ENVIRONMENTAL, CULTURAL AND INSECTICIDAL EFFECTS ON THE VEGETABLE LEAFMINER, *Liriomyza sativae* BLANCHARD, AND ITS PARASITES

By

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This dissertation is proudly dedicated to my mother,
Opal Huddleston Tryon.

"The only way to enjoy life
is to jump in with both feet."

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The vegetable leafminer, *Liriomyza sativae* Blanchard (Diptera: Agromyzidae), has been a serious pest of Florida's tomato and celery industry since 1972. Leafminer populations were studied on commercial vegetable farms in two areas of Florida. Initial research focused on celery and tomato transplant seedlings grown in plant production ranges in Sun City, Florida, during the fall and winter of 1977 and 1978 (October to March). In the spring and summer of 1978 (March to July) the research was conducted on commercial celery farms in Belle Glade, Florida, and complementary laboratory experiments were conducted in Gainesville, Florida.

Adult leafminer invasion of the transplant production farm, monitored with yellow cardboard traps covered by sticky, transparent plastic, was the result of prevailing winds over nearby tomato fields. Ratio of larval mines to stipples was related to adult leafminer preference for host seedlings. Leafminer host preference was influenced by prior host developmental association, by host cultivar and species and seedling age.

The number of adult leafminers and parasites reared from celery leaf samples was influenced by temperature, humidity and the number of leaves per container. The effect of temperature (15.6°, 18.2°, 21.1°, 22.2°, 23.9°, 26.7°, 29.4° and 32.2°C) on pupal development was linear. A degree-day value for pupal development, calculated from 6 constant temperatures, was 127.8 (degree-day C) for the leafminer and 141.2 (degree-day C) for the leafminer parasite, *Opius* spp.

Experimental field plots and seedlings in flats had extremely high levels of parasitism (>90%). The major parasites were *Chrysonotomyia formosa* (Westwood), *Diglyphus intermedius* (Girault) and *Opius* spp. No interactions or interdependence among parasite species could be demonstrated.

Permethrin (0.20 lb. A.I./A.), methamidophos (1.00 lb. A.I./A.), fenvalerate (0.40 lb. A.I./A.) and permethrin (0.10 lb. A.I./A.) + oxamyl (0.25 lb. A.I./A.) were the most effective insecticides significantly (P=0.05) reducing the number of mines on celery and tomato and celery seedlings. Methamidophos was the only insecticide effective in significantly (P=0.05) reducing the number of adult parasites reared from both celery and tomato leaf samples.

INTRODUCTION

Presently, the most important insect pest of Florida's $632 million vegetable industry is the vegetable leafminer, *Liriomyza sativae* Blanchard (Diptera: Agromyzidae). Commercial vegetable growers in Florida listed only *L. sativae* and weather as factors reducing yield in 1978. This pest is specifically listed as an economic problem by both celery and tomato growers (Anonymous, 1978). Damage resulting from stippling by the female leafminer and the mining activities of the larvae defoliate plants may cause death when populations are high.

The tomato growers harvested $132 million worth of produce in Florida from October 1977 to June 1978; this harvest represented 35% of the fresh market tomatoes grown in the United States. Nearly half of the Florida tomato produce is grown on the west coast from Tampa south to Naples.

The Florida celery growers harvested $47 million worth of produce in 1977-78 which was about 25% of the total crop grown in the United States. Nearly 85% of Florida commercial celery is grown on muck soils near Belle Glade (Anonymous, 1978).

The widespread use of synthetic organic pesticides in the 1940's paralleled the emergence of the vegetable leafminer as an important vegetable pest (Oatman and Michelbacher, 1958). During the last 30 years leafminer control has involved a series of pesticides that were effective for only a few growing seasons. In succession, chlorinated hydrocarbons (1940's) and organophosphates (1950's) became ineffective (Lema, 1976). Routine treatments of this fly with insecticides led to resistance by leafminer populations (Genung, 1957, and Poe, 1974b). These chemicals are also toxic to its natural enemies and have released it from most parasite mortality.

The leafminer, therefore, has shifted from a secondary to a primary pest (Oatman and Kennedy, 1976). There is evidence that suppression of natural enemies and resistance to insecticides are the major causes of the change in the leafminer pest status (Glass, 1975).

The leafminer problem is complicated by insecticidal control of other pests, particularly lepidopterous larvae. Insecticides labeled for Lepidoptera larvae are also lethal to leafminer parasites.

Lack of target-specific pesticides for long term control of leafminer plus the impact of Environmental Protection Agency regulations have stimulated research in integrated control methods.

This dissertation details field and laboratory studies of the vegetable leafminer to provide information useful to the development of a functional leafminer management program for Florida's vegetable growers. The research was done on tomato and celery seedlings on a transplant production farm in Sun City, Florida; and on commercial field celery in Belle Glade, Florida.

LITERATURE REVIEW

Systematics of *Liriomyza sativae* Blanchard

Four insect orders, Lepidoptera, Diptera, Hymenoptera and Coleoptera contain species of leafmining insects. Characteristically, mines are formed between upper and lower surfaces of the host plant leaves as the larvae feed on the mesophyll. Some leafmining species are of economic importance because their damage to the plant host may include decreased esthetic appeal of foliage, decreased sales due to demand for pest-free plants, entry points for invasion of pathogens, water stress, decrease in photosynthetic activity, stunting, leaf drop, decreased yields and even plant death. A serious pest to Florida's vegetable industry is *Liriomyza sativae* Blanchard (Diptera: Agromyzidae) (Musgrave *et al*., 1975a).

Species concepts in the Agromyzidae have changed significantly since the turn of this century (Steyskal, 1964). *Liriomyza* are very homogeneous with similar adult morphology and coloration. Spencer (1961) indicates that the only decisive character useful to separate similar species of *Liriomyza* is the male genitalia.

Reports of *Liriomyza* spp. outbreaks prior to the 1970's lack voucher specimens needed for updating records of speciation (C. A. Musgrave, personal communication, 1978).

Four economically important _Liriomyza_ spp. occur on the mainland of the United States (Stegmaier, 1968). Steyskal and Spencer (1973) named the four species as:

Liriomyza brassicae (Riley, 1884)
L. sativae Blanchard, 1938
L. trifolii (Burgess, 1880)
L. huidobrensis (Blanchard, 1926)

Musgrave _et al_. (1975b) listed synonyms of _Liriomyza sativae_ Blanchard species:

Liriomyza pullata Frick, 1952
L. canomarginis Frick, 1952
L. munda Frick, 1957
L. guytona Freeman, 1958
L. phaseolunata Frost, 1943
L. propepusilla Frost, 1954

The accepted common name, 'vegetable leafminer' is descriptive of the host plant status of _L. sativae_. Agromyzid larvae that feed and cause winding trails are named 'serpentine leafminers'. The descriptive common name does not specifically identify the one or possibly more species that may damage Florida vegetable crops (Genung and Harris, 1961).

Physical Description and Life Cycle

The adult _L. sativae_ is "a very small species, wing length from 1.3 mm in male to 1.65 mm in female; frons and all antennal segments bright yellow; mesonotum brilliantly shining black; mesopleura largely yellow but variably black on lower half; legs, coxae and femora bright yellow, tibiae and tarsi only slightly darker, more brownish" (Spencer and Stegmaier, 1973). This leafminer can usually be distinguished from related species by the shining dorsum surface of the thorax, the yellow femora and the yellow vertex between the eyes (Musgrave _et_ _al_., 1975b). Spencer (1961) indicates that microscopic examination of the male genitalia by an expert is necessary to identify _Liriomyza_ species.

Female leafminers use their ovipositors to puncture (stipple) host leaves for feeding and oviposition. Oviposition punctures are practically the same as those for feeding (Webster and Parks, 1913). Ratios for stippling to oviposition range from 5:1 (Oatman and Michelbacher, 1958) to 100:1 (Wolfenbarger, 1947). Nothing is known about oviposition stimuli. 'Exploratory probes' with the ovipositor and initial stippling activities by the female leafminer may be a means of evaluating the suitability of a potential host (Poe _et_ _al_., 1976). The presence of the egg (0.25 mm diameter) in a stipple indicates successful oviposition (Wolfenbarger, 1947). The temperature dependent incubation at 22-25^{o}C lasts 3-4 days (Genung and Harris, 1961).

The laterally compressed yellow maggot excavates a mine between the upper and lower epidermis using its dark sclerotized mandibles to macerate the leaf tissue. The new mine is threadlike but as the larva feeds and grows, the mine gradually widens. The first instar is microscopic (0.12 mm in length) and in a mine 0.25 mm in width. The mature third instar may be up to 3.5 mm long. At the emergence point this trial may be 1.5 mm wide (Oatman and Michelbacher, 1958). Larvae mature in 4-7 days (Poe and Short, 1975).

The mature larva chews a semicircular hole through the epidermis at the end of its mine, the bright yellow larva usually drops to the soil (but occasionally remains on the leaf). In 20-30 minutes the body shortens and thickens, gut contents are voided and the color turns yellow-brown (Oatman and Michelbacher, 1958). The resulting dull-yellow coarctate puparium is 2 mm long. Pupation lasts 7-10 days (Webster and Parks, 1913). Oatman and Michelbacher (1958) determined the pupal stage lasts an average of 9 days at 27°C. The entire life cycle from egg to adult is completed in 21-28 days (Poe and Short, 1975).

Mating occurs soon after emergence, and oviposition begins within 24 h. Genung and Harris (1961) reported that adults live 4-6 days on host plants. Oatman and Michelbacher (1958) reported mating occurred within 6 h. and as late as 20 days after female emergence. Fertile eggs were produced within 12-24 h. of mating. Oatman and Michelbacher's (1958) work on the life span of female and male *L. sativae* needs clarification because a complex of at least 2 species was involved in the study (Jensen and Koehler, 1970; Oatman, personal communication, 1978). This may also be true for some of the other published work on leafminers.

Distribution and Host Plants

Liriomyza sativae has been reported from Cuba, Jamaica, Puerto Rico, Peru, Venezuela, Argentina, Hawaii and Tahiti (Spencer and Stegmaier, 1973, and Perez, 1974). In the United States it is known from Alabama, California, Florida, Ohio, South Carolina, Tennessee, and Texas (Steyskal, 1964; Stegmaier, 1968). It is the most destructive insect pest to commercial vegetable growers in south Florida (Brogdon, 1961) and in the Sacramento and San Joaquin Valleys of California (Oatman and Michelbacher, 1958).

The economic problems created by *L. sativae* are complicated by its wide host range. The plant families and 'common names' of potential crop hosts include

Cucurbitaceae - cantaloupe, cucumber, pumpkin, squash, watermelon

Solanaceae - eggplant, pepper, potato, tobacco, tomato

Leguminoseae - alfalfa, bean, clover, field peas, garden pea, kidney, lima bean

Compositae - aster, chrysanthemum, dahlia, lettuce, marigold, sunflower, zinnia

Cruciferae - cabbage, cauliflower, radish, turnip

Malvaceae - cotton, okra

Umbelliferae - carrot, celery, parsley.

A more comprehensive list of host plants is provided by Stegmaier (1966) and Musgrave *et al*. (1975b). Many of the economically important *Liriomyza* species in the United States utilize the same species of host plants. Additional confusion in listing specific hosts for the *Liriomyza* species is based on misidentification of the leafminer species. Alternate hosts, weeds, also serve as reservoirs and sustain leafminer population between crop seasons in south Florida (Genung and Janes, 1975).

History of the Leafminer as an Economic Pest

Early Reports of Leafminer Damage

Liriomyza sp. has relatively recently been reported to be an important economic pest. Wilcox and Howland (1952) first observed leafminers on southern California tomatoes in 1939. Infestations on cucurbits (cucumbers, melons and squash) were considered serious in 1945 and 1947, the tomato yield in southern California was reduced 25-50%. Wolfenbarger (1948) reported leafminer outbreaks in 1945-48 in south Florida destructive to potatoes, tomatoes, beans, okra, squash and cabbage. During the fall of 1947 severe infestations of *Liriomyza* sp. were reported on lettuce in the Salt River Valley of Arizona and on cantaloupes in July, 1948. In both cases entire fields were abandoned and destroyed (Hills and Taylor, 1951). In Texas, pepper was completely defoliated by leafminers in 1952 resulting in crop abandonment by the growers (Wene, 1953).

Because of the nature of the damage and the several dependent secondary problems, a single "threshold" has not been practical. Consequently a definite "economic threshold" level of damage has not been determined for tomato. Kelsheimer (1963) considered a random sample of tomato leaves containing 5 leafminers as an economically significant level of infestation. Wolfenbarger (1961) used 4-6 mines per larger tomato plant as economically significant. Wolfenbarger and Wolfenbarger (1966) suggested a 40% infestation of tomato leaflets with 1 or more mines an economic threshold level for spraying of tomatoes.

Leafminer damage to crop yield have not provided sufficient information to assist in developing crop thresholds. Potato crops with reduced leafminer populations had increased yields. Tomatoes, however, showed no significant increase in yield with reduction in leafminer populations (Wolfenbarger, 1954). Levins *et al*. (1976) found that control of leafminers on tomato leaves in Florida did not increase yields. Schuster and Jones (1976) likewise failed to demonstrate yield reduction in tomatoes infested with leafminers. Poe *et al*. (1978a), however, demonstrated that the effect of leafminer populations on yield of celery was linearly related to mine density.

Leafminer Parasite Populations Reduced by the Use of Pesticides

The increase in *Liriomyza* populations appear to be a symptom of agricultural spary practices (Hayslip, 1961).

Prior to the early 1940's the leafminer was controlled by its natural enemies, principally hymenopterous parasites. The leafminer was considered a 'minor pest' until the late 1940's and early 1950's when the widespread use of DDT caused a drastic reduction in the number of beneficial leafminer parasites without much effect on the leafminer populations (Wolfenbarger, 1947 and 1958; Hills and Taylor, 1951; Mayeux and Wene, 1950). From a relatively unknown and unimportant pest the leafminer bacame an economic pest of many vegetable crops (Genung and Harris, 1961).

