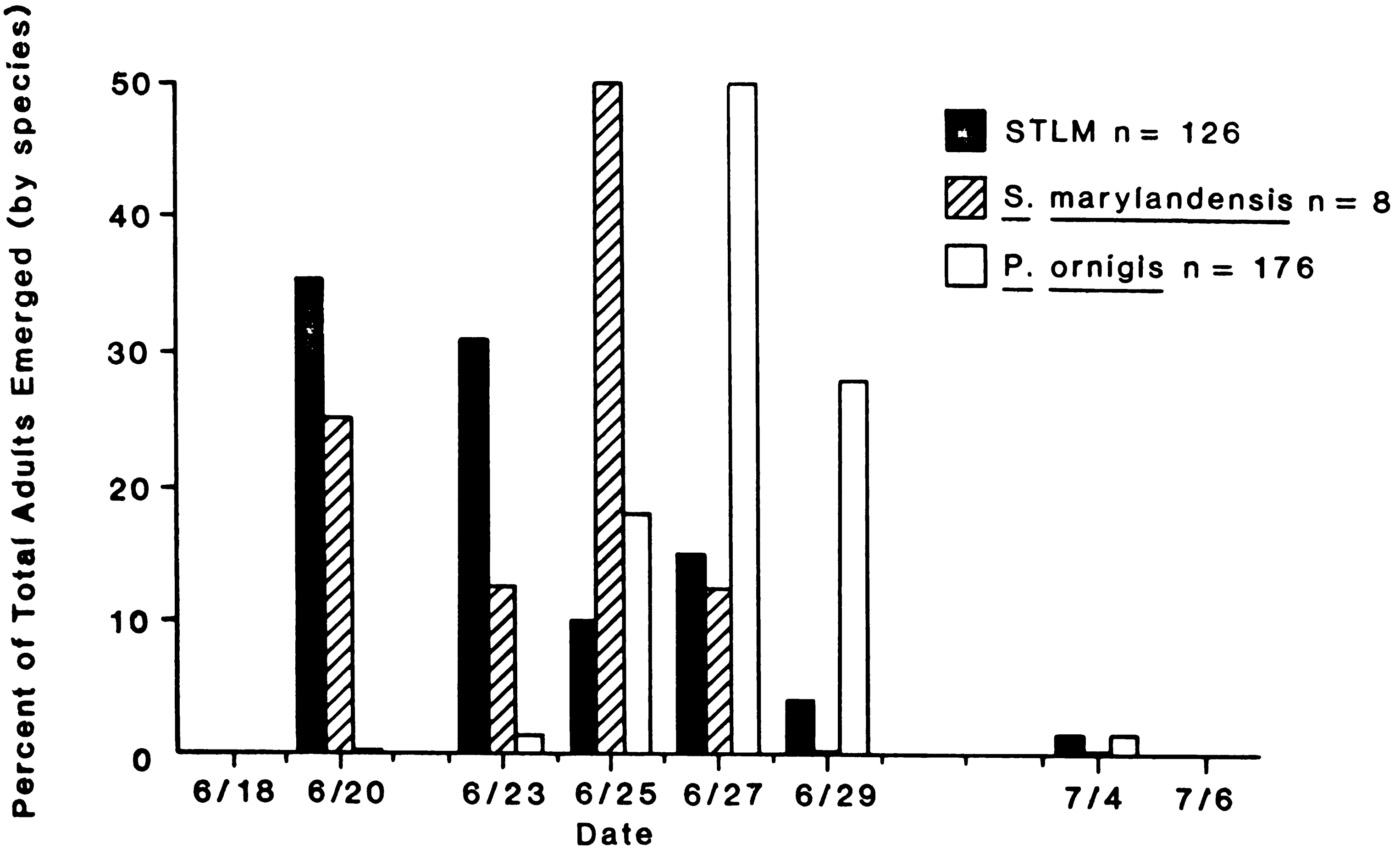

Figure 6: First generation emergence of STLM and major parasitoids from emergence trap.

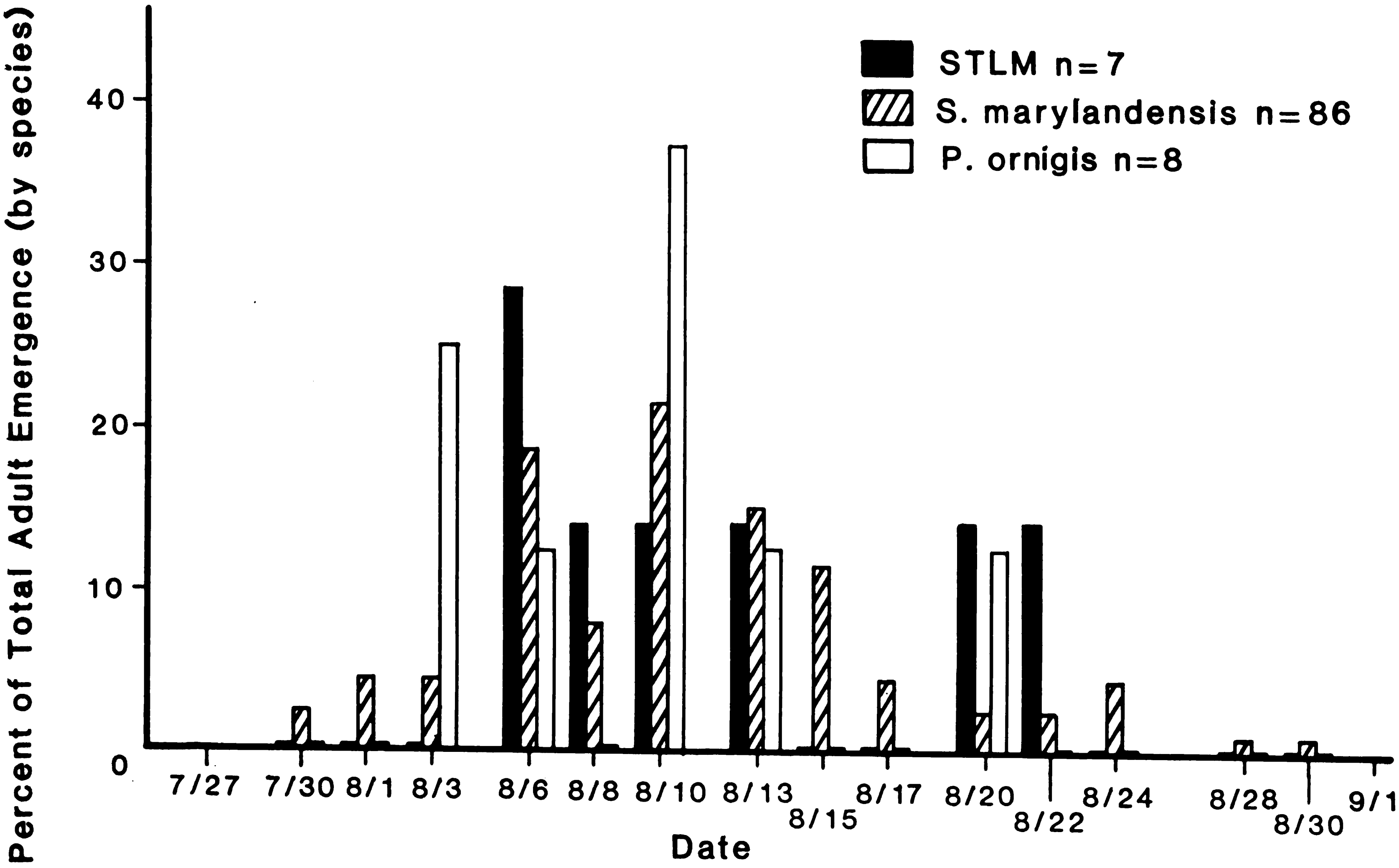

Figure 7: Second generation emergence of STLM and major parasitods from tagged mines on trees.

