Spatial and Diel Activity of *Liriomyza* Species (Diptera: Agromyzidae) in Fresh Market Tomatoes

GEOFFREY W. ZEHNDER AND JOHN T. TRUMBLE

Department of Entomology, University of California,
Riverside, California 92521

Environ. Entomol. 13: 1411–1416 (1984)

ABSTRACT Spatial and diel activities of *Liriomyza* spp. leafminers were investigated weekly using yellow sticky traps which were placed at three different plant heights and monitored during four time periods. Leafminer flight activity peaked from 0700 to 1100 hours, due primarily to movement of males. Diel activity differences between species were not observed, but spatial activity differed between species, with most *L. sativae* Blanchard trapped at the middle plant height while *L. trifolii* (Burgess) were most abundant at the low plant height. Total adults obtained from low or middle traps monitored during any of the three daylight time periods were significantly correlated with cumulative 24-h counts of adults. *L. sativae* was the most abundant species collected in 1981, while *L. trifolii* predominated in 1982. More larvae and puparia were collected in pupal trays between 0700 and 1100 hours than during any other time period, indicating periodicity of larval emergence from foliage. A significant relationship between numbers of pupae in trays and the number of adults captured 2 weeks later provides a suitable tool for forecasting the size of adult populations.

LARVAE OF the leafminers *Liriomyza sativae* Blanchard and *L. trifolii* (Burgess) damage tomato plants by feeding in the leaf mesophyll tissue. Although this feeding significantly reduces photosynthesis in the affected leaves (Johnson et al. 1983), no relationship has been established between tomato yield (measured in volume) and leafminer infestations (Wolfenbarger and Wolfenbarger 1966). However, high populations developing under methomyl spray regimes (Oatman and Kennedy 1976) can cause leaf distortion and premature abscission, which results in sunburn-damaged fruit.

Sampling methods for monitoring leafminer population density include counts of live larvae in foliage, counts of total mines, collections of pupae in trays, and rearing of adults from foliage samples (Levins et al. 1975, Poe et al. 1978, Johnson et al. 1980a). Unfortunately, not all of these techniques are efficient. Counts can be time-consuming and first-instar leafminer larvae are difficult to detect. The number of foliar mines does not provide an accurate estimate of leafminer density, since mines do not disappear after larval emergence (Johnson et al. 1980b). Density estimates based on adult emergence from leaf samples require considerable time, space, and equipment and are difficult to relate quantitatively to natural populations, since laboratory temperatures usually do not accurately reflect temperatures in the field.

Johnson et al. (1980b) found the pupa-tray survey technique to be a fast and accurate method of sampling *L. sativae* populations. He reported a significant correlation ($r = 0.876$) between the mean number of larvae in foliage and the mean number of pupae collected in trays. Because counts of pupae were not made at intervals of less than 48 h, time of peak larval emergence could not be determined. Sticky traps are the preferred method of leafminer survey for immediate detection of population increases (Musgrave et al. 1975). Yellow has proven to be the most effective color for attracting agromyzid leafminer adults (Tryon et al. 1980, Affeldt et al. 1983).

Few attempts have been made to quantify the effects of circadian behavior patterns or trap height on adult leafminer sampling. Previous sampling studies in the field have used counts of adults from traps monitored at 24-h intervals (Schuster et al. 1980, Chandler 1981). Tryon (1980) mentioned that most adults were captured during the warmer part of the day, but data were analyzed for only 24-h intervals. Schuster et al. (1980) observed no differences in counts of leafminer adults taken from sticky traps placed at different heights (10, 20, and 30 cm) in tomatoes, although the numbers of leafminers in foliage sampled at the three heights differed significantly.

This study was designed to determine the spatial and diel activity of adult leafminers and to quantify diel influence on sampling of pupae. Concurrently, differences in spatial and diel activity between *Liriomyza* species and sexes also were investigated.