Pesticides for Leafminer Control

The widespread use of chlorinated hydrocarbon insecticides by vegetable growers beginning in the mid-1940's destroyed biological control for the leafminer; this shifted its status from a minor to a major pest (Wolfenbarger, 1947). Efficacy of these chlorinated hydrocarbons (BHC and aldrin) became less after 1 to 2 growing seasons of use (Wolfenbarger, 1958). BHC and aldrin efficacy also declined with use. By the mid-1950's, Wolfenbarger (1958) had summarized from years of field testing that azinphosmethyl, diazinon, ethion, parathion and phorate were the most effective insecticides on *L. sativae*. By the late 1950's these organophosphates had begun to replace the chlorinated hydrocarbons as the effective chemicals needed to control the vegetable leafminer (Harris, 1959; Smith *et al.*, 1974).

The number of effective chemicals available for leafminer control of vegetables was greatly reduced due to possible tolerance and/or resistance during the 1960's and early 1970's. Genung (1957) reported leafminer resistance to toxaphene in south Florida. Parathion and diazinon were less effective for control of leafminers on tomatoes in south Florida (Hayslip, 1961). By 1970 only azinphosmethyl and dimethoate were recommended for leafminer control. However, azinphosmethyl was approved for use on potatoes and dimethoate was approved for use on certain vegetables (Adlerz, 1968; Smith *et al*., 1974; Poe and Jones, 1972; and Harris, 1962). By 1975, the recommended insecticides dimethoate, azinphosmethyl, parathion and diazinon insecticides did not control leafminer populations at levels acceptable to growers (Musgrave *et al*., 1975b).

In the mid-1970's only oxamyl (Bear, 1976) and a synthetic pyrethroid, permethrin (Poe *et al*., 1978b), were effective in controlling leafminer populations. The problem persists because leafminers have developed resistance to one pesticide after another. Their parasites apparently lack this ability (Woods, 1978) and sole reliance on pesticides for control has resulted in greater not smaller populations of leafminers.

Leafminer Parasites

Identification of the Leafminer Parasite

It is difficult to evaluate parasite effect on leafminers because of the widespread use of pesticides. In Texas, Harding (1965) blamed fluctuations in leafminer populations on absence of regulating parasites. McClanahan (1975) showed that 2 parasite species greatly reduced large *L. sativae* populations on tomato crops in Ontario greenhouses.

The potential importance of parasites in the population dynamics of most agromyzid leafminers must not be overlooked (Hills and Taylor, 1951; Oatman and Michelbacher, 1958; Price and Poe, 1976).

The population dynamics of *L. sativae* and these parasites have not been thoroughly studied. There are many hymenopteran species that parasitize *Liriomyza* spp. Frost (1924) reported 4 families and 80 species of hymenopterous parasites in the United States. From agromyzid leafminers, Stegmaier (1972) reared 31 species in 19 genera in 5 hymenopterous families.

Fourteen species of beneficial wasps have been identified from *L. sativae* in Florida (Musgrave *et al*., 1975b). Although these parasites are practically nonexistent in heavily sprayed fields, they kill from 40-100% of the leafminers in untreated crops (Musgrave *et al*., 1975a). These parasites belong to the families Braconidae, Eulophidae, Pteromalidae and Cynipidae. The most numerous parasite species in Florida are *Halticoptera circulus* (Walker), *Opius dimidiatus* (Ashmead), *Chrysonotomyia* (=*Achrysocharella*) *formosa* (Westwood), and *Diglyphus intermedius* (Girault) (Lema, 1976). *Achrysocharella formosa* Westwood was renamed *Chrysonotomyia formosa* (Westwood) by Yoshimoto (1978). Works by Harding (1965), Stegmaier (1966), and McClanahan (1975, 1977) list various parasitic complexes in North America reared from L. sativae. These parasites are the chief natural enemies of L. sativae. Under field conditions, control could be achieved by relying on naturally-occurring parasitic wasps (Woods, 1978).

Insecticides Eliminate the Natural Enemies of the Leafminer

Oatman and Kennedy (1976) suggested that repeated applications of methomyl induced outbreaks of L. sativae on tomatoes by selectively eliminating parasites without affecting leafminers. They concluded that this was a response to the adverse effect of methomyl on the hymenopterous parasites. When celery is sprayed according to current grower practices, less than 1% of the leafminers were parasitized (Musgrave et al., 1975b). Chemical control by insect growth regulators ZR-619 and ZR-777 on leafminers reduced leafminer emergence but also reduced Opius spp. emergence from 27% to 0% (Poe, 1974a; Lema and Poe, 1978). It was concluded to be of greater potential harm to biological control agents than benefit to leafminer control.

Harris (1962) found that non-systemic insecticides generally increased the intensity of the leafminer infestations and parasite reduction was suggested as the cause.

Since lepidopteran larvae are also important pests, broad spectrum non-selective pesticides have been used which result in increased mortality of the hymenopterous parasites that normally could regulate leafminer numbers. Selective pesticides and/or a greater reliance on *Bacillus thuringienesis* Berliner to control Lepidoptera larvae would presumably reduce leafminer parasite mortality thus benefiting leafminer control. To benefit integrated pest management programs for leafminer control on Florida vegetables, insecticides should be effective against target pests and have minimal effect on the activities of natural enemies (Poe *et al*., 1978b).

DISPERSAL AND HOST SELECTIONS BY VEGETABLE LEAFMINER IN TRANSPLANT PRODUCTION RANGES

Introduction

Vegetable leafminer damage is related not only to pest population levels but also to individual host species and cultivars. Variations in the leafminer injury sustained by tomato varieties (Kelsheimer, 1963) and chrysanthemum cultivars (Webb and Smith, 1970) have been recorded. 'Yellow Iceburg' chrysanthemum is particularly susceptible to stippling and oviposition by *L. sativae* relative to other chrysanthemum cultivars (Schuster and Harbaugh, 1979a). Such a highly preferred host might serve as an indicator for leafminer populations during early dispersal or at low population levels on the transplant range but only if it shows significant stippling and/or mining before the primary economic crop(s) is damaged. Leafminer dispersal patterns are not well known. Oatman and Michelbacher (1958) and Webster and Parks (1913) found initial field infestations of leafminers confined to clusters on plants along the field edges bordered by untreated weeds and irrigation ditch banks. This localized invasion or 'edging affect' was a result of leafminer populations traveling only short distances. Wolfenbarger (1961) found leafminer dispersal at comparatively short distances (<100 ft).

The objectives of this research are to evaluate several sticky trap colors for use in detecting leafminer dispersal onto the transplant production range and to measure active mine and stippling preferences of the leafminer for several plants which might serve as an indicator for leafminer populations.

Materials and Methods

Four experiments were conducted in Sun City, Florida, at a commercial range where commercial vegetable and ornamental transplants are produced. One hundred or more houses (612,000 ft^2) each were covered with semi-transparent fiberglass roof and enclosed on the sides with semi-transparent plastic which can be raised or lowered to maintain a uniform environment. The range is surrounded by 15,000 acres of commercial tomato fields, some of it visible from the production range.

Sticky traps were used to detect invasion of the production range by adult leafminers. Preliminary tests determined the influence of trap color on catch of leafminers. Yellow, yellow-green, orange, green and blue 7" x 7" cardboard sections were stapled to 12" wooden stakes. Adhesive Tack Trap® was spread uniformly on both sides of the cardboard.

Six card traps of each color, randomly located in a nearby commercial tomato field, were observed after 24 h. on 3 dates in November, 1977.

In preliminary tests, transparent plastic bags were slipped over the colored trap board to prevent damage from rain prior to the application of Tack Trap® to determine if flies were still attracted.

Subsequently, yellow cards protected by plastic bags coated on both sides with adhesive were used to measure leafminer dispersed onto the production range. Seven sites (road edges) surrounding the outer edge of the range (with 120 houses) and equal distance apart (≈0.5mi.) were selected to monitor direction of leafminer dispersal onto the range. Four sticky traps per site were observed for adult leafminers after 24 h. of exposure on November 25, December 3, 12, 19, and 26, 1977 and January 5, 1978. New plastic bags were placed over the trap after each observation date. On each date the prevailing wind direction during the time of most leafminer invasion was determined by personal observation and verified by records of the U. S. Weather Bureau at the Tampa International Airport.

'Walter' tomato transplants from 6 to 10 weeks old in a large production house (7,000 ft^2) were observed to determine the region within the house of earliest stippling and active mines. The house was sectioned into 4 equal quadrants (75 ft x 25 ft), subdivided into 4 subquadrants (18 ft x 3 ft). The number of active mines from 100 tomato seedling leaflets randomly selected was recorded for each quadrant and subquadrant on October 19, 23, and 27 and November 4, 8, and 14, 1977.

After the direction and source of the leafminer invasion onto the range was determined with sticky traps, host plant preferences of 12 species and cultivars were tested for susceptibility to leafminer damage: *Chrysanthemum morifolium* 'Yellow Iceberg', *Phaseolus vulgaris* 'Bush Snap', 'Blue Lake', 'Henderson' and 'Pole', *Hibiscus esculentus* 'Clemson Spineless', *Pisum* sp. 'Little Marvel', 'Sugar' and 'Early Alaska', *Lycopersicon esculentum* 'Walter', *Apium graveolens* '2-14', and *Capsicum annuum* 'California Wonder'. Each species and cultivar were seeded in 4 separate styrofoam transplant flats containing a peat + vermiculite (1:1) growing medium. On November 29, 1977, 3 weeks after seedling, 100 transplants per host plant species and cultivar were observed for leafminer stipples and mines. All data were analyzed using analysis of variance (ANOVA) and least significant difference (LSD) tests.

Results and Discussion

Sticky traps provide immediate and quantitative information necessary for the early detection of invading leafminers. The mean number of leafminer adults captured on various trap colors were as follows: yellow 34, yellow-green 14, orange 7, green 4, blue 3 and transparent plastic covered yellow 29 (N=6, L.S.D.=9.9, P=0.05). Yellow and yellow covered with plastic were significantly more effective than the other trap colors in attracting adult leafminers. Cards wet by rain, dew, and sprays faded and became misshapen, giving inconsistent trap catches. The use of the transparent plastic bags with Tack Trap® protected the yellow card but attracted and trapped leafminers.

Sticky traps located on borders of the transplant production range made directional detection of invading leafminers possible (Table 1). The prevailing winds influenced the direction of leafminer invasions. Trap sites nearly facing prevailing winds and in direct line with nearby commercial tomato fields trapped the largest number of adult leafminers.

The 7 trap sites ranged on each sampling date from directly facing the prevailing wind to least in line for each of the 6 dates had the following percent adult leafminers counts; 33.2, 26.2, 14.7, 10.7, 5.5, 4.4 and 3.8 (L.S.D.= 6.2, P=0.05, N=4). Trap counts suggested that the principal source of leafminer population invasions was commercial tomato fields. Sanitary practices and intense insecticide use had eliminated the transplant range as a source of adult leafminers.

Dobzhansky (1970) reported that the slow dispersal of _Drosophilia_ spp. owing to random wanderings of the flies in search of food and oviposition sites is influenced by involuntary wind dispersal over much greater distances (miles). The rate of dispersal of these fruit flies is more rapid at higher than at lower temperatures. This suggests observations that the majority of the adult leafminers were trapped during the warmer part of the day (≈10 AM to 3 PM).

Table 1. Mean number of adult *Liriomyza sativae* Blanchard trapped on plastic covered yellow cards on the cleared periphery of the transplant production farm relative to prevailing winds[1] (N=4).

Date (mo/da)	Predominant 24 h. wind direction	Average no. adult leafminers[2]/trap facing						
		NE	E	SE	SW	W	NW	N
11/25	NW	23	3	2	7	12	40	44
12/3	W	16	3	3	5	23	38	27
12/12	NW	9	2	1	3	17	33	25
12/19	N	4	1	2	2	6	14	12
12/26	N	1	1	2	2	3	4	6
1/5	NW	1	0	1	0	1	0	2

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[1] U. S. Weather Station, Tampa, Fla.

[2] To nearest whole number.

Adult leafminer trap counts over 24 h. averaged 29 per trap in the tomato field, 16 per trap 100 feet away, 16 per trap at the NW edge of the range nearest the source and less than 1 per trap on the SE edge of the range for 25 (dates) observations during November and December, 1977. The Commercial tomato fields in the area were abandoned after harvest (late November and December, 1977, and January 1978). Leafminers produced on the crop residue invaded down-wind transplant houses and made production of pest-free transplants more difficult. This problem could be prevented by destruction of crop residue and sanitation (Poe, 1973 and Kelsheimer, 1961).

Adult location preference for oviposition within the house (sides down during the day) made detection more rapid. On the 6 dates during October and November, 1977, 100 tomato transplants 6-8 weeks old were examined in each quadrant for active mines. The average number of leafminers per 100 plants from the 4 quadrants was: NW=5.9, SW=3.9, NE=1.9 and SE=1.5 (L.S.D.=1.4, P=0.05). Seedlings in the NW quadrant had a significantly greater number of mines. This result might be explained by exposure of this area to the prevailing winds and infestation source. The NW quadrant was subdivided in 4 subquadrants and examined for active mines per 100 tomato transplants on 3 dates in November (NW=6.9, SW=6.5, NE=5.3 and SE=4.9, L.S.D.=1.99, P=0.05). There were few significant differences between active mine counts in the NW subquadrants although the transplants on the outer edge of the transplant house (NW and SW subquadrants) had the greatest number of active mines. Oatman and Michelbacher (1958) reported this 'edging effect' from initial field infestations on tomatoes along edges boarded by untreated weeds serving as a leafminer source.

Results of the leafminer stippling and oviposition trials involving 2-3 week old hosts are summarized in Table 2. Webb and Smith (1969) found that egg hatch and larval mortality were influenced by host variety.

Active mines were not numerous on tomato, L. esculentum ('Walter'), bean, P. vulgaris ('Bush Snap') and C. morifolium ('Yellow Iceberg') transplants (each averaged 1.8 mines/plant). P. sativum ('Early Alaska' Pea), P. vulgaris ('Pole' Bean) and C. annuum ('California Wonder' Pepper) had the fewest active mines (<0.07 mines/plant). The greatest number of stipples was on C. morifolium ('Yellow Iceberg'), P. vulgaris ('Bush Snap' Bean and 'Blue Lake' Bean) and H. esculentus ('Clemson Spineless') transplants (>30.0 stipples/plant (Table 2). C. annuum ('California Wonder' Pepper) and P. vulgaris ('Pole' Bean) had the fewest stipples (<2.0 stipples/plant). It appeared that oviposition and stippling host preferences existed, were measurable, and could make the use of indicator crops promising. Tomato had a significantly (P=0.05) larger oviposition to stippling ratio (1:12) than the other 11 hosts which suggested an egg laying preference relative to feeding. Six of the selected species and cultivars had ratios of approximately 1:23 (oviposition to

Table 2. Stippling and oviposition by *Liriomyza sativae* Blanchard on 12 host plant species and cultivars 3 weeks old grown in a transplant production house (N=100 plants).