DISCUSSION

In an unsprayed orchard, _P_. _ornigis_ and _S_. _marylandensis_ were major causes of STLM mortality. _S_. _marylandensis_ not only parasitizes 'tissue-feeders' but also feeds on them without ovipositing (Van Driesche and Taub 1983). The impact of this action on the pest population is often lumped together with other mortality factors. The two species act complimentarily over the season on STLM populations. The first and third generations are usually dominated by _P_. _ornigis_ while the second generation is usually dominated by _S_. _marylandensis_. Any modification of management practices designed to conserve these beneficial insects could help to alleviate the STLM problem.

Johnson et al. (1976) discuss the existence of a "biological window", or a time during the life cycle of the pest where application of a control measure will not affect the natural enemies. They showed a 20 day gap between spring emergence of STLM adults and emergence of _P_. _ornigis_. The data confirms the existence of this window during spring emergence for both parasitoid species. Shorter biological windows also seem to be present between peak STLM and peak _P_. _ornigis_ in both first and second generation emergence. These occurrences could be exploited by using a relatively

short residual spray that has adulticidal and ovicidal activities (see chapter 2). The problem with implementing this as a management strategy for spring brood emergence is that a petal fall spray would take place during the critical period after parasitoid emergence but before oviposition and would most likely be deleterious to the STLM parasitoids. The petal fall spray is considered one of the most critical and necessary sprays of the season by many growers. Other possible means of conserving parasitoid populations could be the use of chemicals less toxic to the parasitoids, reduced dosages, or less complete coverage by spraying alternate rows (Van Driesche and Taub 1983).

When making management decisions concerning STLM that are based on action thresholds of numbers of mines/leaf, parasitism rates should be taken into account. Pest managers need to be trained to recognize the parasitoids of STLM and their symptoms. Ideally, we should be able to predict the impact that the next generation of parasitoids will have on STLM populations, based on the present parasitoid generation numbers. Until we reach that point, however, action thresholds should be based on number of unparasitized mines/leaf.

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II. OVICIDAL ACTIVITY OF INSECTICIDES ON THE SPOTTED TENTIFORM LEAFMINER (LEPIDOPTERA: GRACILLARIDAE).

ABSTRACT

Several insecticides were tested for ovicidal activity on spotted tentiform leafminer (STLM), Phyllonorycter blancardella (F.). In one laboratory experiment, fenvalerate and methomyl caused 88 and 72% egg mortality, respectively, while endosulfan was less effective (29.6% egg mortality). The control (water) had the lowest egg mortality (8%). In a second laboratory experiment, fenvalerate, permethrin, and methomyl caused 92, 92, and 77% egg mortality, respectively, while the control showed low egg mortality (13%). In field applications, fenvalerate and diflubenzuron were effective ovicides (100 and 70.7% egg mortality, respectively). Single-tree applications of fenvalerate and diflubenzuron showed both treatments to be ovicidal at low rates. Insecticides targeted at the egg stage and applied before hatch add a new dimension to STLM management.

INTRODUCTION

The spotted tentiform leafminer (STLM), Phyllonorycter blancardella (F.), has become a sporadic, yet important pest in Michigan apple orchards (Dutcher and Howitt 1978). Damage to the leaves is caused by mining of the larval stages. This feeding reduces chlorophyll content and the photosynthetic rate of the leaves (Proctor et al. 1982). Heavy infestations can lead to early leaf abscission (Maier 1983), a reduction in terminal growth, fruit growth stunting, premature ripening and fruit drop, and a reduction of fruit set the year following infestation (Kremer 1963, Pottinger and LeRoux 1971, Reissig et al. 1982).

STLM has three generations per year in Michigan. The third-generation overwinters as pupae in the leaf litter. In April, the spring brood of adults emerges and lays eggs on the underside of the unfolding leaves. There are five larval instars (Pottinger and LeRoux 1971), the first three are passed as sap-feeding larvae, which are dorso-ventrally compressed and feed by shearing cells and ingesting the cell contents. After the third instar, larvae undergo a hypermetamorphosis, becoming more cylindrical and developing thoracic legs and prolegs. Their feeding habit changes to chewing out irregular patches of the mesophyll cells of the upper inside surface of the mine. As these threads dry they cause an arching of the mine that results in a tentiform appearance (Pottinger and LeRoux 1971).

Previous work on management of gracillariid leafminers with insecticides has been aimed at controlling the adult and larval life stages (Dutcher and Howitt 1978, Free et al. 1980), Weires 1981, Coli and Prokopy 1982). Our work was undertaken to determine the activity of selected insecticides on STLM eggs.

MATERIALS AND METHODS

Laboratory Experiments. The first laboratory experiment was conducted in May 1983. Twelve one year-old 'Red Delicious' apple seedlings were potted and placed in a growth chamber to induce leaf growth. Once fully leafed, the seedlings were put in a large screened cage and exposed to adult STLM, which had been collected as overwintering pupae found in the previous year's apple leaf litter. Four days later, when each seedling had a minimum of 25 eggs, the eggs were counted with the aid of a stereomicroscope and marked by flagging the petiole of each leaf that had eggs. Leaves with one to four eggs were used in the experiment, excess eggs were removed. Four treatments with three replicates each were applied in a completely randomized design to the 12 seedlings. The chemicals were measured using micropipets, then mixed with 3,785 ml of water in proportions corresponding to recommended field rates. To simulate a dilute application by an airblast sprayer, treatments were applied with hand held plant misters until the point of spray runoff.

After 10 days at room temperature, when all healthy eggs would have hatched, each egg was examined microscopically, and classified as dead or having hatched (both live and dead larvae were classified as hatched eggs). Data was transformed to arcsin $\sqrt{y}$ before performing an analysis of variance to test for treatment differences.

A second experiment was conducted in July 1983, using the same design as the previous experiment, except that four replicates of each treatment were applied. The STLM adults used to provide the eggs were from first-generation mines that had been collected from an unsprayed orchard and reared at room temperature.

Field Experiments. Fenvalerate was so successful in laboratory experiments (see Table 4), that we decided it would be appropriate to test its ovicidal effect under field conditions in 1984. The insect growth regulator diflubenzuron, which had been observed to be ovicidal on STLM (J.G. Connell, personal communication), was also tested.

The first experiment was set up in a heavily infested orchard near Pullman, Michigan that contained 'Red Delicious' and 'Golden Delicious' trees set on a spacing of 5.5 m between trees and 6.4 m between rows. There were 15 trees in each 0.05 ha plot. Treatments were assigned in a randomized complete block design with three replicates. Diflubenzuron was applied on 23 June, during second adult flight period, but before second-generation eggs had been observed on the leaves (it is recommended that diflubenzuron be applied to the leaves before egg deposition (J.G. Connell, personal communication)). Fenvalerate was applied on 26 June, after eggs had been observed on the leaves. The treatments were applied with an

air blast sprayer with 1,640 liters of water per ha.