Methods and Materials

The study was conducted during the summers of 1981 and 1982 at the University of California's

South Coast Field Station in Santa Ana, Calif. Fresh market tomatoes ('Petoseed' #7718 VF) were transplanted 9 June 1981 and 8 June 1982, and grown according to local commercial practices. The test plots were arranged in a randomized complete block design with four blocks, each with three rows of tomatoes (10.0 m long with 2.1-m centers). Blocks were separated by at least one buffer row. The test plots were sprayed weekly with methomyl (1.0 kg [AI]/ha) to maintain high leafminer populations (Trumble and Toscano 1983).

Flies were trapped using 28-by-15-cm yellow rigid PVC sheets of 10-mil thickness (Hillcor Plastics, 11739 Willake St., Santa Fe Springs, CA 90670) which had one side coated with a thin layer of Tack-Trap. Each sheet was attached to a cardboard backing of the same size with a 5-cm binder clip. Plastic sheets with cardboard supports (hereafter referred to as "traps") could then be clipped to wooden stakes placed adjacent to tomato plants. Sharpened sticks were stapled to the bottom of the cardboard supports so that 36 traps (enough for one sampling period) could be inserted on a piece of styrofoam (75 by 50 by 7.5 cm). The entire unit then could be carried into and out of the field with relative ease.

One trap was attached to each of three wooden stakes spaced at equal intervals in each row. Stakes were cut at different lengths so that traps were randomly assigned to one of three plant heights: (1) low plant height (ground level to 28 cm throughout the growing season), (2) middle plant height (determined by taking the average height of 36 plants, dividing by two, then centering the middle trap at this height on the plant), or (3) high plant height (bottom of trap placed 5 cm above the top of the plant). At the initiation of sampling, traps did not overlap. By placing traps in the vertical plane of the foliage, the area of attractiveness was limited to immediately in front of the traps and problems associated with overlapping trap heights were held to a minimum.

Periodicity of larval emergence from foliage was investigated by placing four styrofoam trays of 22.9 by 27.9 by 1.6 cm per row (Mobilfoam, size 2S, Zellerbach Paper Co., Los Angeles, Calif.) on the ground under the plants, with the largest side parallel to the row (Johnson et al. 1980b). Larvae dropping out of the foliage immediately above the trays were collected.

Each sampling date was separated into four time periods: 0700 to 1100, 1100 to 1500, 1500 to 2000, and 2000 to 0700 hours. Clean sticky traps and pupa trays were placed in the field at the beginning of each period and traps and trays from the preceding period were assessed for that number of adults and pupae, respectively. Adult *Liriomyza* on sticky traps also were sexed and identified to species using characters described by Spencer (1973). Utilization of this system allowed for inspection of 12 sticky traps at each height per time period (144 sticky traps per sampling date), and

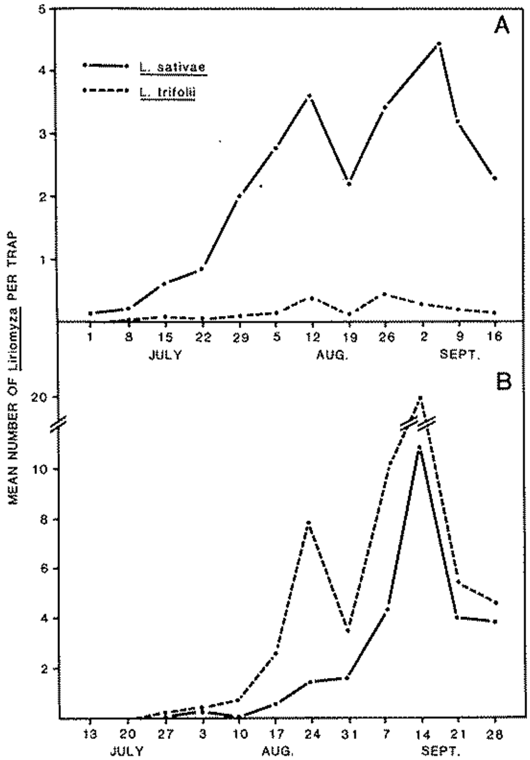

Fig. 1. Population trends of *Liriomyza* spp. in pole tomatoes: (A) 1981; (B) 1982.