Crop	Host Species (Cultivar)	Total stipples	% plants stippled	Total mines	% plants mined	Ratio of active mines to stippling
Tomato	*Lycopersicon esculentum* ('Walter')	2400bc[1]	100	198a	91	1:12a
Bean	*Phaseolus vulgaris* ('Blue Lake')	3600b	99	169ab	94	1:22b
Pea	*Pisum sativum* ('Little Marvel')	2700bc	85	124bc	54	1:22b
Celery	*Apium graveolens* ('2-14')	950d	100	44d	38	1:22b
Pea	*Pisum sativum* ('Sugar')	2500bc	100	114c	90	1:22b
Okra	*Hibiscus esculentus* ('Clemson Spineless')	3300b	100	144b	72	1:23b
Bean	*Phaseolus vulgaris* ('Bush Snap')	4800ab	100	198a	100	1:24b
Bean	*Phaseolus vulgaris* ('Pole')	120f	21	4e	4	1:30bc
Bean	*Phaseolus lunatus* ('Henderson')	600de	72	19de	25	1"32bc
Chrysanthemum	*Chrysanthemum morifolium* ('Yellow Iceberg')	6100a	100	190a	100	1:32bc
Pea	*Pisum sativum* ('Early Alaska')	384e	48	6e	5	1:64d
Pepper	*Capsicum annuum* ('California Wonder')	184ef	40	1e	1	1:80d

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[1] Numbers in a column followed by the same letter are not significantly different at the P=0.05 level, Duncan's multiple range test.

stippling) which indicated similar egg laying to feeding preference. Only P. sativum, 'Early Alaska' and pepper had oviposition to stippling ratios of 1:32, 1:64 and 1:80. These ratios might be useful to reflect leafminer host preference with more accuracy than counting active mines or stipples per host. These active mine or stipple counts, do not give information relating to host leaf surface area necessary to evaluate relative host preferences.

Stippling was first observed on true leaves 4 to 6 days after seed germination on beans ('Bush Snap' and 'Blue Lake'). The other transplants tested remained free of stipples and were generally slower to germinate by 2-5 days for about 2 weeks after seedling despite the constant presence of large populations of adult leafminers. Sticky trap counts ranged from 11 through 27 per trap/24 h. during the seedling tests, averaging 15 adult leafminers/trap/24 h. This 6 to 9 day delay in active stippling and oviposition activities was attributed to the physiological condition of the host and perhaps its small size. 'Exploratory probes' by the female with her ovipositor prior to feeding or egg laying involved touching but without noticeably penetrating the host leaf surface.

Initial stippling activities by the female leafminer might not only be a method of obtaining food and gathering more sensory information following these "probes" but also a means of evaluating the suitability of a potential host. Poe et al. (1976), Poe and Green (1974), Woltz and Kelsheimer

(1968), and Schuster and Harbaugh (1979b) reported that leafminer activities were influenced by the physiological condition and age of the host. Musgrave *et al.* (1975a) found active mine counts increased rapidly during "vegetative growth" but declined sharply during "senescence."

The female leafminer's ability to preferentially select a host can work as an isolating mechanism for segments of a leafminer population. Oatman and Michelbacher (1958) report *L. pictella* (=*sativae*) population levels vary considerably from field to field and even within areas in the same field. Genung and Harris (1961) reported the response of leafminer populations to similar pesticide treatments in a similar geographical region to be erratic in south Florida. They explained the differences in leafminer population responses to the presence of more than one physiological strain(s), or the existence of several leafminer species. The possibility that the number of animals that may be speciating sympatrically might exceed or at least equal the number of those speciating allopatrically, more emphasis should be placed on biological studies involving sympatric species in the future for both academic and practical reasons. From an agricultural an understanding of speciation mechanisms is essential to the development of realistic pest control programs (Bush, 1975).

In summary, the use of yellow traps, knowledge of specific host preference, and transplant house areas showing early oviposition and stippling damage may make monitoring leafminer invasions more efficient and effective.

EFFECT OF INSECTICIDES ON POPULATIONS OF THE VEGETABLE LEAFMINER AND ON FOUR PARASITE SPECIES ON TOMATO AND CELERY SEEDLINGS

Introduction

This study was undertaken to evaluate and compare the effect of several insecticides on leafminer populations and their parasites in vegetable seedlings.

Materials and Methods

Celery cultivar '2-14' celery and 'Walter' tomato seeds were sown in 18 flats in a commercial house at the production range in Sun City, Florida (Fall 1977). The seedlings were grown for 10 weeks in a soilless (50% vermiculite and 50% peat) growing medium. Each flat of 64 plants received a different insecticide treatment with 2 mixed cultivars (32 plants each).

Nine insecticides, 3 at different rates and 5 combinations were tested for their effects on leafminers and their parasites: permethrin (3.2EC), oxamyl (2L), permethrin (2EC), diazinon (4EC), kinoprene (5E), methomyl (1.8L), methamidophos (4E), acephate (75SP), permethrin (2EC) + oxamyl (2L), permethrin (2EC), diazinon (4EC), permethrin (2EC) + methomyl (1.8L), oxamyl (2L) + dimethoate (4EC) + naled (8EC), and dimethoate (4EC) + naled (8EC) (rates in Table 3).

Table 3. Response of *Liriomyza sativae* Blanchard and parasites to insecticides used singly and in combination on '2-14' celery and 'Walter' tomato seedlings (Fall 1977, N=16).

Treatment					
Material	Formulation	Rate lb.A.I./A.	Mean total insects	Mean total leafminers	Mean total parasites
permethrin	2EC	0.20	0.00	0.00	0.00
permethrin	2EC	0.10			
plus oxamyl	2L	0.25	0.91	0.02	0.89
permethrin	3.2EC	0.20	1.07	0.02	1.05
oxamyl	2L	1.00	2.00	0.00	2.00
permethrin	2EC	0.10	2.74	0.13	2.61
methamidophos	4EC	0.50	2.98	0.22	2.76
permethrin	2EC	0.05			
plus diazinon	4EC	0.50	3.41	0.27	3.14
permethrin	2EC	0.10			
plus methomyl	1.8L	0.25	5.38	0.89	4.49
permethrin	3.2EC	0.10	5.52	1.02	4.50
oxamyl	2L	1.00			
plus dimethoate	4EC	1.00			
plus naled	8EC	1.00	6.27	0.02	6.25
kinoprene	5E	0.60	6.42	0.95	5.47
acephate	75SP	1.00	7.25	0.25	7.00
naled	8EC	1.00			
plus dimethoate	4EC	1.00	11.02	3.25	7.77
diazinon	4EC	1.00	11.27	0.89	10.38
methomyl	1.8L	1.00	11.78	1.01	10.77
permethrin	2EC	0.05	17.40	0.76	16.64
oxamyl	2L	0.25	26.29	2.15	24.14
check			19.24	0.73	18.51
L.S.D.(P=0.05)			3.22	2.07	3.01

Table 3. Extended.

	Mean number of adults reared per 4 seedlings			
% Parasites	'2-14' celery		'Walter' tomato	
	Parasites	Leafminers	Parasites	Leafminers
00	0.00	0.00	0.00	0.00
98	1.75	0.04	0.03	0.00
98	2.00	0.00	0.10	0.03
100	1.04	0.00	2.96	0.00
95	1.24	0.26	3.98	0.00
93	2.65	0.04	2.87	0.40
92	4.75	0.51	1.53	0.02
83	4.75	0.51	4.24	2.26
95	6.01	2.02	2.98	0.02
100	6.26	0.02	6.24	0.02
84	5.47	0.87	5.77	1.03
97	8.01	0.25	5.99	0.25
71	9.02	3.97	6.51	2.53
92	6.74	0.49	14.02	1.29
91	6.52	1.04	15.02	0.98
96	20.25	1.00	13.02	0.52
92	17.02	1.04	31.26	3.25
96	17.49	0.98	19.52	0.48
11.0	2.19	0.42	3.29	0.90

On November 25, 1977, flats of uninfested and untreated celery and tomato seedlings 10 weeks old were placed in a transplant production house on the NW edge of the production range, an area where adult leafminers were present. Yellow traps as previously described were placed in the transplant house and monitored daily during the tests. On December 1, 7, 13 and 19, 1977, replicated units of seedlings were treated with foliar sprays applied with a hand sprayer. On December 21, leaves from 2 plants were placed in one-pint sherbet containers (2 plants/cultivar/pint, N=20) and held in the laboratory (ave. temp. 14°C, ave. humid. 44%). Adult leafminers and parasites that emerged from the foliage were sorted and counted after 5 weeks.

Results and Discussion

The population of adult leafminers in the invaded transplant production house was moderate to high. Sticky trap counts for the 26 days averaged 11 adult leafminers/24 h./trap (range 6-24). The mean numbers of total adult insects (leafminers and parasites) reared from treated foliage were significantly less (P=0.05) than the number from untreated foliage except for oxamyl (0.25 lb. A.I./A.) and permethrin (2EC, 0.05 lb. A.I./A.) treatments. Both treatments were 1/2 to 1/4 of the recommended concentration. The fewest insects were reared from foliage treated with permethrin (3.2EC, 0.20 lb. A.I./A.), permethrin (2EC, 0.10 lb. A.I./A.), oxamyl (1.00 lb. A.I./A.), methamidophos (0.50 lb. A.I./A) and permethrin (2EC, 0.10 lb. A.I./A.) + oxamyl (0.25 lb. A.I./A.) since significantly (P=0.05) fewer insects were reared from the celery and tomato seedlings. Permethrin (0.20 lb. A.I./A.) and permethrin (0.10 lb. A.I./A.) plus oxamyl (0.25 lb. A.I./A.) reduced the mean number of adults reared from foliage by 100% and 95% respectively relative to the untreated check (Table 3). The remaining effective treatments reduced reared adult insects by at least 86%.

A major problem in evaluating the insecticide against leafminers was the high level of parasitism. Only 4% of the adult insects reared from untreated samples were leafminers. The other insects were the parasites, Chrysonotomyia formosa, Diglyphus intermedius and Opius spp. Only 3 treatments, naled (1.00 lb. A.I./A.) + dimethoate (1.00 lb. A.I./A.) (71% parasites), permethrin (0.10 lb. A.I./A.) + methomyl (0.25 lb. A.I./A.) (85% parasites) and kinoprene (0.60 lb. A.I./A.) (84% parasites) had less than 90% parasitization. The likelihood that many leafminer larvae were parasitized prior to insecticide application may have significantly altered larval survival rates to make insecticide efficacy against the leafminer impossible to measure.

This high level of parasitism was evident in the untreated (96%) as well as the treated (71% through 100%) celery plots. This may have provided useful information on leafminer oviposition since the total parasites and leafminers reared correspond to numbers of eggs laid.

Rearing results show the leafminer female did not discriminate between '2-14' celery or 'Walter' tomato in the untreated check (18 adult insects/4 celery seedling and 20 adult insects/4 tomato seedlings, respectively, L.S.D.=5.2). More insects were reared from celery than tomato in treatments of permethrin (2EC, 0.10 lb. A.I./A.) + oxamyl (0.25 lb. A.I./A.), permethrin (3.2EC, 0.20 lb. A.I./A.), permethrin (2EC, 0.05 lb. A.I./A.) + diazinon (0.50 lb. A.I./A.), permethrin (2EC, 0.10 lb. A.I./A.) and permethrin (2EC, 0.05 lb. A.I./A.). More insects were reared from tomatoes than celery in treatments with permethrin (0.10 lb. A.I./A.), diazinon (1.00 lb. A.I./A.), methomyl (1.00 lb. A.I./A.) and oxamyl (0.25 lb. A.I./A.). It appears that response of leafminer to treated hosts might be related to the treatment and not simply to host cultivars (Table 2).

Control with oxamyl (0.25 lb. A.I./A.) + permethrin (0.10 lb. A.I./A.) in combination was better than either insecticide alone. The number of insects reared from oxamyl (0.25 lb. A.I./A.) and permethrin (2EC, 0.10 lb. A.I./A.) treated foliage was 97% and 66% greater than of reared from foliar samples treated with the oxamyl/permethrin combination. This data suggests that two insecticides (oxamyl + permethrin) at concentrations 1/4 to 1/2 recommended field concentration can give short term leafminer control. By reducing rates costs are reduced, parasites are conserved and the selection rate for leafminer resistance to these insecticides is reduced.

In summary, permethrin (3.2EC, 0.20 lb. A.I./A.), permethrin (2EC, 0.10 lb. A.I./A.) + oxamyl (0.25 lb. A.I./A.), permethrin (3.2EC, 0.20 lb. A.I./A.), oxamyl (1.00 lb. A.I./A.), permethrin (0.10 lb. A.I./A.) and methamidophos (0.50 lb. A.I./A.) significantly (P=0.05) reduced insects reared from foliage. The parasite:host ratio was high which made evaluation of effects on leafminer larval survival inconclusive. Naled + dimethoate had a significantly greater effect in reducing parasitism than did permethrin + oxamyl. Oxamyl + permethrin in combination more effectively reduced leafminer and parasite numbers than either product used alone. Use of reduced rates of insecticides in combination may save the grower money, allow insecticides to remain effective over longer periods of time, decrease parasite mortality and decrease the amount of toxin in the environment. Properly integrated mortality due to chemicals and biological agents will provide the level of protection necessary to prevent crop loss (Poe *et al.*, 1978a). In transplant production and ornamental industry, where zero damage levels are required pesticides remain the most powerful and dependable tool for crop protection.

INFLUENCE OF CULTIVAR, SEEDLING AGE AND TIME OF DAY ON OVIPOSITION BY THE VEGETABLE LEAFMINER

Introduction

The age and physiological state of a potential host plant are important in determining its relative suitability to leafminer stippling and oviposition (Poe, 1974b). Musgrave *et al.* (1975a) found that counts of active mines increased rapidly during "vegetable growth" and declined sharply during "sinescence." Pepper, which is not considered a favored host of the leafminer, showed stippling on only the primary leaves of the seedling and after secondary leaf growth, no further stipples or mines were observed (Elmore, 1954).