On 28 June, a small branch at an average height of 2 m was pruned from the west side of the central tree of each plot. The branches were brought back to the laboratory, examined microscopically, and 25 eggs from each sample were chosen for future observation. The location of each egg was marked by placing a hole in the leaf 5 mm from the egg on the leaf margin side of the egg and on a line perpendicular to the leaf's mid vein. The branches were placed in water as bouquets and stored in a growth chamber at 24°C and a 16:8 (L:D) photoperiod. On 8 July, the marked eggs were examined microscopically and classified as dead or having hatched. An analysis of variance was performed to test for treatment differences.

The second experiment was designed to test the efficacy of three rates of diflubenzuron as an ovicide. In an adjacent orchard, treatments were assigned to single 'Red Delicious' trees as a completely randomized design with 4 replicates. Treatments were applied on 23 June with a high pressure handgun to the point of spray runoff. On 28 June, sample branches were pruned and eggs marked and stored as described in the previous experiment. Egg mortality was evaluated on 8 July, in the same manner as described in the previous experiment.

The third experiment was designed to test the efficacy of fenvalerate at three different rates on third-generation eggs. Treatments were assigned to single 'Red Delicious' trees in a completely randomized design with four replicates. Treatments were applied on 14 August, after third-generation egg deposition had been observed. When the sprays had dried, small branches were pruned and the same procedure for marking and storing the eggs was followed as in the earlier field experiments. Egg mortality was evaluated on 23 August, in the same manner as described for the first field experiment.

RESULTS AND DISCUSSION

In the laboratory, fenvalerate and permethrin worked well as ovicides (Table 4). Methomyl was less effective, and endosulfan was the least effective. The control, using water as a treatment, had a relatively low egg mortality in both experiments.

In the orchard blocks in which the efficacy of fenvalerate and diflubenzuron were tested, fenvalerate was an excellent ovicide (Table 5). Diflubenzuron also had ovicidal activity.

The single-tree plots showed that fenvalerate and diflubenzuron were ovicidal, even at reduced rates (Table 5).

All treatments were applied at dilute rates, thus ensuring good coverage. We do not know whether concentrate sprays would be effective.

In the past, two strategies of chemical control of gracillariid leafminers have been recommended; sprays targeted at the adults and timed to their emergence, or systemic insecticides timed to control the sap-feeding larvae (Dutcher and Howitt 1978, Pree et al. 1980, Weires 1981, Coli and Prokopy 1982).

Control of adults is often difficult because of their prolonged emergence and may require multiple sprays. The

Table 4: Laboratory evaluation of ovicidal activity of several insecticides on spotted tentiform leafminer

Material and formulation[a]	Rate- gAI/378 liters[b]	Mean % egg mortality[c]
Experiment 1		
Fenvalerate 2.4EC	21	88.8 a
Methomyl 1.8EC	204	72.0 a
Endosulfan 3EC	231	29.6 b
Water (control)	-	8.0 c
Experiment 2		
Fenvalerate 2.4EC	21	92.0 a
Permethrin 2EC	23	92.0 a
Methomyl 1.8EC	204	77.0 a
Water (control)	-	13.0 b

[a] EC, emulsifiable concentrate.

[b] Sprays based on dilute rate of 3740 liters/hectare.

[c] Means followed by the same letter are not significantly different at the P=0.05 level (Duncan's (1955) new multiple range test).

Table 5: Ovicidal activity of field applications of selected insecticides on spotted tentiform leafminer

Material and formulation[a]	Rate- gAI/ha[b]	Mean % egg mortality[c]
Blocks		
Fenvalerate 2.4EC	336	100.0 a
Diflubenzuron 25WP	210	70.7 b
Control	-	12.0 c
Single trees		
Diflubenzuron 25WP	280	71.0 ab
Diflubenzuron 25WP	210	57.0 b
Diflubenzuron 25WP	140	76.0 a
Control	-	12.0 c
Single trees		
Fenvalerate 2.4EC	224	73.0 a
Fenvalerate 2.4EC	168	68.5 a
Fenvalerate 2.4EC	112	68.0 a
Control	-	9.0 b

[a] EC, emulsifiable concentrate; WP, wettable powder.

[b] Sprays applied at 1640 liters/hectare.

[c] Means followed by the same letter are not significantly different at the P=0.05 level (Duncan's (1955) new multiple range test).

pyrethroids fenvalerate and permethrin are often used as adulticides, especially for spring brood emergence. Sprays generally start at tight cluster (blossom buds exposed, but tightly appressed (Chapman 1966)), for first emerging moths.

Using an insecticide that acts as both an adulticide and an ovicide can cut the number of spring brood treatments to one well-timed spray at full pink (1-3 days before bloom (Chapman 1966)), before egg hatch. This spray can control existing eggs, as well as adults with egg laying potential. Although STLM eggs are less than 0.4 mm wide (Pottinger and LeRoux 1971), it may be feasible for growers or pest management specialists to monitor egg deposition with a magnifying hand lens, or by examining leaf samples microscopically, and to make spray decisions based on an expected number of mines per leaf.

Although fenvalerate was effective as an ovicide against second-/ and third-generation STLM, this ovicide/ adulticide strategy is best suited for first-generation control, when good coverage is more easily obtained because the trees are not fully leafed, and when a pyrethroid spray is least disruptive to STLM parasitoids and mite predators.

Diflubenzuron is not currently registered for use on apples, but it showed promise as an ovicide. As an insect growth regulator, it is probably not effective as an adulticide, but its use as a second-/ or third-generation ovicide could be advantageous because it would be less harmful to the adult parasitoids of STLM larvae than are conventional chemical controls.

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III. THE EFFECT OF SIMULATED SPOTTED TENTIFORM LEAFMINER (LEPIDOPTERA: GRACILLARIIDAE) DAMAGE, AFTER FRUIT SET, ON APPLE SIZING.

ABSTRACT

In 1983, fruiting spurs on 'Red Delicious' trees were girdles or left ungirdled, and 0, 15, or 30% of their leaf area was removed with a paper hole punch after 'June drop' to determine the effect of defoliation on fruit size. Apple weights at the time of treatment were estimated from a curve relating fruit diameter to fruit weight. Changes in weight by August 16 and harvest were measured. Ungirdled spurs had significantly larger fruit than girdled spurs, but there were no significant differences in fruit size among the defoliation levels. In 1984, 50-90 cm branches on 'Golden Delicious' trees were girdled and adjusted to 10:1, 15:1, or 20:1 leaf:fruit ratios after 'June drop'. Different levels of second and third generation spotted tentiform leafminer infestations were simulated with an elliptical hole punch that was similar in size (80 mm^2) and shape to a 'tissue-feeding' mine. Changes in weight by August 27 and harvest were measured. The effect of leaf:fruit ratio on weight gain was highly significant. The effect of different infestation levels on weight gain was not significant, even with three second generation and five third generation mines/leaf. In both experiments there were significant correlations between leaf area remaining after defoliation and weight gain of apples. This type of

research is important for establishing damage-yield relationships for foliage feeding insects.

INTRODUCTION

Establishing an economic injury level is one of the priorities of any Integrated Pest Management program. Stern et al. (1959) considered the economic injury level to be "the lowest pest population density that will cause economic damage". The ability to predict damage-yield relationships is of primary importance in determining an economic injury level for a pest.

Establishing damage-yield relationships is especially difficult for apple pests that do not directly attack the fruit, but are foliage feeders. Studying the economic significance of damage-yield relationships in apples is further complicated by the fact that growers are not trying to obtain maximum yield for their inputs. Apple size is important in determining marketability and therefore the profitability of the crop. Thinning the fruit (increasing the leaf:fruit ratio) decreases yield, but increases fruit size and quality. The apple grower is interested in reaching the point where size is optimum, but yield is not decreased too much.