48 pupa trays per time period (192 trays per sampling date).

Adult counts were analyzed initially using a complete factorial design with block, time period, and trap height as the main effects. This analysis provided information on the variation of *L. sativae*, *L. trifolii*, males, females, and all adults observed within each main effect. Duncan's (1955) multiple range test (DMRT) was used on main effect means to determine significant differences between time period and trap height means. Analysis was performed on data for the complete season as well as on data accumulated for each sampling date. Pupa counts were analyzed using DMRT on time period means. Reanalysis of diel activity data, based on counts adjusted to number per trap per hour or tray per hour, generated identical results and were therefore not included separately. Correlation coefficients were calculated using Pearson's correlation analysis.

Results and Discussion

Species Population Trends. The leafminer species present in tomato plots in 1981 and 1982 were *L. sativae* and *L. trifolii*. *L. sativae* was predominant throughout the 1981 season (Fig. 1A), constituting at least 80% of the total mean adult population on all sampling dates. Low counts on

Table 1. Mean number of adults per sticky trap by time period

Adult leafminers	1981				1982			
	0700–1100	1100–1500	1500–2000	2000–0700	0700–1100	1100–1500	1500–2000	2000–0700
Total	3.5a	2.0c	3.0b	0.8d	14.7a	11.2b	7.5c	0.4d
Males	2.5a	1.2c	1.9b	0.7d	12.5a	8.4b	5.7c	0.3d
Females	1.0a	0.8b	1.1a	0.1c	2.2b	2.8a	1.8b	0.1c
L. sativae	3.3a	1.9c	2.7b	0.8d	6.0a	3.3b	1.8c	0.2d
L. trifolii	0.2b	0.1b	0.3a	0.0c	8.7a	7.9a	5.7b	0.2c

Means in a row within the same year, followed by the same letter, are not significantly different ($P < 0.05$; DMRT).

19 August probably were due to movement of a weather front that produced overcast conditions and abnormally low temperatures. Species dominance shifted in 1982 (Fig. 1B), with *L. trifolii* counts exceeding *L. sativae* by over 50% from 27 July to 14 September. Concurrent field studies at South Coast Field Station, in which adults reared from foliage samples were identified weekly, showed the preference of *L. sativae* for tomatoes and of *L. trifolii* for celery (Zehnder and Trumble 1984). The high numbers of *L. trifolii* collected on sticky traps in tomatoes in 1982 may therefore reflect the beginnings of a species shift on tomatoes in California.

Diel Activity of Adults. Analysis of means obtained from total adult counts from all sampling dates revealed significantly more adults trapped between 0700 and 1100 hours, with fewest adults trapped between 2000 and 0700 hours (Table 1). A greater proportion of males than females were collected on traps (1981: *L. sativae* = 68%, *L. trifolii* = 67%; 1982: *L. sativae* = 75%, *L. trifolii* = 82%). Analogous results were reported by Chandler (1981), where more males than females were captured in an evaluation of trap shapes and color intensities for detection of *Liriomyza* species. Since sex ratios determined by rearing larvae from tomato and celery foliage revealed an approximately equivalent sex ratio (1981: *L. sativae* = 53% males, *L. trifolii* = 56% males; 1982: *L. sativae* = 46% males, *L. trifolii* = 51% males) (Zehnder and Trumble 1984), the skewed sex ratio observed in the present study may be explained in behavioral terms. The females may spend more time on the leaves during oviposition or the males may tend to visit a greater number of leaves in search of food and females. The activity pattern observed for males is selectively advantageous, since males exhibiting such behavior develop a reproductive advantage by increasing the number of sexual encounters (Smith and Prokopy 1981). Selection pressure for early activity in females would not be as great unless oviposition sites were limited, which was not the case in our study.