Time of day also influences leafminer activity. Oatman and Michelbacher (1958) reported that feeding and oviposition stipples were produced almost entirely during the daylight hours. Stipples were produced between 7 AM and 7 PM with twice the number of fertile eggs being laid between 7 AM - 1 PM than from 1 - 7 PM. Elmore (1954) observed adults fed from stipples only at midday during high temperatures.

The purpose of this research was to measure the influence of seedling age and time of day on susceptibility to leafminer damage and subsequent parasite activity.

Materials and Methods

In early October, 1977, 'Walter' tomato and '2-14' celery cultivars were seeded in styrofoam transplant flats using vermiculite and peat growing medium with 25 seedlings per flat. One hundred celery and 100 tomato seedlings were exposed to adult leafminers in a transplant production house near (within 200 ft.) untreated commercial tomato fields. To measure the influence of 'Walter' tomato or '2-14' celery and seedling age on leafminer host preference, weekly counts of stipples and active mines were made during the 6 weeks of the experiment. The seedlings were grown without pesticides.

Additional flats were seeded with 'Walter' tomato and '2-14' celery in early October, 1977 (25 seedlings/flat, 200 seedlings/species). These 16 flats were placed inside a muslin tent within a transplant production house near the SE edge of the range away from prevailing winds and leafminer adults. These seedlings were grown without pesticides for 12 weeks and were then taken for exposure to a local commercial tomato field. Pesticide use in the field had ceased since it had been harvested several weeks earlier allowing the build-up of large populations of adult leafminers. Four exposure time intervals were selected: 6 AM - 10 AM (4 h.), 10 AM - 3 PM (5 h.), 3 PM - 7 PM (4 h.) and 7 PM - 6 AM (11 h.). Twenty seedlings each of '2-14' celery and 'Walter' tomato were randomly placed in 2 transplant flats and placed between rows in the commercial tomato field at each designated time interval on December 11, 1977. All seedling flats not in use remained isolated under the muslin cloth in a transplant production range between trips to the field to avoid exposure to adult leafminers. A flat of mixed cultivar seedlings remained under the muslin tent during the 6 days of field testing as a control. The transplant flats were taken to the field 6 times, each at the specific time regime during the experimental period of December 11-16, 1977. The field exposures were repeated to permit possible parasitism of active mines and were terminated prior to any leafminer pupation. On the sixth day 4 seedlings were placed in labeled pint sherbet cups. All foliage from seedlings were placed in each pint container (=80% full) and kept in a laboratory (non-temperature regulated). Six weeks later adult leafminers and parasites were identified and counted.

Yellow sticky traps as previously described were used to determine the relative number of adult leafminers.

Results and Discussion

Daily sticky trap counts indicated a moderate pest pressure with an average of 16 adult leafminers/24 h./trap during the 6 weeks of the test. Stippling was first noted on 10 day old tomato and 15 day old celery seedlings (Table 4) (both need 3-6 days for germination). Few stipples were counted on celery (>22 stipples/plant) for the first 25 days. Between 25 and 34 days of age, stippling increased 16 fold on celery (from 22 to 349 stipples/plant). Tomato seedlings had a greater number of stipples/plant relative to

Table 4. Influence of seedling ages and hosts on numbers of stipples and active mines made by the vegetable leafminer, *Liriomyza sativae* Blanchard (Sun City, Florida, Fall 1977 N=100/day).

Age (Days)	Average number of stipples and mines/seedling					
	'2-14' celery			'Walter' tomato		
	stipples[1]	active[1] mines	stippling to active mine ratio	stipples[1]	active[1] mines	stippling to active mine ratio
10	0	0	-	8	0	-
15	4	0	-	19	0	-
18	9	0	-	49	1	35:1
21	15	0	37:1	61	2	25:1
25	22	1	32:1	70	3	21:1
29	149	2	83:1	91	5	19:1
34	349	7	47:1	147	8	18:1
39	836	10	83:1	618	10	60:1

[1] Accummulative.

celery for the first 25 days, although at this same age (3-4 weeks) the total leaf area of the celery seedlings was notably greater than the tomato seedlings. This suggested that stippling was influenced by the available leaf surface area as well as the specific host species and host leaf age.

The number of active mines remained low (<0.5 mines/plant) for the first 16 days and 22 days on tomato and celery, respectively. Active mine counts for celery remained lower than tomato until the 39th day when both had similar (10 mines/plant) number of active mines per seedling. The leafminers had oviposition host preference for tomato during the first 4 weeks as indicated by the relatively high active mine counts. The increase in active mines on 5-6 week old celery relative to the tomato seedlings might be due to the noticeable increase in the celery leaf area.

The ratio of active mines to stippling could serve as an indicator of the host plant preference of the adult female (Table 2). Since this ratio changed from 35:1 (day 18) to 18:1 (day 34), tomato apparently becomes more preferable as an oviposition host, The constant increase of the oviposition to stippling ratio relative to celery demonstrated a preference for tomato as a host for oviposition and larval maturation. Host preference by leafminers for tomato seedlings might be explained in part by their prior development on nearby staked 'Walter' tomatoes. "Insects often become conditioned to the plant species they have (been) fed on and that this affects their subsequent preferences. This has been observed both for larvae and for newly emerged adults," (Jermy, et al., 1968).

The influence of the 4 specific time intervals during 24 h. on adult leafminer activity is shown in Table 5. These untreated seedlings of 'Walter' tomato and '2-14' celery cultivars were exposed to large populations of adult leafminers (57 adult leafminers/day/trap) in fields of untreated commercial staked tomatoes. Sunrise was at 6 AM, sunset near 7 PM. The temperature was above 17^{O}C between 10 AM and 3 PM during the 6 days of testing. The average high and low temperature was 21^{O}C and 18^{O}C, respectively.

Only 6.8% of the active mines were counted in plants exposed from 7 PM to 6 AM. These support the findings of Oatman and Michelbacher (1958) and Elmore (1954), that leafminer activity was confined to the daylight hours. The greatest number of active mines/24 h. occurred in the 6-10 AM period (2.4 active mines/h./plant/day and in the 10 AM - 3 PM (2.0 active mines/h./plant/day). Mining activity in both periods was significantly greater (P=0.05) than either the 3 PM - 7 PM or 7 PM - 6 AM time intervals. Celery seedlings had significantly (P=0.05) more active mines during exposure in the 6 AM - 10 AM period with 2.9 active mines/h./plant/day than the other 3 time periods. Mining activity was most extensive during the 10 AM - 3 PM interval with 3.0 active mines/plant/h. on tomato. The 6 AM - 3 PM (2 time intervals

Table 5. Influence of time of day on the number of active mines by the vegetable leafminer, *Liriomyza sativae* Blanchard, on 12 week old 'Walter' tomato and '2-14' celery seedlings exposed to field populations of leafminers during 6 days of testing in Sun City, Florida (Dec. 1977, N=20).

Time interval	Mean number of mines/plant			
	'2-14' celery	'Walter' tomato	Total mines	Mines/ h./day
6 AM-10 AM	11.5	7.4	9.4	2.4
10 AM- 3 PM	7.6	12.0	9.8	2.0
3 PM- 7 PM	8.3	4.4	3.8	1.0
7 PM- 6 AM	0.8	2.6	1.7	0.2
Total (24 h.)	23.1	26.5	24.7	1.0
L.S.D.(P=0.05)	3.1	3.5	3.3	0.9

combined) period had 78% of the total active mines on both celery and tomato seedlings. These data parallel those of Oatman and Michelbacher (1958).

Ninety percent of the total adult insects reared from the tomato and celery seedlings were hymenopterous parasites of the leafminer. Four parasite species reared were *Chrysonotomyia formosa* (Westwood), *Diglyphus intermedius* (Girault), *Opius* spp. and *Halticoptera circulus* (Walker)[1]. Percent parasitism for each of the 4 parasites and numbers of leafminers did not change significantly (P=0.05) over the 4 time intervals (Table 6). The interrelationship of *C. formosa* populations and *D. intermedius* was not significant (Figure 1). The total number of *D. intermedius* and *C. formosa* parasites increased in direct relation to the increase in total parasites ($y = 0.985 + 0.19X$, $R^2 = 0.88$ and $Y = -0.414 + 0.58x$, $R^2 = 0.93$, respectively). This indicated that hyperparasitism or any other interdependent relationship between these 2 predominant parasites (*C. formosa* 48% and *D. intermedius* 21% of the total insects reared) were unsubstantiated. Regression analysis of parasite populations versus total active mines on celery and tomato seedlings showed that parasite populations increased at the same rate as the numbers of active mines (celery: $y = -0.67 + 0.99\ x$, $R^2 = 0.99$ and tomato: $y = -0.48 + 0.95x$, $R^2 = 0.99$). This implies that at these levels of leafminer populations control by this

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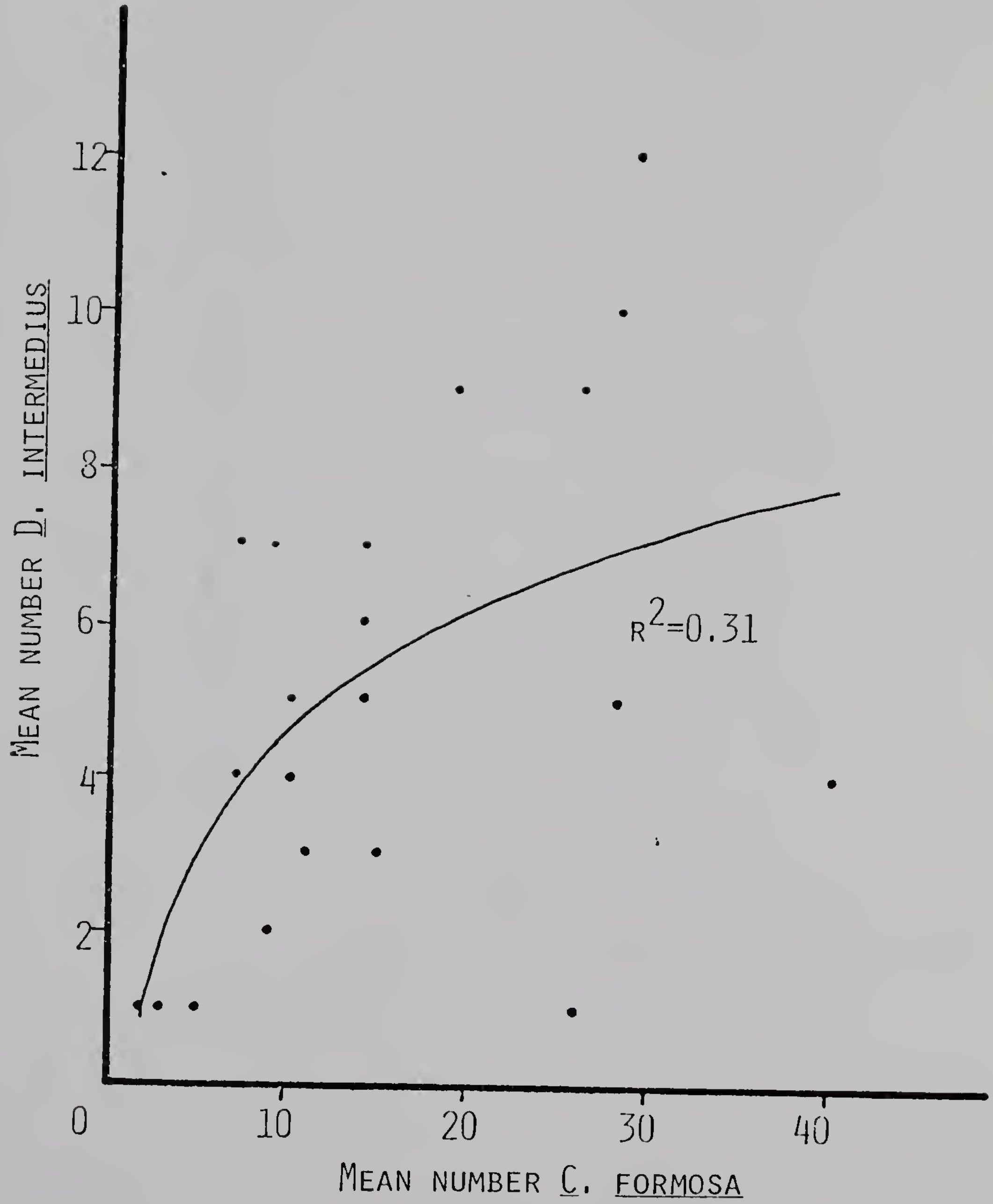
[1] Identified by Dr. C. A. Musgrave, IFAS, University of Florida, Gainesville, Florida.

Table 6. Influence of time of day on the number of active mines by the vegetable leafminer, *Liriomyza sativae* Blanchard, and its parasites on 12 week old 'Walter' tomato and '2-14' celery seedlings exposed to field populations of leafminers during 6 days of testing in Sun City, Florida (Dec. 1977, N=40).

Time of exposure	Total insects reared	% of total insects by species				
		L.s.[1]	C.f.[1]	D.i.[1]	O.d.[1]	H.c.[1]
6 AM-10 AM	311	14	40	22	20	3
10 AM- 3 PM	335	5	53	21	18	3
3 PM- 7 PM	128	13	51	18	15	3
7 PM- 6 AM	58	8	59	20	10	4
Total (24 h.)	832	10	49	21	18	3
L.S.D.(P=0.05)		8	22	5	11	2

[1] L.s. = *Liriomyza sativae* Blanchard,
C.f. = *Chrysonotomyia formosa* (Westwood),
D.i. = *Diglyphus intermedius* (Girault),
O.d. = *Opius* spp.
H.c. = *Halticoptera circulus* (Walker).

igure 1. Relationship of *Chrysonotomyia formosa* (Westwood) populations to *Diglyphus intermedius* (Girault) populations from celery and tomato seedlings sampled in Sun City, Florida (Dec. 1977).


Mean number D. intermedius
12
10
8
6
4
2
0
10
20
30
40
Mean number C. formosa
R2=0.31

parasite complex is possible. However, the demand for damage free commercial transplants rule out the use of biological control at the present time. However, in field populations of leafminers, biological control by hymenopterous parasites should be a part of the development of any pest management programs.