The effects of leaf area on fruit sizing have been well studied (Haller and Magness 1925, Magness 1928, Link 1973, Williams 1979), and thinning recommendations are based on these studies. The effects of defoliation caused by insects and mites are less clear.

In the past, the effects of leaf damage on fruit yield have been inferred by studying the effect on photosynthetic capacity of the leaves (Pn) in the laboratory. Hall and Feree (1976) found that losses in leaf area by artificial defoliation of up to 7.5% had no significant effect on Pn. They also found that insect feeding simulated by many small holes resulted in a larger decrease in Pn than an equal area removed by large holes. The suggestion has been made that the remaining leaf area is able to compensate for lost area by increasing its photosynthetic efficiency (Flore and Irwin 1983, Proctor et al. 1982). Flore and Irwin (1983) found that up to 20% of the leaf area could be removed interveinally without a significant reduction in Pn. Correlating losses in Pn with yield reductions well enough to make predictions has yet to be done.

In the case of the spotted tentiform leafminer (STLM), *Phyllonorycter blancardella* (F.), infestations have been reported to cause a reduction in terminal growth, fruit growth stunting, premature ripening and fruit drop, and a reduction of fruit set the year following infestation (Kremer 1963, Pottinger and LeRoux 1971). These reports were based largely on observations rather than quantitative measurements. Reissig et al. (1982) present quantitative data that indicate a premature ripening and drop of fruit from 35+ year old 'McIntosh' trees with gracillariid leafminer infestations that exceed 2 mines/leaf (combined 1st and 2nd generation counts).

In one orchard of 'Red Delicious' that had an unsprayed section with a combined first and second generation average of over four mines/leaf, there was a reduction in average fruit size between it and the lightly infested treated section. Their data also indicated that a reduction in fruit set and subsequent crop load (grams of apples per cm branch circumference) in 'Ida Red' and 'Rome Beauty' was sometimes associated with leafminer damage. Maeir (1983) showed that destruction of more than 20% of the leaf surface by gracillariid leafminers promoted early leaf abscission in 'McIntosh'.

The objective of this study was to investigate the effect of simulated STLM damage on apple sizing during the season of infestation. Second and third generation damage, which occur after fruit set, were chosen to be studied because low, untreated first generation populations can typically build up to high densities that are perceived to be damaging in these two final generations. This large population increase seems more prevalent in the case of commercial orchards that have low parasitism rates (Coli and Prokopy 1982, Van Driesche and Taub 1983). Since natural STLM infestations at varied levels are difficult to obtain, damage was simulated by artificial defoliation.

MATERIALS AND METHODS

1983 - Effect of artificial defoliation of spur leaves on apple weight increase.

Six fruiting spurs from each compass point (N,E,S,W) were selected on 10 eleven year old 'Red Delicious' trees grown on M106 rootstock. The trees were between 2.7 and 3.7 m tall, and set on a spacing of 4.3 x 6 m, in an orchard free of STLM infestation. The length and width of each leaf was measured, and the formula L * W * .7 was used to estimate the leaf area of each leaf on each spur (from previous work by J. Flore, personal communication). The following treatments were randomized among the 6 spurs: untreated; 15% defoliation; 30% defoliation; girdled - no defoliation; girdled - 15% defoliation; and girdled - 30% defoliation. Girdling was carried out to isolate the spurs from the carbohydrate resources of the remainder of the tree, and was accomplished by removing a 3-6 mm wide ring of bark and phloem, down to the cambium, from the base of each spur. Defoliation was accomplished using a circular paper hole punch with an area of 32 mm^2. The holes were punched interveinally in the leaves, in a random pattern on each spur. The treatments were carried out on July 19 and 20, and coincided with the first observations of second generation 'tissue-feeding' mines in a nearby orchard.

Four measurements of diameter (two lengths, two widths) were taken for each apple with a caliper micrometer on July 21. A sample of 30 apples, not involved in the treatments, were then measured in the same manner, picked and weighed. The surface area of each apple was estimated by using the formula πd^2 (surface area of a sphere) and was regressed against weight. A prediction equation was generated to estimate the weight of each apple attached to a treated spur. On August 16, new measurements were taken and a new prediction equation was generated to estimate the apple weights in the same manner as described above.

Apples were checked weekly for early abscission, any abscissed apples were deleted from the data set used to determine final change in weight. A standard pest management program was followed throughout the season, with pesticides applied as needed. No irrigation was available. The apples were harvested and their final weights were determined on September 24.

1984 - Simulated STLM damage at three crop loads.

This experiment was set up as a randomized complete block design on five eleven year-old 'Golden Delicious Smoothee' trees on M106 rootstocks. The trees were between 2.7 and 3.7 m tall, and set on a spacing of 4.3 x 6 m. They were in alternate rows to the trees used in the 1983 experiment. Twelve branches with basal cross section diameters of approximately 10-15 mm and leaf to fruit ratios of less than 10:1 were chosen and flagged in each tree. A factorial set of treatments of 0, 1, 2 and 3 mines/leaf at each of the following leaf to fruit ratios; 10:1, 15:1, and 20:1, were randomly assigned. The desired leaf to fruit ratio of each branch was obtained by removing fruit or entire spurs. Terminals were removed. Leaves judged to have an area of less than 140 mm^2 were not counted. No more than 1 fruit/spur was left. Each branch had from 4-6 fruit. The simulated mines were added on July 16, to coincide with fruit observations of 2nd generation 'tissue-feeding' mines in a nearby orchard. The mines were simulated by using a hole punch that had been modified to punch an elliptical hole with an area of 80 mm^2 similar in size and shape to a 'tissue-feeding' mine. The mines were punched interveinally in a random pattern on the leaves and within the branch (to simulate natural infestations, larger leaves often had a larger proportion of mines). Each branch was then girdled by removing a 3-6 mm wide ring of bark and phloem, down to the cambium, from its base.

The final leaf area for each branch was calculated by counting the number of spur or shoot leaves, multiplying them by the mean area of a spur or shoot leaf from that tree, then subtracting the defoliated area. The mean spur and shoot leaf was estimated from a sample of 10 shoots and 10 spurs randomly selected from each tree. The area of each leaf was calculated using the formula L*W*.7 (from previous work by J. Flore, personal communication).

Four measurements of diameter (two lengths, two widths) were made for each apple with a caliper micrometer on July 17. Twenty-five apples not involved in the treatments were then measured in the same manner, picked, and weighed. The surface area of each apple was estimated using the formula πd^2 (surface area of a sphere), and was regressed against weight. A prediction equation was generated to estimate the weight of each apple on a branch. On August 27, new diameter measurements were taken, and a new prediction equation was generated to estimate the apple weights in the same manner as described above.

On August 28 and 29, the number of leaves and simulated mines on each branch were re-counted, and new simulated mines were added to give a total of two, three, and five mines/leaf on the previous treatments of one, two, and three mines/leaf, respectively. This added defoliation was timed to coincide with the first observed third generation 'tissue-feeding' mines in a nearby orchard.

Throughout the experiment, all the apples were checked weekly for early abscission. If an apple fell, the branch was re-adjusted to its assigned leaf to fruit ratio by removing leaves. A standard pest management program was followed throughout the season, with pesticides applied as needed. No irrigation was available. The apples were harvested and their final weights were determined on September 23.

RESULTS

1983 Experiment

Using a calculated surface area to estimate the weight of hanging 'Red Delicious' apples proved to be effective, as is seen by their significant correlations (Figure 8).