Counts of adults separated by species and analyzed for time-period differences revealed higher numbers of *L. sativae* from 0700 to 1100 hours in both 1981 and 1982 (Table 1). More *L. trifolii* were trapped from 1500 to 2000 hours in 1981, with no significant difference in mean numbers of *L. trifolii* trapped from 0700 to 1100 and 1100 to 1500 hours in 1982. Since peak numbers of *L. sativae* collected from 0700 to 1100 hours were probably influenced by male activity, and diel trends of *L. trifolii* during 1981 and 1982 were not consistent, no inference concerning time period preferences between species can be made. Although a positive correlation of ambient temperature with diurnal activity was established for *Rhagoletis* species (Smith and Prokopy 1981), temperature alone did not appear to affect *Liriomyza* flight activity patterns: catches in traps were not significantly correlated with maximum or minimum temperatures for a time period.

Adult Spatial Activity. Analysis of total numbers of adults separated by trap height revealed that more adults were trapped at the middle plant height in 1981, with higher numbers recorded from the low plant height in 1982 (Table 2). Fewest adults were captured at the high plant height during either year. Comparisons of entire-season counts between species indicated significant spatial activity differences between *L. sativae* and *L. trifolii* (Table 2). In 1981, significantly more *L. sativae* were collected at the middle plant height, while *L. trifolii* counts were greater at the low plant height. *L. trifolii* was again more numerous at the low plant height in 1982, but no significant differences were found in *L. sativae* counts taken at the low and middle plant heights.

Spatial activity differences between species were clearly evident when trap height counts were analyzed by date. *L. sativae* counts were higher at the middle plant height on 16 of 18 sampling dates in 1981 and 1982, with significance shown on eight sampling dates (Fig. 2). More *L. trifolii* were

Table 2. Mean number of adults per sticky trap by trap height

Adult leafminers	1981			1982		
	Low	Middle	High	Low	Middle	High
Total	2.6b	3.5a	0.8c	13.0a	10.0b	2.4c
Males	1.7b	2.6a	0.5c	10.5a	8.0b	1.7c
Females	0.9a	0.9a	0.3b	2.5a	2.0b	0.7c
L. sativae	2.3b	3.3a	0.8c	3.8a	3.8a	0.8b
L. trifolii	0.3a	0.2b	0.0c	9.2a	6.2b	1.6c

Means in a row within the same year, followed by the same letter, are not significantly different ($P < 0.05$; DMRT).