In summary, stippling to active mine ratios and counts of stipples and active mines indicated leafminer host preference for 'Walter' tomato relative to '2-14' celery seedlings of the same age. As seedlings aged the susceptibility of these 2 cultivars to leafminer damage increased. The majority (78%) of the leafminer active mines were found on celery and tomato foliage exposed to field populations of leafminers between 6 AM and 3 PM. Population densities of _C_. _formosa_ and _D_. _intermedius_ were not demonstrated to be interdependent. Parasitism increased directly as the number of active mines increased. Thus at these population levels, parasite control of the leafminer population was viable.

MORTALITY OF THE VEGETABLE LEAFMINER AND PARASITE POPULATIONS BY SELECTED INSECTICIDES APPLIED TO CELERY

Introduction

The objective of this study was to determine the impact of several insecticides, in populations of leafminers and their parasites.

Materials and Methods

The insecticide tests were conducted on '2-14' celery commercially grown on organic muck in Belle Glade, Florida (March to June, 1978). Each plot was 20 x 20 ft. (150 celery plants in 30 rows) with a 20 x 20 ft. buffer plot separating each plot. Fourteen treatments (plots) were randomized in each of 4 blocks. The experimental celery blocks were separated from the commercial celery by several untreated rows of celery and an irrigation canal.

Five insecticides and 2 combinations of 2 insecticides were tested for their effect on adult leafminers and their parasites. The insecticides were: fenvalerate, permethrin, oxamyl, sulprofos, methamidophos, permethrin + oxamyl and acephate + naled. Seedlings were transplanted on February 27, 1978, and foliar sprays were applied at 5 day intervals (2 permethrin treatments were applied at 10 day intervals) from March 22 through May 26, 1978. A tractor-mounted boom sprayer with three #5 nozzles per row was used to apply 5.05 gallons/plot at 150 psi.

Celery trifoliate leaves were sampled at random from each plot on May 4, 11, 19, and 29. Foliar sprays were applied May 5, 10, 15, 20 and 25 during the period of sampling. All sampling was done 4 days after spraying except on May 11th (sprayed 10 h. before sampling). Foliar samples consisted of 7 randomly picked trifoliate leaves, placed in a 1/2 pint sherbet rearing container. Twelve samples were collected per treatment per collecting date. Ten whole plants were also collected on May 19, 1978, from each treatment and placed at the rate of 1 plant per 15 pint sherbet containers. The pint containers were held in an air conditioned laboratory for 6 weeks (ave. temp. 23°C and ave. R.H. 57%) and then leafminer adults and parasites were identified and counted.

Results and Discussion

The population of leafminers was low (<4 insects per 7 trifoliate leaves) on commercial celery fields until May 1, 1978. After May 1, the leafminer populations increased (45 insects per 7 trifoliate leaves on May 4).

Mean number of adult insects reared from field samples were significantly (P=0.05) lower in all treated plots than in the check plot except for fenvalerate (0.25, 0.05 and 0.10 lb. A.I./A.), sulprofos and acephate + naled (Table 7).

Table 7. Effects of selected insecticides (14 treatments) on the vegetable leafminer, *Liriomyza sativae* Blanchard, and its parasites on '2-14' celery (Belle Glade, Florida, May, 1978 N=80).

Treatment			Mean number adults per 7 trifoliates[3]		
Material	Formulation	Rate[1] lb. A.I./A.	Total insects	Leaf-miners	Parasites
fenvalerate	4EC	0.025	60.4	44.0	16.4
fenvalerate	4EC	0.05	45.4	31.9	13.6
fenvalerate	4EC	0.10	39.4	27.1	12.3
fenvalerate	4EC	0.20	24.4	17.3	7.1
fenvalerate	4EC	0.40	16.6	12.5	4.0
permethrin	2EC	0.20	16.4	12.6	3.8
oxamyl	2L	1.00	30.4	22.8	7.6
sulprofos	6EC	1.00	42.3	30.4	11.9
methamidophos	6EC	1.00	9.5	8.4	1.0
permethrin	2EC	0.10			
and oxamyl	2L	0.50	22.8	16.2	6.6
acephate	4EC	1.00			
and naled	8EC	1.00	34.8	28.1	6.7
permethrin	2EC	0.10[2]	27.5	22.2	5.3
permethrin	2EC	0.20[2]	24.9	20.0	4.9
check	-	-	43.6	33.6	10.1
L.S.D.(P=0.05)	-	-	11.0	7.2	3.1

[1] Sprayed every 5 days from March 12 through May 29, 1978 (except 2 permethrin treatments).

[2] Sprayed every 10 days.

[3] Collected May 4, 11, 19 and 29, 1978 (20 samples/treatment/date).

[4] Four plants/treatment.

Table 7. Extended.

% Para-sites	Total para-sites	% Parasite Species of Total Parasites *Chrysonotomyia formosa*	*Diglyphus intermedius*	*Opius* spp.	Leafminers trails/oz at harvest[4]
27.1	611	69	25	6	21.0
29.8	539	60	34	6	18.4
31.3	401	70	25	5	14.9
28.9	283	82	14	4	10.3
24.3	106	83	10	7	6.4
23.1	102	68	16	16	5.2
25.0	152	77	9	14	15.1
28.1	461	65	28	7	19.3
10.9	68	46	30	24	9.8
28.9	236	74	19	7	9.2
19.3	501	71	23	6	22.4
19.3	345	64	24	12	14.6
19.5	301	61	21	18	13.6
23.1	607	44	31	24	23.5
8.11	-	16.2	10.2	9.7	-

Rearing counts were lowest on celery protected by fenvalerate (0.40 lb. A.I./A.), permethrin (0.20 lb. A.I./A.) (sprayed every 5 days), and methamidophos (1.00 lb. A.I./A.).

Methamidophos was the only treatment with significantly (P=0.05) less parasitism (10.9% parasites) relative to the check (23.1% parasites, L.S.D.=8.1). Mean numbers of adult parasites reared from foliage samples was highest with fenvalerate (0.025, 0.05 and 0.10 lb. A.I./A.) and sulprofos. The fewest number of adult parasites were reared from foliage samples treated with methamidophos, permethrin (0.20 lb. A.I./A.) (sprayed every 5 days) and fenvalerate (0.40 lb. A.I./A.). Permethrin (0.10 and 0.20 lb. A.I./A.) sprayed every 10 days consistently resulted in more total insects reared from foliage than permethrin (0.20 lb. A.I./A.) sprayed at 5 day intervals, although the difference was not significant (P=0.05). The number of adult leafminers reared from foliage samples was significantly (P=0.05) higher for permethrin (0.20 lb. A.I./A.) sprayed at 10 day intervals than those sprayed at 5 day intervals.

Chrysonotomyia _formosa_ was the predominant parasite (>50% of total parasites) in foliage samples from all insecticide treatments except for the methamidophos treatment (Table 7). The other 12 insecticide treatments showed a _C. formosa_ adult percentage/sample between 61% and 83% (check= 44%, L.S.D.=16.3). Methamidophos parasite ratios were nearly identical to the check sample ratio. On possible explanation for these results may be natural fluctuations when only small populations exist. Lema and Poe (in press) reported *C. formosa* preferentially parasitized older (120 h.) leafminer larvae (probably 3rd instars). The reduction in percentages of *C. formosa* adult in methamidophos samples relative to the other 12 insecticide treatments may be a result of a reduction in potential 3rd instar hosts, repellancy, mortality effects on *C. formosa* adults or chance. That 12 other insecticide treatments favor *C. formosa* survival relative to the other two species of parasites is indicated by data in Table 8.

Numbers of mines per ounce of foliage at harvest (Table 7) indicate fenvalerate (0.40 lb. A.I./A.) and permethrin (0.20 lb. A.I./A., sprayed every 5 days) had fewest mines per total plant weight. Damage thresholds due to leafminers are important in developing I.P.M. programs. Total mines per ounce on foliage from whole celery plants at harvest provides no information about the distribution of the mines. Musgrave *et al*. (1977) reported that 50% (17 of 34 petioles) of the outer petioles are lost naturally during growth of the plant or were stripped after harvesting. Mines on these petioles may not alter the value of the marketable celery and are of minimal importance in establishing threshold damage levels. A second factor reducing the importance of total mine counts per weight of harvested celery pertains to the time of the mining activity relative to the date of harvesting. Those mines active at the time of harvest may have

Table 8. Effects of selected insecticides (14 treatments) on the vegetable leafminer, *Liriomyza sativae* Blanchard, and its parasites on '2-14' celery. Whole celery plant samples were collected in Belle Glade, Florida, May 29, 1978 (N=10).

Treatment			Mean number reared adults per whole plant			
Material	Formu-lation	Rate[1] lb. A.I./A.	Total	Leaf-miners	Para-sites	% Parasitism
fenvalerate	4EC	0.025	204.8	163.2	41.6	20
fenvalerate	4EC	0.05	155.0	117.9	37.1	24
fenvalerate	4EC	0.10	128.4	97.9	30.6	24
fenvalerate	4EC	0.20	76.9	62.4	14.6	18
fenvalerate	4EC	0.40	62.6	52.3	10.4	16
permethrin	2EC	0.20	48.4	43.6	4.8	10
oxamyl	2L	1.00	110.4	92.6	17.8	16
sulprofos	6EC	1.00	149.1	118.6	30.5	20
methamidophos	6EC	1.00	26.1	22.2	3.9	15
permethrin	2EC	0.10				
plus oxamyl	2L	0.50	85.9	72.2	13.7	16
acephate	4EC	1.00				
plus naled	8EC	1.00	109.9	84.8	25.1	23
permethrin	2EC	0.10[2]	92.7	76.1	16.6	18
permethrin	2EC	0.20[2]	85.5	68.0	17.6	20
check	-	-	155.4	119.9	35.5	22
L.S.D.(P=0.05)	-	-	50.4	41.6	11.8	7

[1] Sprayed every 5 days from March 12 through May 29, 1978.
[2] Sprayed every 10 days.

considerably less effect on yield than mines active during rapid vegetative growth of younger and smaller celery plants. The number of mines and their influence on celery yield may be dependent on plant size and stage of vegetative growth.

Table 8 gives mean numbers of total adult insects (leafminers and parasites) reared from whole plant samples taken from the 14 treatments. The data are not significantly different (P=0.05) from those obtained from trifoliate leaflet samples. Only permethrin (0.20 lb. A.I./A.) and methamidophos significantly (P=0.05) lowered parasite percentages compared to the check (9.9%, 15.1% and 22.8%, respectively, L.S.D.=6.4). This was true for only methamidophos according to data from sampling of trifoliate leaflets.

The 5 fenvalerate treatment rates steadily decreased numbers of reared leafminers and parasites as the concentration of insecticide increased from 0.025 to 0.40 lb. A.I./A. (Figure 2). The logarithmic values of the adult population sample provided data necessary in developing a linear equation to express the relationship between pounds of A.I./A. and adult insect population levels during the 4 sampling dates.[1] Each sampling date during May, 1978, had different population levels of leafminers and parasites with 45, 18, 137 and 122 adults reared per 7 trifoliate leaf sample (May

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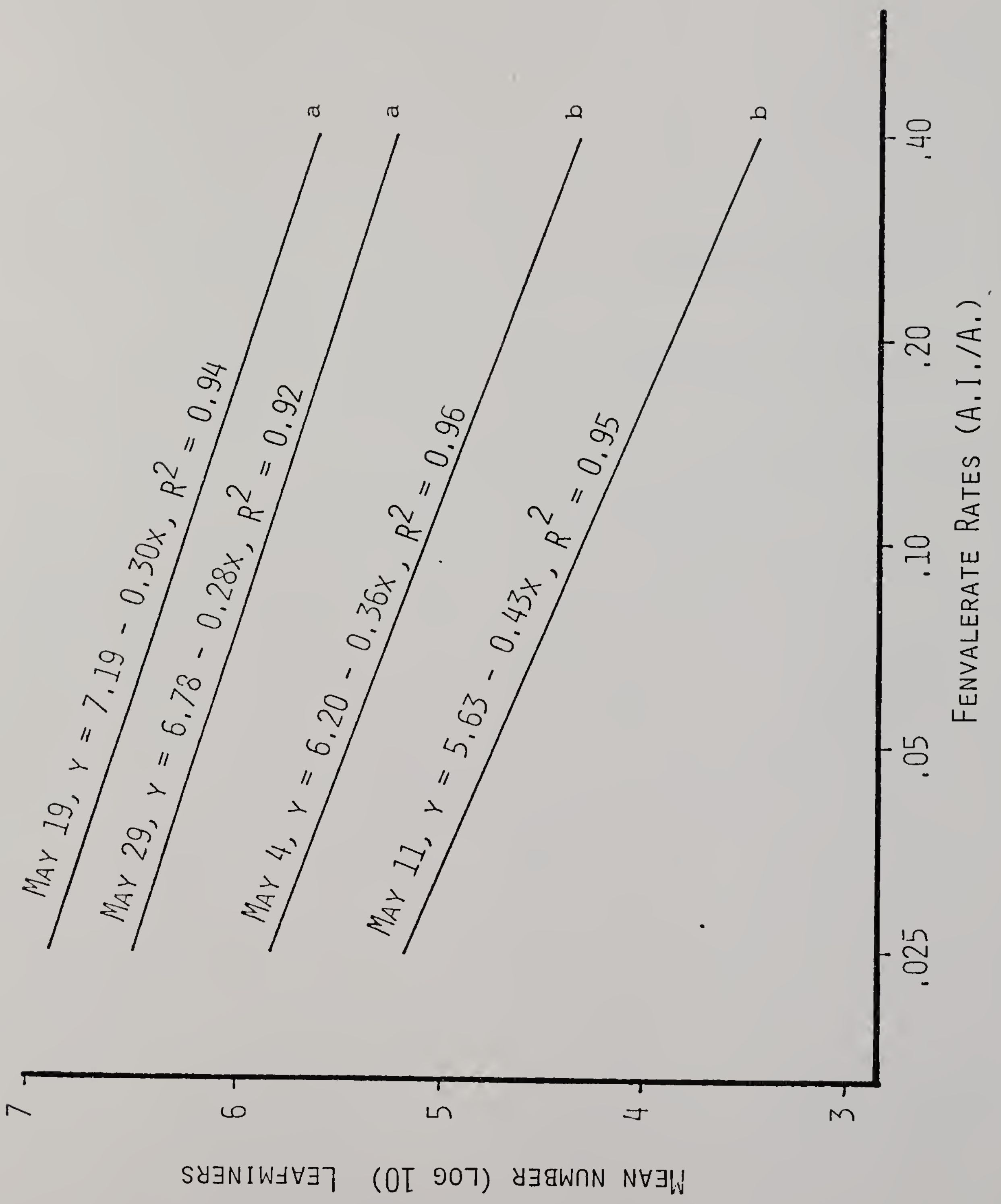
[1] Assistance for the statistical analysis provided by Dr. J. A. Cornell, Associate Professor, IFAS Statistics Department, University of Florida.