The effect of girdling vs. not girdling the spurs was significant (Table 6). Ungirdled spurs showed a higher weight gain (> 345% difference by harvest) than girdled spurs.

There was no significant effect of the different defoliation levels on either girdled or ungirdled spurs, although for girdled spurs there was a trend of decreasing weight gain with higher levels of defoliation. There were no significant girdling x defoliation interactions in this experiment. The effect of blocking by trees proved to be significant.

The importance of the leaf area remaining after defoliation to weight gain is evident when looking at the data from the girdled treatments. There is a linear relationship between the two variables within the intervals we studied (Figures 9 and 10). The association between leaf area and weight gain is less evident for the ungirdled treatments.

There were no observable differences in premature fruit drop between the treatments by harvest time (September 24).

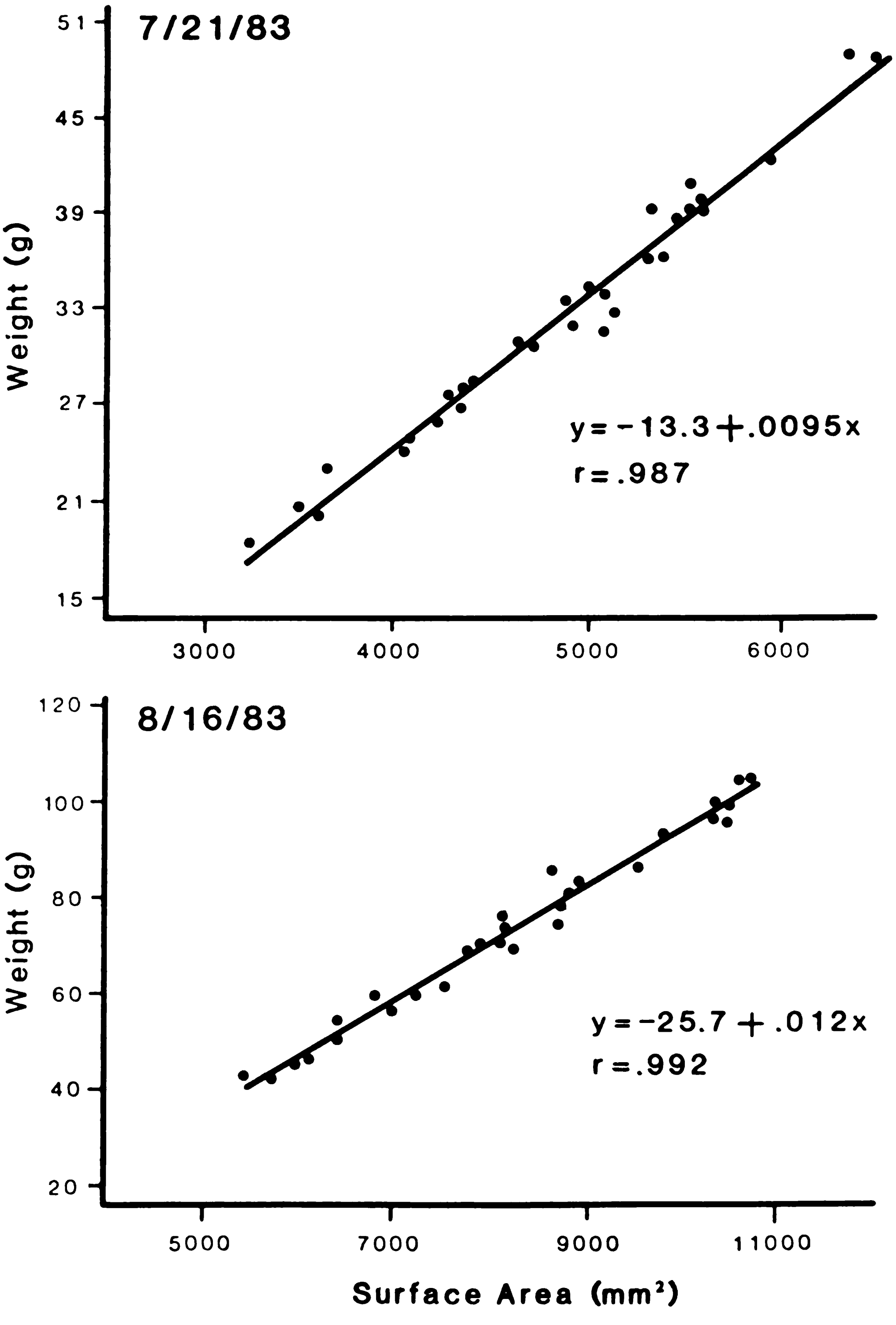

Figure 8: Prediction equations for apple weight based on surface area. 1983 - 'Red Delicious'.

Table 6: Effects of girdling and defoliation of spurs on apple weight gain, 1983.

Girdling	% defoliation	Increase in weight[a] Treatment to 8/16	Treatment to 9/24
-	0	43.3 a	100.8 a
-	15	44.3 a	102.1 a
-	30	44.9 a	105.9 a
+	0	15.9 b	29.2 b
+	15	13.7 b	27.7 b
+	30	12.7 b	26.8 b

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[a] Means followed by the same letter are not significantly different at the P=0.05 level (Duncan's (1955) new multiple range test).