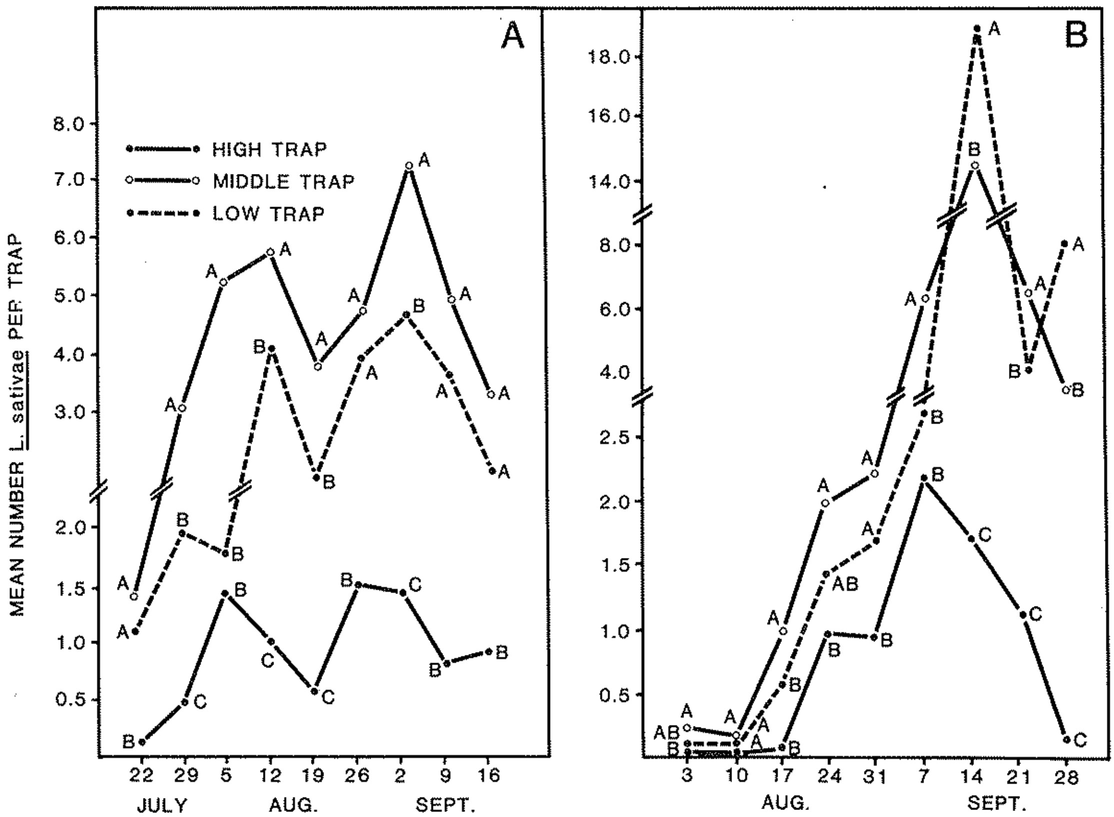

Fig. 2. Spatial distribution of *Liriomyza sativae* in pole tomatoes: (A) 1981; (B) 1982. Mean values within each date, having the same letter, are not significantly different ($P \leq 0.05$; DMRT).

trapped at the low plant height on 15 of 18 sampling dates, with low traps capturing significantly larger numbers of flies on 10 sampling dates (Fig. 3). Although species dominance was reversed in 1982, spatial preferences between species remained constant.

Since *L. sativae* and *L. trifolii* are closely related species with overlapping host ranges (Spencer 1973, Zehnder and Trumble 1983), evolution of behavioral mechanisms for either niche selection or enhancement of genetic isolation between species can be expected. However, whether the spatial activity differences seen in this experiment are exclusion mechanisms or are indirect results of other isolating mechanisms are questions for further study.

Monitoring Adult Activity. Numbers of adults monitored during the three daylight time periods were significantly correlated with cumulative 24-h counts (0700–1100: 1981, $r = 0.93$; 1982, $r = 0.97$. 1100–1500: 1981, $r = 0.94$; 1982, $r = 0.99$. 1500–2000: 1981, $r = 0.95$; 1982, $r = 0.74$). Counts taken from 2000 to 0700 hours were not significantly correlated with cumulative 24-h counts since nocturnal flight activity was minimal. Low, middle, and high trap counts were also significantly correlated with total counts, although low and middle traps yielded the highest correlation coefficients (Low: 1981, $r = 0.97$; 1982, $r = 0.98$. Middle: 1981, $r = 0.98$; 1982, $r = 0.99$. High: 1981, $r = 0.86$; 1982, $r = 0.81$). With the exception of time period/trap height combinations taken from 2000 to 0700 hours, counts taken from all combinations of time periods and trap heights were significantly correlated with total daily counts.

Unfortunately, sticky traps left in the field for extended periods accumulate debris and other insect species, making leafminer identification tedious and difficult. Therefore, exposure of traps for the shortest time period that will permit accurate population monitoring is desirable. Based on the relationships between trap height, time period, and total adult collections, a monitoring program using sticky traps placed at the bottom or middle of the plant, and monitored during any of the daylight time periods, will provide a reliable indication of adult leafminer population trends.