<u>Figure 2</u>. Effect of population density on mortality by 5 concentrations of fenvalerate from celery samples collected at Belle Glade, Fla., Spring 1978 (N=12). Slopes followed by the sam letter do not differ significantly at P=0.05 as determined by Duncan's new multiple range test.


May 19, Y = 7.19 - 0.30X, R^2 = 0.94
a
May 29, Y = 6.78 - 0.28X, R^2 = 0.92
a
May 4, Y = 6.20 - 0.36X, R^2 = 0.96
b
May 11, Y = 5.63 - 0.43X, R^2 = 0.95
b
7
6
5
4
3
Mean Number (Log 10) Leafminers
.025
.05
.10
.20
.40
Fenvalerate Rates (A.I./A.)

4, May 11, May 19 and May 29, respectively. The slope of the equation was greater when sampling was done on celery with low leafminer populations. This implies that when field populations are high insecticides used at higher rates are not as effective. The increased slope of the line at lower pest population levels also may be influenced by equal volumes of insecticide providing more effective coverage on younger, smaller celery than on the older plants. Trifoliate leaflet samples collected on May 29, 19 and 11, 1978 also had more lb. A.I./A. (45%, 27% and 18%, respectively) applied to the celery trifoliates than those samples May 4. These changes in pounds A.I./A. through increased applications and plant size effective insecticide dosage and a possible density dependent factor must all be considered in the evaluation of an insecticide on a target pest. Leafminer mines per ounce of foliage decreased at the rate of fenvalerate increased from 0.025 to 0.40 lb. A.I./A. This indicated a direct relationship in mines per unit yield and fenvalerate concentration. Poe _et_ _al_. (1978b) found that the average weight and grade of marketable celery were improved with decreasing levels of leafminers. They found the relationship of increased pesticide concentrations to plant weight per number of leafminers was linear.

In summary, methamidophos (1.00 lb. A.I./A.), permethrin (0.20 lb. A.I./A.) and fenvalerate (0.40 lb. A.I./A.) provided the most effective leafminer control. Methamidophos was the most effective in reducing numbers of parasites relative to the number of leafminers reared. Parasites, _D_. _intermedius_ and _Opius_ spp., were a larger percentage of the total parasites collected from foliage treated with methamidophos than from the other 13 treatments. Samples of trifoliate leaflets were not significantly different from whole plant samples for measuring treatment effects and took considerably less sampling time. The use of mines per ounce of foliage at harvest was a poor measure of insecticide effects on leafminers. Petioles removed prior to marketing and age of celery during mining activity were important considerations in evaluating mining activity on celery yield.

INFLUENCE OF SAMPLE SIZE AND AGE OF CELERY PETIOLE ON THE REARING OF ADULT LEAFMINERS AND THEIR PARASITES

Introduction

This research reports data from experiments to determine the influence and importance of sample size (leaflets/container), sample location of leaflets on the celery plant and sample rearing conditions in evaluating their influence on numbers of insects reared per celery trifoliate leaflet.

Materials and Methods

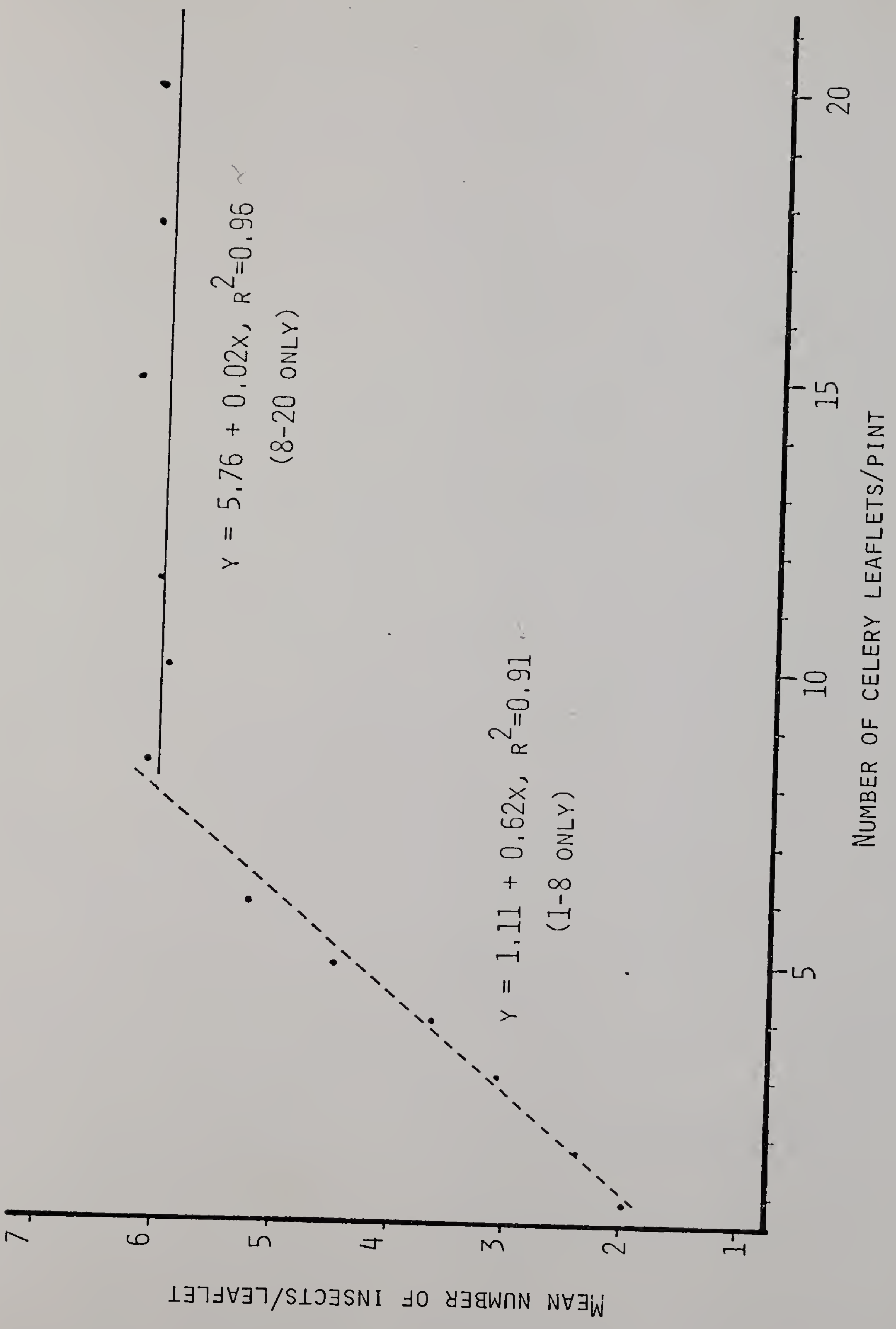
Ten week old untreated '2-14' celery, was sampled on a commercial farm in Belle Glade, Florida (March to June, 1978). Four 20 x 20 ft. blocks (each with 6 rows of 30 plants) were separated from untreated commercial celery by an irrigation ditch and several rows of untreated celery (> 30 ft.). On May 29, samples consisting of 1, 2, 3, 4, 5, 6, 8, 10, 12, 15, 18 and 20 celery trifoliate leaflets were selected at random from each of 4 blocks of celery. Each sample size was replicated 20 times to determine the effect of the number of trifoliate leaves per pint rearing container on adult insect emergence. A second test compared only 7 and 12 celery trifoliate leaflets per pint, each replicated 15 times. All samples were returned to the lab in Gainesville, Florida, where those from the first trial (1 through 20 trifoliates/pint) were held at 23°C (20-25°C range) and 57% relative humidity (35-68% range). A second group of samples (7 and 12 trifoliates/pint) were held outdoors inside a shaded protected cage during June, 1978 in Gainesville, Florida. During the test the average temperature was 24°C (21-30°C range) and average relative humidity was 89% (78-100% range). Hygrothermagraphs were used for all temperature and relative humidity measurements. All rearing containers were held for 6 weeks, before adult leafminers and parasites were identified and counted.

To determine the effect of the position of the petiole on the plant (petiole age) on the number of insects reared, petioles were stripped in order from oldest, outermost inward to the heart from whole celery plants. Each pint rearing container was labeled with a plant number (1-60) and a petiole profile number (1-15). Older outermost petioles were discarded on plants with more than 15 petioles. These 900 pint containers were also taken to Gainesville, held for 6 weeks in the laboratory and then the leafminers and parasites were identified and counted.

Results and Discussion

The number of celery trifoliate leaves per pint significantly (P=0.05) influenced the number of insects reared per celery trifoliate leaf (Figure 3). A decrease in the number of celery leaves per pint rearing container from trifoliate leaves showed a corresponding decrease in the

Figure 3. Influence of numbers of celery trifoliate leaves (biomass) on the mean number of insects (leafminer and parasites) reared in pint containers (Belle Glade, Fla., Spring 1978, N=20).


Y = 5.76 + 0.02X, R^2=0.96
(8-20 ONLY)
Y = 1.11 + 0.62X, R^2=0.91
(1-8 ONLY)
MEAN NUMBER OF INSECTS/LEAFLET
NUMBER OF CELERY LEAFLETS/PINT
1
2
3
4
5
6
7
5
10
15
20

mean number of reared insects (leafminer and parasites) emerged per trifoliate leaf. This adult insect emergence rate per trifoliate leaf in samples with 1-8 trifoliates, is represented by the linear equation, $y = 1.11 + 0.62 X$ ($r^2 = 0.91$). The larger sample sizes (8-20 trifoliates/pint) had no significant difference in mean number of adult insects reared/trifoliate leaf ($P=0.05$) with values ranging from 5.5 to 6.0 insects/trifoliate leaf. This was represented by the horizontal line ($y = 5.76 + .02x$, $r^2 = 0.96$). A minimum of 8 trifoliate leaves per pint was needed for maximum adult emergence per sampled trifoliate leaf. The reduced adult emergent rates with fewer leaves per sample was attributed to desiccation of the leaves which reduced the time available for egg and larval maturation. Increased numbers of celery leaves per pint held at moderate humidity levels (50% R.H.) apparently slows the loss of moisture and increases the time that the host is suitable for larval development.

The interaction of increased humidity and sample size (7 vs. 12 trifoliate leaves) was observed on 2 celery trifoliate leaf samples (7 and 12 trifoliates/pint) reared outside in Gainesville, Florida. With the increased temperature (24°C) and humidity (>89% R.H.), the 7 trifoliate per samples had more adult insects emerge per trifoliate leaf than from the 12 trifoliate leaf samples (5.42 to 2.70 insects/trifoliate, respectively, L.S.D.=2.16). Increased bacterial and fungal decay was observed in those 12 trifoliate leaf samples decreasing the time that the leaves could serve as a suitable host for leafminer larval development. In fact, several of the 12-trifoliate leaf samples had decayed so extensively that adult insect emergence was nearly impossible. The 7 trifoliate leaf samples had sufficient air space inside the container to perhaps reduce the effect of the high humidity outside. Consequently, to optimize measurements of leafminer populations, careful attention must be given to leaf sample size (biomass) per container relative to rearing conditions since this may influence the humidity within the pint rearing containers. Not only may the number of trifoliate leaves per sample influence the humidity within the container, but also the leaf moisture when collected. External moisture may be from morning dew, rain and pesticide sprays. With humidity maintained between 30-70%, 10 to 15 celery trifoliates per sample would allow maximum adult emergence per leaf. Other variables, including container size, moisture on the leaves, etc., must be considered in designing sampling procedures.

Relative humidity outside the rearing containers, number of trifoliate leaves per sample and container size influence and interact with each other and must be considered collectively to maximize the number of adult leafminers and parasites reared from sampled celery leaves. A significantly (P=0.05) greater number of adult insects, nearly 50% of all adults, were reared from medium-aged petioles (numbers