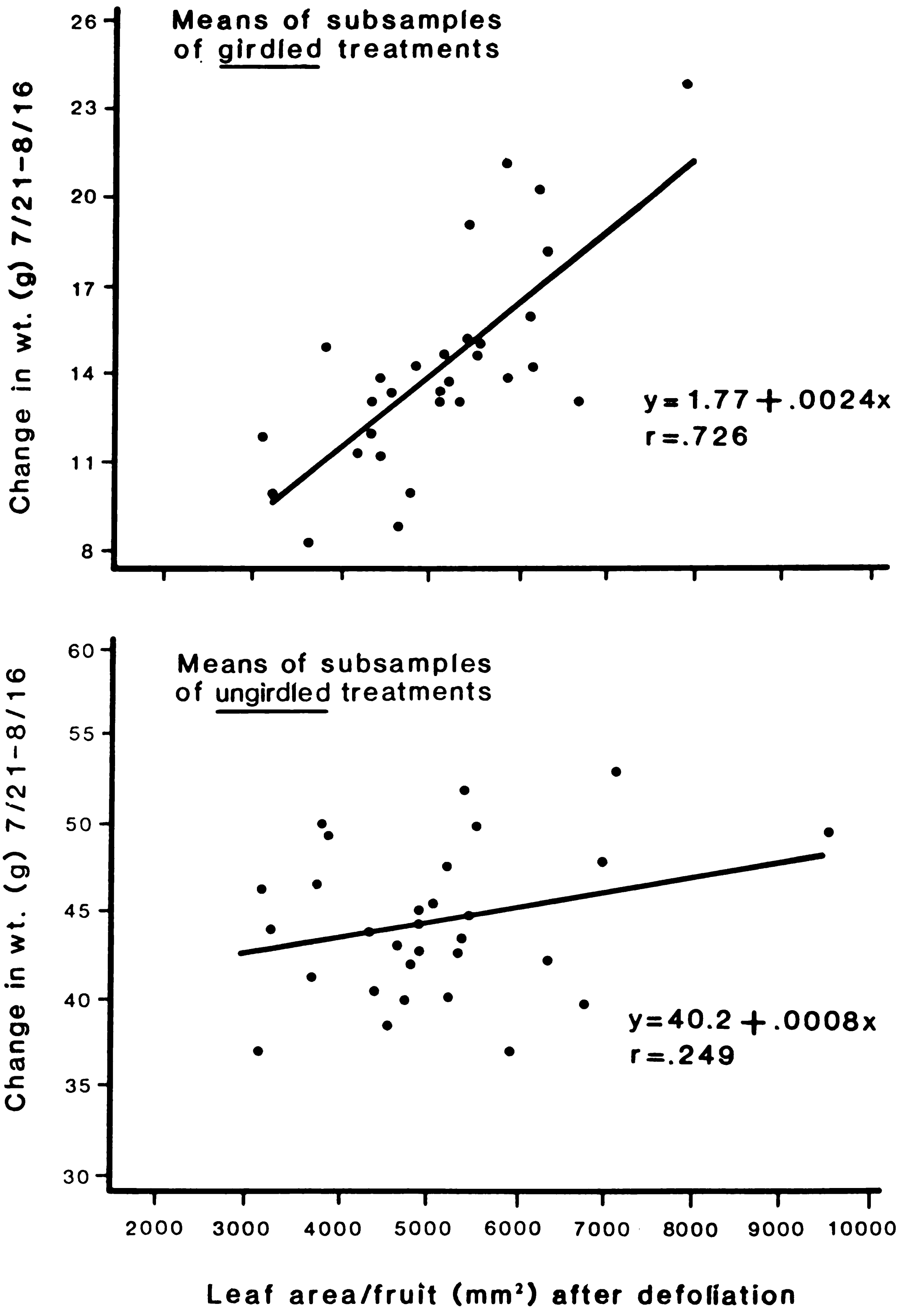

Figure 9: Effect of leaf area per fruit on weight gain. Treatment to 8/16/83.

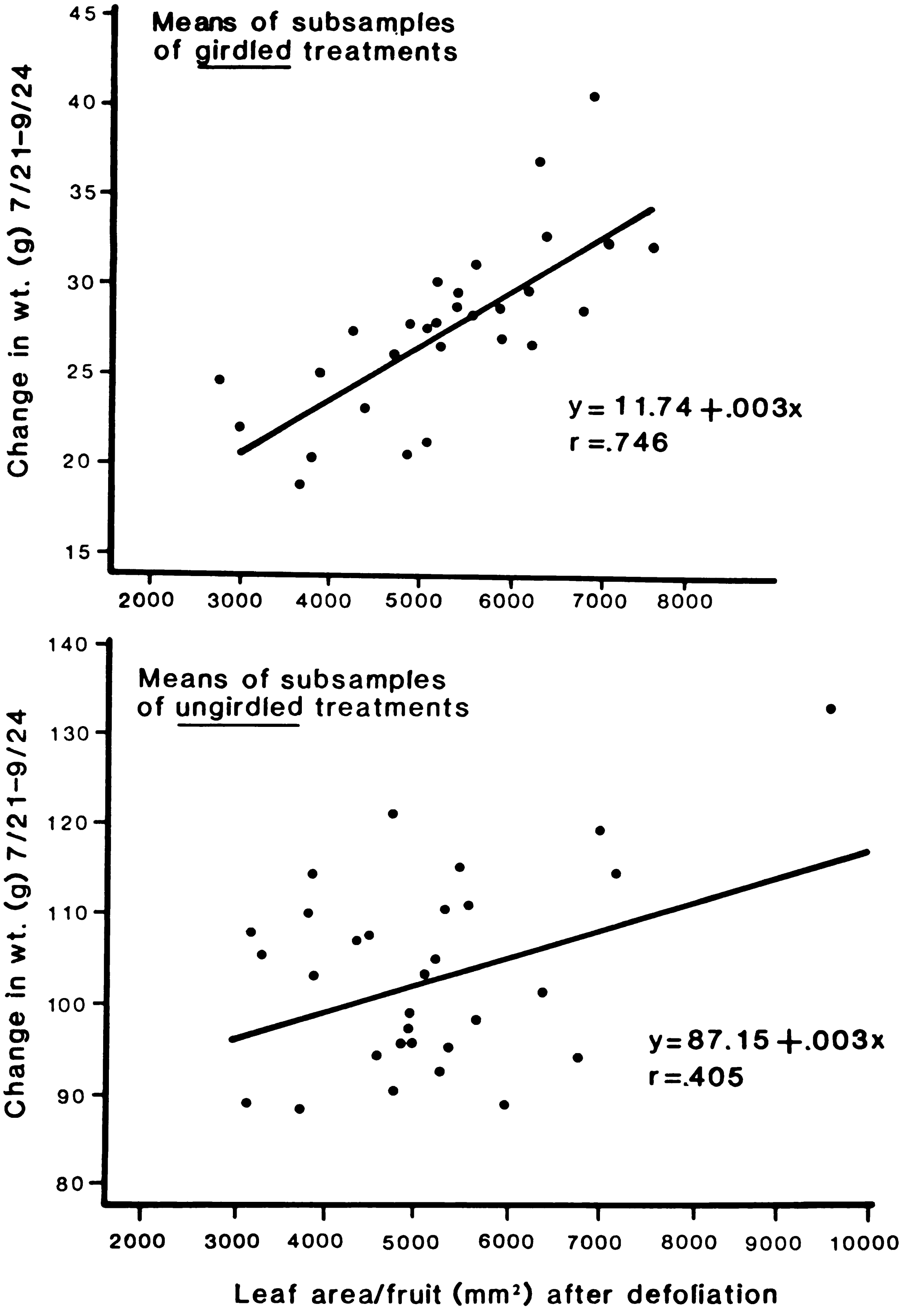

Figure 10: Effect of leaf area per fruit on weight gain.
Treatment to harvest (9/24/83).

1984 Experiment

The prediction equations for the weight of hanging apples based on calculated surface area for 'Golden Delicious' were similar to the equations generated for 'Red Delicious' in 1983 (Figures 8 and 11).

The interaction of crop load and simulated leafminer damage are summarized as follows (Tables 7 and 8). In the analysis of this factorial experiment, the effects of different leaf:fruit ratios (Table 11), and blocking by tree were highly significant (Table 9). There was no significant effect due to different infestation levels (Table 10), nor were there significant leaf:fruit ratio x infestation interactions (Table 9).

As in the 1983 experiment, the leaf area remaining after defoliation was important in determining the fruit weight gain. The relationship between leaf area and weight gain is linear within the intervals that we studied (Figure 12).

There were no observable differences in premature fruit drop between the treatments by harvest time (September 23).

Table 7: Interactive effects of crop load and simulated leafminer damage on change in apple weight (grams) from 7/16 to 8/27.

No. simulated mines/leaf (Gen. 2, Gen. 3)	Leaf:Fruit Ratio		
	10:1	15:1	20:1
0,0	14.6 a	22.2 bc	27.4 e
1,2	11.7 a	23.8bcd	23.1bcd
2,3	11.7 a	18.0 abc	25.6 de
3,5	12.9 a	17.1 ab	28.0 e

Means followed by the same letter are not significantly different at the P=0.05 level (Duncan's (1955) new multiple range test).

Table 8: Interactive effects of crop load and simulated leafminer damage on change in apple weight (grams) from 7/16 to 9/23.

No. simulated mines/leaf (Gen. 2, Gen. 3)	Leaf:Fruit Ratio		
	10:1	15:1	20:1
0,0	20.2 a	33.3 bc	45.0 e
1,2	22.8 a	34.2 bcd	36.3 cde
2,3	16.8 a	26.8 abc	41.0 de
3,5	17.3 a	24.7 ab	45.7 e

Means followed by the same letter are not significantly different at the P=0.05 level (Duncan's (1955) new multiple range test.