Diel Activity of Larvae. The number of larvae and puparia counted on pupa trays between 0700 and 1100 hours was significantly greater than the number from other time periods on 19 of 24 sampling dates in 1981 and 1982. Similar periodicity of larval emergence has been demonstrated for the agromyzid *Phytomyza lanati* (Tauber and Tauber

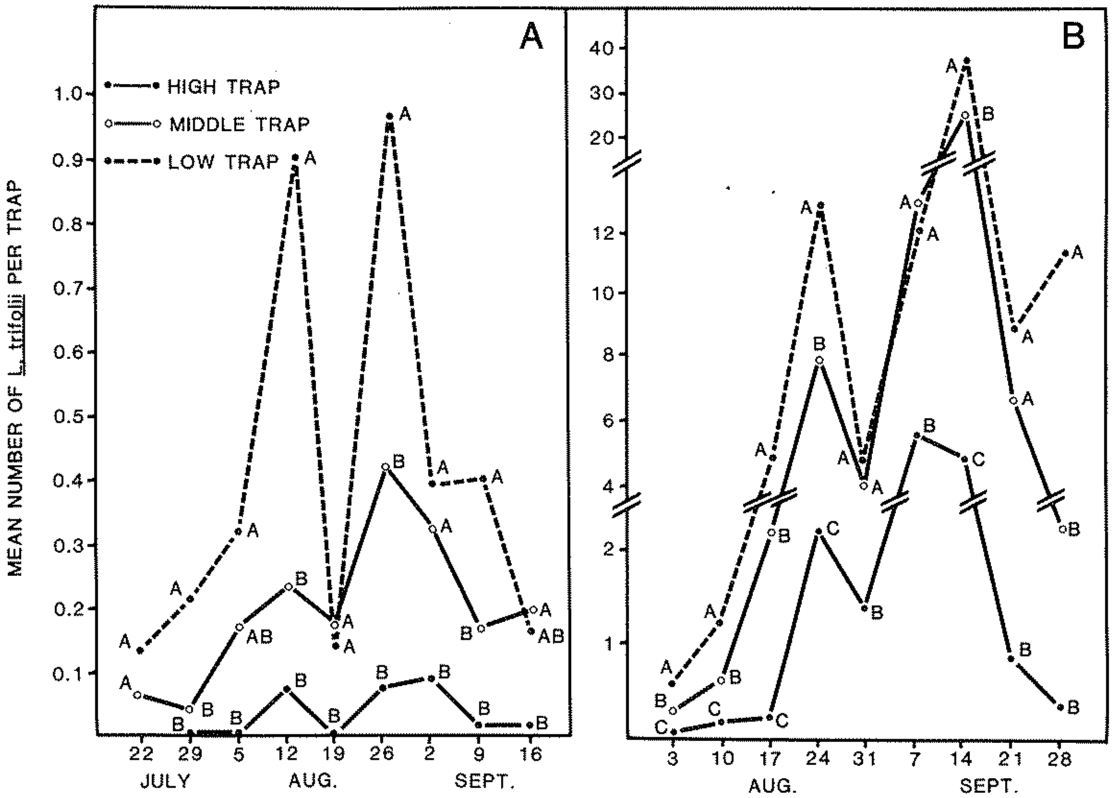

Fig. 3. Spatial distribution of *Liriomyza trifolii* in pole tomatoes: (A) 1981; (B) 1982. Mean values within each date, having the same letter, are not significantly different ($P \leq 0.05$; DMRT).

1966) and for other dipteran species, including *Dacus dorsalis*, *D. oleae*, and *Ceratitis capitata* (Saunders 1982). For leafminers, chances of survival may be increased by early morning larval emergence, since environmental conditions include moderate temperatures and high relative humidity, and are suitable for survival before puparium formation.

Significant correlation coefficients (1981: $r = 0.77$; 1982: $r = 0.97$) between adult and pupa counts were obtained by pairing pupa counts with numbers of adults captured on traps 2 weeks later. This relationship has a clear biological basis, since the *Liriomyza* spp. pupal stage lasts from 7 to 14 days at 20 to 30°C (Leibee 1981). Thus, pupa-tray surveys are useful for forecasting adult density levels as well as assessing larval populations.