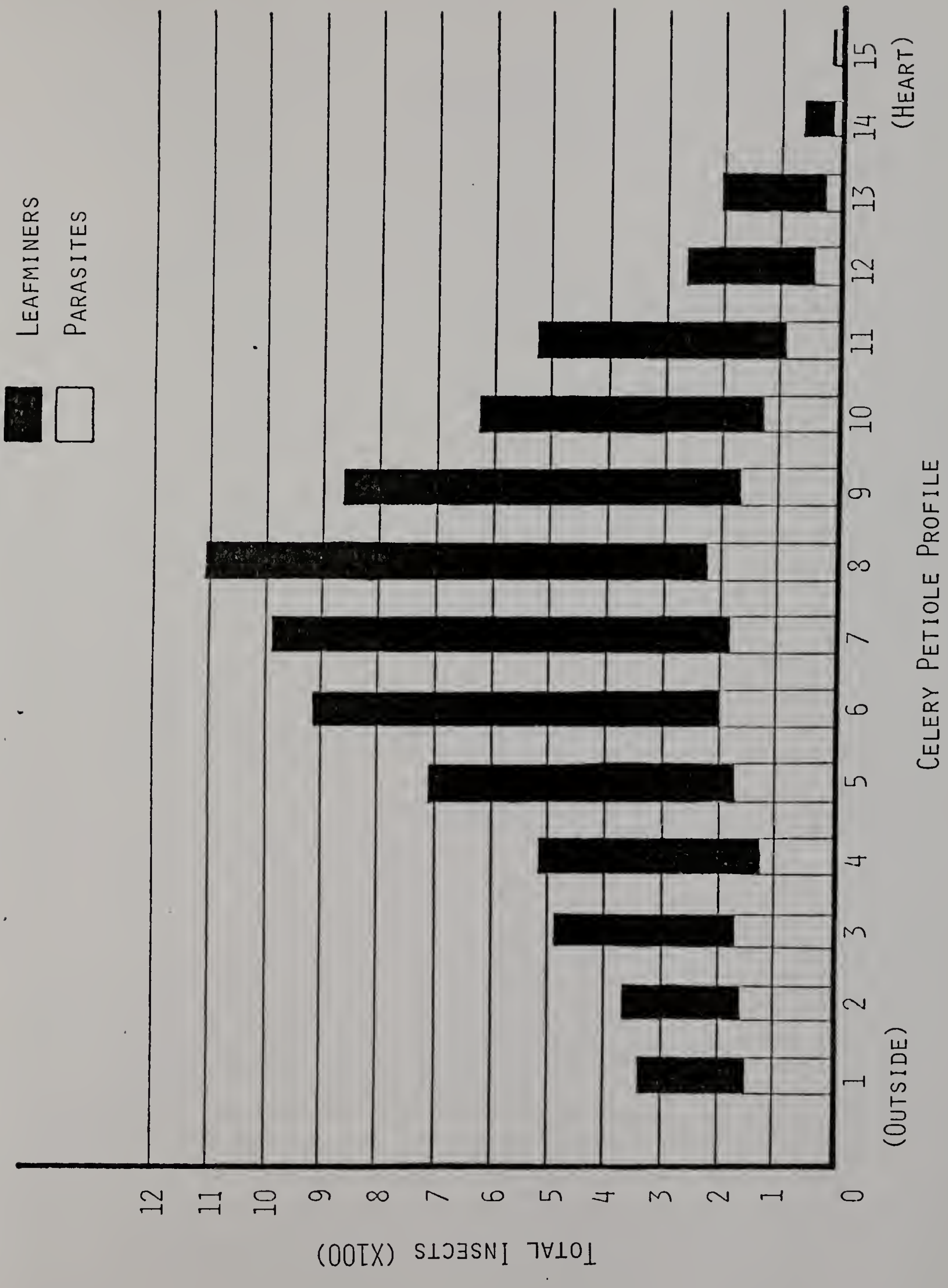
6-9) (Table 9). These medium-age but mature celery petioles (positions 6-9) were the tallest with a much softer texture than the older, coarser petioles and a larger surface area than most of the other petioles. Fewer insects were reared from older leaves (numbers 1-4) because there was less oviposition and larval mining area due to previous mining, change in leaf physiology and fewer active mines due to emergence prior to sampling. Although percent parasitism gradually decreased from the oldest to the youngest petioles, most parasites were in the medium-aged petioles (numbers 5-9). Reduction in numbers of insects emerging from the youngest and oldest petiole sample may have also been influenced by less leaf biomass available per sample (youngest petioles) and less leaf moisture (oldest petioles). Previous work established that sample moisture levels and leaf biomass per sample influenced insect emergence (Figure 3). A graphic representation of the numbers of adult leafminers and parasites relative to petiole location (whole plant profile) is presented in Figure 4.

Musgrave _et al_. (1977) found the leafminer had little effect on crop production comparing treated and untreated fields since plants in both areas grew at comparable rates, had comparable yields and numbers of mines remaining on marketable plants. The mine counts and data on reared leafminers prior to harvest indicated more damage to the untreated celery (i.e. 58.3 leafminers per 20 trifoliate leaves from untreated versus 3.9 leafminers). However, when

Table 9. *Liriomyza sativae* Blanchard and parasites reared from petioles of 10-week old '2-14' celery collected on a commercial farm in Belle Glade, Florida, on May 29, 1978 (N=60 whole plants).

Petiole location	Average number adult insects reared/petiole Leaf-miners	Parasites	Total	Percent parasitism
1 (outside)	3.2	2.5	5.8	43.9
2	3.4	2.6	6.0	43.5
3	5.3	2.8	8.1	34.5
4	6.3	2.3	8.6	27.0
5	9.0	3.0	11.0	25.0
6	11.8	3.4	15.2	22.2
7	13.3	3.1	16.4	18.8
8	14.9	3.8	18.7	20.4
9	11.5	2.8	14.3	19.7
10	8.4	2.1	10.5	19.9
11	7.3	1.6	8.8	17.6
12	3.6	0.8	4.4	18.2
13	2.7	0.7	3.4	19.3
14	0.9	0.2	1.1	17.0
15 (heart)	0.2	0.0	0.2	13.0
Total (whole plant)	101.7	31.7	132.4	24.0
L.S.D.	4.38	1.19	5.94	11.2

Figure 4. Influence of celery petiole location on the plant on the number of insects (leafminer and parasites) reared from '2-14' celery (Belle Glade, Fla., during May, 1978, N=60 whole plants).



Leafminers
Parasites
Total Insects (X100)
0
1
2
3
4
5
6
7
8
9
10
11
12
Celery Petiole Profile
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
(Outside)
(Heart)

harvested and trimmed for the market, 90-100% of the mines on both untreated and treated celery plants were eliminated. In trimming, nearly 50% of the outer petioles were stripped. Thus, if mines are objectionable on marketable portions of the plant, 90-100% of the mines are removed by standard harvest procedures. Poe *et al*. (1978a), found that celery stalk weight and grade were improved with decreasing levels of leafminers. They found a linear relationship between pesticide concentrations and plant weight and leafminer numbers. Extensive mining during early, rapid growth of celery might reduce photosynthesis sufficiently to cause yield reduction, but this has not been confirmed. Economic injury levels on celery must be established to evaluate the effectiveness of pest management procedures to help the grower produce a high quality crop.

In conclusion, sampling procedures must be carefully considered prior to evaluation of field populations of leafminers. The container size, sample size per container and physical rearing conditions must be established prior to initiating the research and included with any resulting research reports. Sampling procedures used in this research are not to be advocated for all leafminer research but to help point out the need for each sampling variable (host age, sample size, rearing environment) to be considered prior to initiation of the research. Celery profile studies not only demonstrate the possibility of sampling petioles of only certain ages can bias the data but can also help develop a leafminer damage threshold level for future control programs.

DEGREE-DAY, DEVELOPMENT RATE AND PERCENT EMERGENCE OF THE VEGETABLE LEAFMINER PUPAE AND THE PARASITE, *Opius* spp., REARED FROM CELERY FOLIAGE

Introduction

The rate of insect development is a function of temperature. The temperature relationship is usually linear and is the starting point for heat unit computing methods (Abrami, 1972). The theory of temperature summation defines an index for heat energy required to complete a given stage (Eckenrode and Chapman, 1972; Foster and Taylor, 1975). The degree-day or linear heat unit (a unit of departure from a base temperature) has been a useful method in predicting developmental rates for several insects (Williams and Mac Kay, 1970; Reid and Laing, 1976). The history of the degree-day method and the basic principles behind its calculation and modification for local geographical biases are given by Allen (1976). Several temperature regimes are used to calculate the development rate, percent emergence and estimation of degree day for the leafminer pupae and its parasite, *Opius* spp.

Materials and Methods

Commercial fields of '2-14' celery were sampled for the vegetable leafminer in May 1978 in Belle Glade, Florida.

One hundred sixty five pint sherbet containers with 12 celery trifoliate leaves each were taken to the University of Florida, Gainesville, Florida, laboratory. Fifteen pint containers were placed at each of eleven experimental rearing temperatures. Ten of the experimental temperature regimes were maintained in Calumet growth chambers (Model XL42). Eight of the temperatures were held constant at 32.2°, 29.4°, 26.7°, 23.9°, 22.2°, 21.1°, 18.2° and 15.6°C (ranging ± 3% each). Two other growth chambers had fluctuating temperature regimes, one was used to simulate Orlando, Florida, in January, and the other a 16°C day and 2°C night. The average relative humidity in all ten growth chambers was 54% ± 17%. The Orlando simulation was taken from U. S. Weather Bureau high and low temperatures for January, 1978. The average daily high and low temperatures were 15.6°C and 2.0°C with seven nights of subfreezing temperatures (0.0 to -4.0°C). The 16°C day and 2°C night (12 h.:12 h.) temperature cycle was used to eliminate the influence of freezing from the Orlando temperature regime and thus its effect on leafminer emergence and development rates. The 11th regime was in an outdoor rearing cage in Gainesville, Florida, during June, 1978. The average daily highs and lows were 32.4°C and 21.9°C with the relative humidity ranging from 74% and 99% (average was 89%). All temperatures and relative humidities were recorded on hygrothermographs.

All newly emerged leafminer pupae were removed daily from the pint rearing containers and placed in separate plastic vials (4 oz). These vials were kept with the temperature regime from which the pupae were collected. Each day the pint and vial rearing containers were observed for adult emergence (leafminers and their parasites) which were removed, identified and counted. Pupal development rates and degree-day estimations were possible because the length of time for pupal maturation at each experimental temperature regime could be calculated. Degree-day values were determined for each experimental temperature trial using Allen's (1976) Fortran program which corrects for a Florida bias. Development rate (1/T) was calculated from 8 constant temperature regimes degree-day values.

Results and Discussion

Temperature was a significant ($P=0.05$) factor in influencing the mean number of pupae collected per celery trifoliate leaf (Table 10). Pupal development increased in length (days) as a linear function of lower rearing temperatures for both the leafminer and *Opius* spp. (Figure 5). The development rates of *Opius* spp. and the leafminer pupae are represented by the equations, $y = -0.001 + 0.438x$ and $y = -0.411 + 0.312x$, respectively (R^2 for both >0.95). The celery foliage held in the Gainesville outdoor temperature regime (ave. temp. 27°C and R.H. 89%) had 12.6 pupae per trifoliate leaf. The Orlando regime (January, 1978) and the

Table 10. Effect of temperature on emergence of the adult vegetable leafminer, *Liriomyza sativae* Blanchard, and its parasites from '2-14' celery foliage reared in 11 temperature regimes (N=15 pint containers per treatment, 12 celery trifoliates per pint).

Rearing temperature regimes (C^{o})	Mean number leafminer pupae/trifoliate	% Adult[1] emergence from pupae	% Leafminer pupal parasitism[2]	% total[3] parasitism
32.2^{o}	7.2	84.7	6.9	28.2
29.4^{o}	6.1	86.8	4.6	22.8
26.7^{o}	5.6	88.9	5.5	23.4
23.9^{o}	5.4	77.4	3.5	18.5
22.2^{o}	5.6	78.3	5.0	43.7
21.1^{o}	5.3	78.5	6.2	49.5
18.2^{o}	5.2	47.1	8.2	53.7
15.6^{o}	3.4	43.7	11.7	54.3
Orlando[4]	0.7	13.9	2.3	51.5
Gainesville[5]	12.6	62.1	9.7	21.9
16^{o}:2^{o}[6]	1.8	43.2	17.7	70.1
L.S.D.(P=0.05)	1.9	19.3	8.3	-

[1] Leafminer and *Opius* spp. adults.

[2] *Opius* spp.

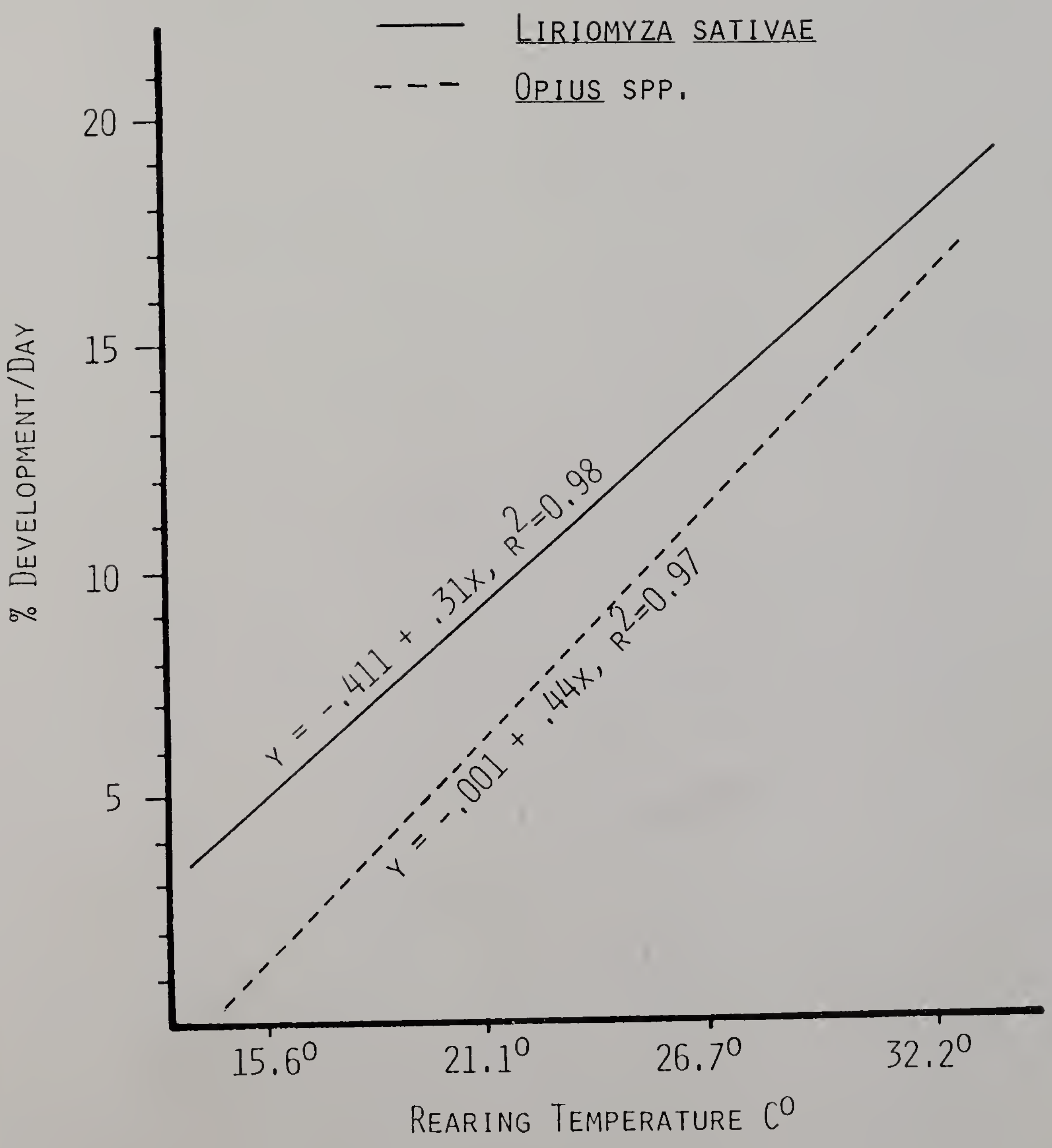
[3] Includes *Opius* spp., *Chrysonotomyia formosa* and *Diglyphus intermedius*.