Table 9: Mean squares showing the effects of leaf:fruit ratio and different infestation levels on apple weight gain.

Source of Variation	df	Mean Square
Tree	4	180.26***
Treatments	11	161.03***
L:F Ratio	2	744.93***
Infestation level	3	28.88
Ratio x infestation	6	32.48
Error	44	22.04

*** Highly significant (P<.0001)

Table 10: Defoliation level effects on apple weight gain (averaged across leaf:fruit ratios).

No. simulated mines/leaf (Gen. 2, Gen. 3)	Increase in Weight (g)	
	by 8/27	by harvest (9/23)
0,0	21.4	32.8
1,2	21.0	31.1
2,3	19.4	29.2
3,5	18.4	28.2

No significant differences were found between means within columns at the P=0.05 level (Duncan's (1955) new multiple range test).

Table 11: Leaf:fruit ratio effects on apple weight gain (averaged across defoliation levels).

Leaf:Fruit Ratio	Increase in Weight (g)[a]	
	by 8/27	by harvest (9/23)
10:1	13.8 a	19.3 a
15:1	20.3 b	29.8 b
20:1	26.0 c	42.0 c

[a] Means followed by the same letter within columns are not significantly different at the P=0.05 level (Duncan's (1955) new multiple range test).

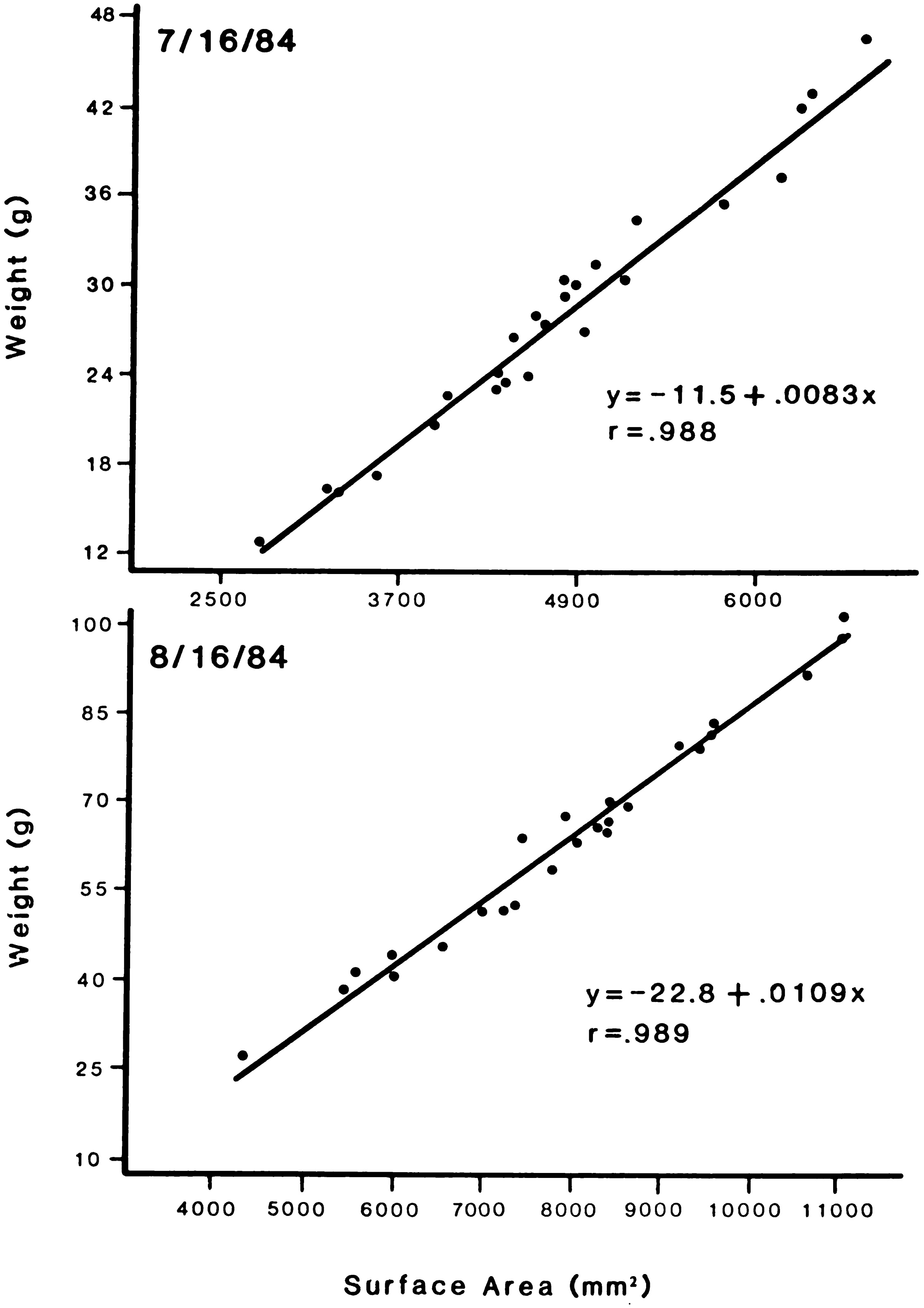

Figure 11: Prediction equations for apple weight based on surface area. 1984 - 'Golden Delicious'.

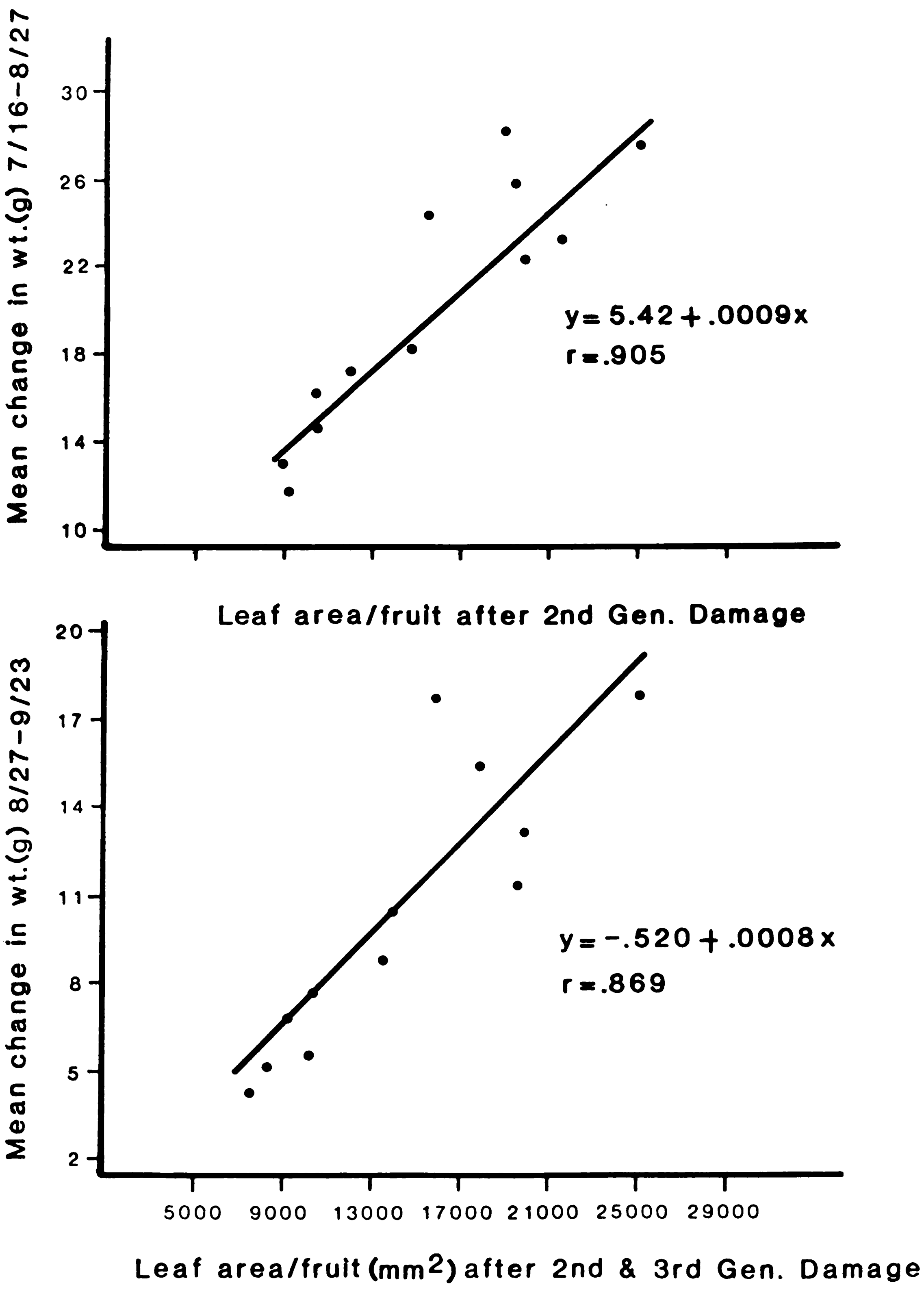

Figure 12: Effect of leaf area per fruit on weight gain. 'Golden Delicious' 1984.

DISCUSSION

The fact that ungirdled spurs showed a higher weight gain than girdled spurs in the 1983 experiment shows that girdling was necessary to study the localized effects of defoliation. Our work agrees with other studies that have shown that other sources within the tree provide carbohydrates to the fruit on the ungirdled spur (Feree and Palmer 1982).

The significant correlations between leaf area and weight gained for girdled spurs indicate that girdling restricts the carbohydrate supply of the fruit to the local spur leaves, while an ungirdled spur is free to receive carbohydrates from other sources such as nearby non-bearing spurs, stored carbohydrate in the scaffold branch, or carbohydrate supplied from the terminal shoots.

Even with our treatments of 30% defoliation in 1983, and three and five simulated second and third generation mines in 1984 (approximately 22 and 36% reduction in spur leaf area, respectively), we did not reach a threshold where significant differences could be seen in apple sizing. This may be attributed to compensation by increased photosynthetic activity of the remaining leaf tissue (Flore 1983, Proctor et al. 1982). The data do seem to indicate that under our specific conditions the recommended action threshold of two mines/leaf for second generation populations of STLM (Weires 1981, Reissig et al. 1982) was too conservative. However, we were not able to measure the effect of second generation mining on next year's fruit bud formation, nor did we fully investigate the effect on fruit drop, because of our relatively early harvest dates.

Rainfall during the months of July, August and September of 1983 and 1984 were below average. This is reflected in the relatively small size of the fruit for both years.

Both years' data show that the leaf area remaining after defoliation is important in determining final fruit size, even when defoliation occurs after fruit set. This has important implications when setting thresholds for leaf feeding insects. Ames et al. (1984) showed differential effects of mite feeding at different crop loads on fruit size and other parameters affecting crop value. Crop load should play an important role in deciding the impact of foliage feeders on fruit sizing, and economic thresholds or treatment strategies should be varied accordingly.

The block effect was important in both experiments. This shows that the potential for fruit sizing varies from tree to tree, even with similar leaf area to fruit relationships. The potential for larger fruit may depend on the previous vigor of the tree and previous stored carbohydrates. This is yet another variable to be considered when establishing damage-yield relationships.

When simulated mines are compared to actual mines, there may be important physical and physiological differences that could affect the results obtained in this type of experiment. Ethylene is produced by damaged tissue, and is important in regulating fruit abscission (Edgerton 1971). Mines simulated with a hole punch remove the area of the 'damaged' leaf tissue, while actual STLM mines leave this tissue intact, and could therefore be producing more ethylene. In the case of an actual mine the damage is sealed within the leaf epidermis. This may cause more ethylene to be translocated rather than volatilized. Simulated mines may have a more drastic effect on Pn over time because the whole area is removed at once, while with an actual mine the area is slowly eaten away. Simulated mines may also cause more water loss by the leaf because of the cut area around the mine perimeter contrasted with the sealed STLM mine.

Photosynthetic efficiency will vary depending on the light trapping efficiency of the tree (Hall and Feree 1976), as will the impact of STLM infestations. The pruning practices and the planting densities of orchards will determine light trapping efficiency. Weather, scion-rootstock interactions (Feree and Barden 1971), and cultural practices (Feree 1978) also affect net photosynthesis of apple trees. To be able to accurately predict damage-yield relationships of STLM and other foliage feeders under varying conditions, more joint research needs to be carried out between horticulturalists and entomologists.

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CONCLUSION

The spotted tentiform leafminer is an intriguing apple pest to study for many reasons. It is sporadic, and its population dynamics are not well understood. In unsprayed orchards its populations are kept under control by natural mortality factors, yet in commercial orchards populations can explode. This suggests that biological control could work under proper conditions, but in view of the current management practices for other pests, would seem almost impossible to implement. Its interveinal leafmining habit is perceived to be harmful to apple trees, yet damage-yield relationships are not well understood, and economic injury levels have been set using observations more than quantitative data. STLM will remain a controversial pest until more of the questions concerning its role in the apple system are answered.

The objective of this thesis was to add new and pertinent information to the pool of knowledge on STLM, with the hopes of bettering our management practices.

In keeping with the concept of researching an integrated pest management program for STLM, it was found that parasitoids are effective in maintaining STLM populations below thresholds, and that there are certain times in the life cycle of the pest when short residual chemical controls would miss the susceptible parasitoids.

It was also found that the number of adulticide sprays can be reduced by using well timed pyrethroid sprays targeted at the adults and eggs, or by using a Dimilin spray targeted at the eggs. By timing a spray to the adults and eggs, rather than 'sap-feeding' larvae, parasitoids have a better chance of escaping harm because there is more time between the spray and their emergence. Dimilin would have an added advantage, in that being and insect growth regulator, it would probably not adversely affect adult parasitoids. In either case, since 100% kill is difficult to obtain, any surviving STLM could serve as sources for future parasitoid development.

If a spring brood adulticide/ovicide spray was correctly timed to kill STLM eggs and miss the parasitoids, it is unlikely that second and third generations would build up to damaging levels. We found that fruit sizing would not be significantly decreased with 30% defoliation, or with the simulation of three second and five third generation mines/leaf. This is above the current recommended thresholds of two second generation and three third generation mines/leaf, but we recognize that damage-yield relationships will vary under different environmental and cultural conditions. Pest managers should take this into account as well as parasitism levels and mortality of the previous generation when deciding whether an insecticide application is necessary.

This is the essence of an Integrated Pest Management program, to monitor a pest's development throughout the season to see if it reaches economic thresholds, and if it does, to know how your management action will affect the system. Since STLM and its parasitoids are only a small part of the apple pest complex, this work needs to be integrated into an overall pest management system for apples.

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