[4] Temperature regime simulated Orlando, Florida during January 4-30, 1978.

[5] Reared in protected cages outdoors in Gainesville, Florida during June 1-19, 1978.

[6] 12 h.:12 h. temperature cycle of 16^{o}C day and 2^{o}C night.

Figure 5. Influence of temperature in *Liriomyza sativae* Blanchard and its parasite, *Opius* spp., pupae reared from '2-14' celery foliage (Belle Glade, Fla., Spring 1978, N=15, 12 trifoliate leaves per pint).


LIRIOMYZA SATIVAE
OPIUS SPP.
Y = -.411 + .31X, R^2=0.98
Y = -.001 + .44X, R^2=0.97
20
15
10
5
% DEVELOPMENT/DAY
15.6^0
21.1^0
26.7^0
32.2^0
REARING TEMPERATURE C^0

$16^{\circ}:2^{\circ}C$ regime resulted in 0.7 and 1.8 pupae per celery trifoliate leaf, respectively. In all of the other regimes at least 3.4 larvae emerged per trifoliate leaf.

Percent emergence of adult leafminers and parasites were significantly greater (P=0.05) at constant temperatures above $21.1^{\circ}C$ (>75% emergence). The fluctuating Gainesville regime resulted in only 62% emergence. This low value was the result of fungal decay evident in the rearing containers and vials. The Orlando trial with 7 nights of subfreezing temperatures had reduced adult emergence (13.4%). The rate of *Opius* spp. emergence relative to the leafminer was significantly greater (P=0.05) at the cooler temperature. The $15.6^{\circ}C$ and $16^{\circ}:2^{\circ}C$ temperature regimes had 11.7% and 17.7% *Opius* spp. parasitism. The Orlando regime had but 2.3% *Opius* spp. parasitism indicating freezing affected survival.

Total parasitism included not only *Opius* spp., but the 2 parasites *Chrysonotomyia formosa* (77.4%) and *Diglyphus intermedius* (22.4%). Percent parasite emergence increased as rearing temperatures decreased. This ranged from 18-28% parasitism at $23.9^{\circ}C$ and above to 43-70% at temperatures below $23.9^{\circ}C$. *Chrysonotomyia formosa* was the most numerous of the 3 taxa of parasites reared. Both *C. formosa* and *Opius* spp. had larger emergence rates in cooler temperatures relative to the leafminer. The freezing temperatures of the Orlando regime had a greater mortality effect on the exposed *Opius* spp. parasites (in vials) than on *C. formosa* in celery trifoliate leaves inside pint containers. Previously, Harding (1965) observed a high rate of parasitism and its associated decrease in miner numbers in the colder months in Texas.

Development time for the leafminer and Opius spp. increased significantly ($P=0.05$) as the temperatures decreased (Table 11). Development of leafminer pupae took 5.7 days at 32.2°C to 21.0 days at 15.6°C; in the same temperature range, Opius spp. took 6.4 days to 27.4 days. In all trials this parasite required a longer average time (>1 day) to mature than the leafminer.

The longer development times for Opius spp. relative to the leafminer may provide a competitive advantage over other leafminer parasites when the leafminer life cycle is synchronized. Opius spp. females parasitize the leafminer larva within 24 h. after hatching (Lema and Poe, in press). A slight delay in Opius spp. adult emergence would increase its efficiency in finding available leafminer larvae if both populations are synchronous and thus newly hatched leafminer larvae are available for the adult parasites. Leafminer field populations are generally synchronous only during initial periods of invasion.

The length of time for adult emergence of the leafminer and 3 parasites, Opius spp., C. formosa and D. intermedius, from celery leaf samples increased as the experimental rearing temperatures decreased. Adult leafminers and parasite peak emergence (>70%) occurred over longer periods of time at cooler temperatures (7-9 days when reared at 32.2°C to

Table 11. Mean development rate and degree-day values for the vegetable leafminer, *Liriomyza sativae* Blanchard, and the parasite, *Opius* spp., reared from '2-14' celery trifoliate leaves at 11 temperature regimes (N=15 pint containers, 12 trifoliates per pint).

Rearing temperature trial ($^{\circ}$C)	Mean development time (days)					
	Opius spp.			*Liriomyza sativae*		
	No. pupae collected	Degree-day	Development rate	No. pupae collected	Degree-day	Development rate
32.2°	6.4	143.6	.157	5.7	128.0	.177
29.4°	6.8	134.7	.147	6.4	127.0	.156
26.7°	8.1	138.4	.124	7.3	125.3	.137
23.9°	9.8	141.9	.102	9.4	136.4	.109
22.2°	10.8	140.1	.093	10.1	127.0	.100
21.1°	10.8	124.6	.092	10.3	118.7	.095
18.2°	20.0	173.8	.050	15.4	134.0	.067
15.6°	27.4	164.5	.039	21.0	126.3	.048
Orlando[1]	12.1	53.8	-	10.1	83.4	-
Gainesville[2]	9.3	150.4	-	8.4	134.5	-
16°:2°[3]	25.3	51.9	-	20.7	42.4	-
L.S.D.(P=0.05)	2.6	19.9		2.09	16.2	

[1] Temperature simulated Orlando, Florida during January 4-30, 1978, in growth chamber. Mean temperature 16°-2°C (day/night), 7 nights of freezing (-4°C coldest).

[2] Protected outdoor cages in Gainesville, Florida, June 1-19, 1978. 33.7°/22.4°C day/night average (R.H. 62-99%).

[3] Growth chambers 12 h.:12 h. - 16°:2°C cycle.

10-16 days at 23.9°C, 19-39 days at 15.6°C and 21-53 days at the 16°:2°C temperature regimes). Adult _Opius_ spp. emerge from leafminer pupae and as the rearing temperatures decreased did not have such a noted increase in the length of time for peak emergence (>70%) (9-10 days at 32.2°C, 13-14 days at 23.9°C and 31-36 days at 15.6°C). Five percent of the total adult _C_. _formosa_ and _D_. _intermedius_ emerged 7 weeks or later after collecting the celery trifoliate leaves when reared at the Orlando or 16°:2°C temperature regimes. _Chrysonotomyia_ _formosa_ was the predominant (97.8% of total adult insects) late emerging parasite. The leafminer adults at these lower temperatures rarely emerged 30 days after collecting the leaf samples (<0.8%).

This information may suggest 2 separate tactics by these leafminer parasites. The increased number of days for the _C_. _formosa_ and _D_. _intermedius_ adults to emerge relative to its leafminer host and _Opius_ spp. suggests that these parasites are more competitive when the leafminer populations are asynchronous. Leafminer field populations are generally asynchronous. _Chrysonotomya_ _formosa_ has been reported to preferentially parasitize the 120 h.-old leafminer larvae (3rd instars?). This contrasts with the _Opius_ spp. which parasitizes all 3 instars from 24 h. through 120 h. after egg hatch (Lema and Poe, in press). Thus _C_. _formosa_ may be more selective in host stage preference (3rd instar only) and has less synchrony of adult emergence than _Opius_ spp. With so little known about the leafminer parasite interactions, conclusions await further research.

The ability of parasites and leafminer populations to survive during the cooler months in central Florida may result from extending the length of time for the insect to mature (particularly the pupal stage). The low survival rate (% adult emergence) for leafminer pupae reared in the fluctuating Orlando (7 nights of freezing) regime might not have been so drastic had the leafminer larvae been permitted to pupate on or in the soil; this might insulate the pupae from the full effects of the cooler winter temperatures.

Growth curves for both leafminer and *Opius* spp. were calculated using degree-day values. Since degree-day value calculations required a lower temperature threshold for pupal development, 10°C was selected based on data available on other Diptera (Allen, 1978, personal communication). This was further substantiated by Jensen and Koehler (1970) who found 25% *Liriomyza* sp. adult emergence at 12.8°C.

The average degree-day C° for 2500 leafminer pupae and 210 *Opius* spp. reared at 8 different constant temperature regimes was 127.8 and 141.2 (degree-day C°), respectively. These 2 means were not significantly different from degree-day values for each constant temperature regime. These degree-day values reflect the delay in *Opius* spp. adult emergence relative to the adult leafminer. The only inconsistent degree-day estimations were with pupae reared at the

16°:2°C and Orlando regimes with degree-day values of less than 100. Apparently subthreshold temperatures affect critical developmental mechanisms within the pupae.

Degree-day and rate of development values may assist in identifying possible genetic differences in 2 (or more) otherwise indistinguishable leafminer populations and help in predicting population fluctuations so vital to developing effective pest management programs.

CONCLUSION

The following conclusions are drawn from research on the vegetable leafminer, *Liriomyza sativae* Blanchard, and its parasites. This research began with tomato, celery and other hosts grown on a transplant production range in Sun City, Florida, during October to March, 1977-78.

Research was also conducted on commercial celery grown in the Belle Glade, Florida, area during March to June, 1978.

(1) Dispersal of adult leafminers by the prevailing winds into the transplant production range and houses was effectively monitored by yellow cardboard traps covered by sticky, transparent plastic.

(2) Abandoned post-harvest tomato fields appeared to be a major reservoir of adult leafminers in the Sun City, Florida, area during late fall and winter, 1977.

(3) 'Walter' tomato and '2-14' celery seedlings required 2 and 3 weeks, respectively, (3-6 days for germination of each) from seedling to show susceptibility to adult leafminer oviposition.

(4) The active mines to stippling ratios of 'Walter' tomato seedlings increased from 1:35 at day 18 to 1:18 at day 34 which indicated an increased egg-laying preference by female leafminers.

(5) Ratio of active larval mines to stippling were effectively used to evaluate the relative attractiveness of 12 host species and cultivar. This ratio minimizes the influence of the host leaf surface area in evaluating the specific host preferences.

(6) Host preference for oviposition of the female leafminer for 'Walter' tomato was suggested by an active mine to stippling ratio (1:12) that was significantly greater than for 11 other species of hosts tested (1:22 through 1:80). This preference could have been influenced by leafminer prior association with commercial field 'Walter' tomatoes.

(7) Moderate humidity levels (=50%) and 8 through 20 celery trifoliate leaves per pint sample container resulted in a larger mean number of insects reared per leaflet than smaller pint.

(8) Increased rearing temperatures (to 32.2°C) resulted in a larger mean number of insects reared per celery trifoliate leaf.

(9) Sampling celery trifoliate leaves was as effective a technique as sampling whole plants in evaluating the influence of selected insecticides on total insects (leafminers and parasites) reared per treatment.

(10) More than 75% of leafminer oviposition on tomato and celery occurred between 6 AM and 3 PM while parasite activity remained constant relative to the number of active mines during a 24 h. interval.

(11) Fenvalerate (0.40 lb. A.I./A.), permethrin (2EC, 0.20 lb. A.I./A.), methamidophos (1.00 lb. A.I./A.), and oxamyl (0.25 lb. A.I./A.) + permethrin (2EC, 0.1 lb. A.I./A.) were the most effective of the insecticides tested in reducing the mean number of insects reared from celery foliage samples.

(12) A major problem in evaluation of the insecticide treatments in the Sun City, Florida, area or prevention of leafminer damage was the extremely high level of parasitism (>90%) during the winter of 1977.

(13) Three species of parasites important to biological control of the vegetable leafminer were _Chrysonotomyia formosa_ (Westwood), _Diglyphus intermedius_ (Girault), and _Opius_ spp.

(14) Although oxamyl and permethrin are among the most effective labeled materials for leafminer control on celery, lower rates of the 2 insecticides may be combined, resulting in significantly lower leafminer counts and less residue pollution than either material used alone.

(15) Out of 5 insecticides and 2 combinations of 2 insecticides, methamidophos was the only insecticide treatment that significantly decreased parasitism of the vegetable leafminer during the 2 months of weekly applications.

(16) As concentration of fenvalerate increased from 0.025 to 0.40 lb. A.I./A., numbers of adult leafminers and parasites collected from celery leaflet samples decreased in an inverse linear manner.

(17) Insecticides (i.e. fenvalerate) may be more effective at lower leafminer population levels. This protection from leafminer damage is influenced by the total A.I./A. applied and changes in plant size.

(18) The emergence of adult leafminers was significantly greater at temperatures held constant above 21.1°C (>75%) than those where the pupae were held at cooler temperatures.

(19) Freezing (7 nights of -4°C) was detrimental to emergence of leafminer adults (13.9%) relative to a similar temperature regime minus the subfreezing temperatures (43.2%).

(20) Parasite _Opius_ spp.emergence increased relative to the leafminer at cooler temperatures (<15.6°C).

(21) Leafminer pupal development is influenced by temperature and may be slowed by an average of 1 day per degree decrease over a 32.2° to 15.6°C range.

(22) _Opius_ spp. pupae (and egg?) had a longer development time (ave. 1 to 2 days) over the 32.2° to 15.6°C temperature range than the leafminer.

(23) At harvest mature celery foliage is significantly more attractive for leafminer oviposition activity than the peripheral or central foliage.

(24) Population densities of _C. formosa_ and _D. intermedius_ was shown not to be interdependent.

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BIOGRAPHICAL SKETCH

The author was born on July 28, 1946, in Morgantown, West Virginia. Upon graduation from Morgantown High School in 1964, he entered Lawrence University in Appleton, Wisconsin. In December, 1968, he received the degree of Bachelor of Arts with Honors in Research and a major in Biology from Lawrence University. He taught biology and mathematics and coached wrestling at Grafton High School in Grafton, Wisconsin, a suburb of Milwaukee. In the fall of 1972 he enrolled as a graduate student in the Botany Department, College of Arts and Sciences, at the University of Florida, receiving the Master of Science degree in March, 1975. He enrolled in the Department of Entomology and Nematology, College of Agriculture, at the University of Florida during the Fall 1974, and has pursued work toward the degree of Doctor of Philosophy.

On September 27, 1978, he married Carolyn Yvonne O'Hara and proved that teaching undergraduate CBS 231 can be most rewarding.

He is currently a member of the Entomological Society of America and the Florida Entomological Society.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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