Knowledge of the distribution and circadian activity patterns of both adult and larval stages of *Liriomyza* infesting tomatoes is of practical use in an integrated pest management program. Chemical applications can be timed for periods when adults are sedentary (2000–0700 hours) or very active (0700–1100 hours). Similarly, larvae exiting from leaves from 0700 to 1100 hours are more exposed to contact with pesticides than in any other portion of the day. Finally, monitoring techniques can be streamlined and simplified by trapping only during peak activity periods, thus reducing the losses due to inclement weather and the time and effort required for sampling and identification.

Acknowledgments

We thank C. Huszar of the Statistics Dept., Univ. Calif., Riverside, for advice on statistical analysis. The critical reviews of M. P. Parrella, T. M. Perring, and H. Nakakihara improved this manuscript and are appreciated.

References Cited

Affeldt, H. A., R. W. Thimijan, F. F. Smith, and R. E. Webb. 1983. Response of the greenhouse whitefly (Homoptera: Aleyrodidae) and the vegetable leafminer (Diptera: Agromyzidae) to photospectra. J. Econ. Entomol. 76: 1405–1409.

Chandler, L. D. 1981. Evaluation of different shapes and color intensities of yellow traps for use in population monitoring of dipterous leaf miners. Southwest. Entomol. 6: 23–27.

Duncan, D. B. 1955. Multiple range and multiple *F* tests. Biometrics 11: 1–42.

Johnson, M. W., E. R. Oatman, J. A. Wyman, and R. A. Van Steenwyk. 1980a. Effects of insecticides on populations of the vegetable leafminer and associated parasites on fall pole tomatoes. J. Econ. Entomol. 73: 67–71.

1980b. A technique for monitoring *Liriomyza sativae* in fresh market tomatoes. Ibid. 73: 552–555.

Johnson, M. W., S. C. Welter, N. C. Toscano, I. P. Ting, and J. T. Trumble. 1983. Reduction of tomato leaflet photosynthesis rates by mining activity of *Liriomyza sativae* (Diptera: Agromyzidae). Ibid. 76: 1061–1063.

Leibee, G. L. 1981. Development of *Liriomyza trifolii* on celery. Proc. 2nd Int. Conf. Biol. Control *Liriomyza* Leafminers: 35–41.

Levins, R. A., S. L. Poe, R. C. Littell, and J. P. Jones. 1975. Effectiveness of a leafminer control program for Florida tomato production. J. Econ. Entomol. 68: 772–774.

Musgrave, C. A., S. L. Poe, and D. R. Bennett. 1975. Leafminer population estimation in polycultured vegetables. Proc. Fla. State Hortic. Soc. 88: 156–160.

Oatman, E. R., and G. G. Kennedy. 1976. Methomyl-induced outbreak of *Liriomyza sativae* on tomato. J. Econ. Entomol. 69: 667–668.

Poe, S. L., P. H. Everett, D. J. Schuster, and C. A. Musgrave. 1978. Insecticidal effects on *Liriomyza sativae* larvae and their parasites on tomato. J. Ga. Entomol. Soc. 13: 322–327.

Saunders, D. S. 1982. Insect clocks. Pergamon, New York.

Schuster, D. J., R. T. Montgomery, D. L. Gibbs, G. A. Marlowe, Jr., J. P. Jones, and A. J. Overman. 1980. The tomato pest management program in Manatee and Hillsborough Counties, 1978–1980. Proc. Fla. State Hortic. Soc. 93: 235–239.

Smith, D. C., and R. J. Prokopy. 1981. Seasonal and diurnal activity of *Rhagoletis mendax* in nature. Ann. Entomol. Soc. Am. 74: 462–466.

Spencer, K. A. 1973. Agromyzidae (Diptera) of Economic Importance. Dr. W. Junk, The Hague. 418 pp.

Tauber, M. J., and C. A. Tauber. 1966. Behavior and cyclic activity associated with pupation of *Phytomyza lanati* Spencer (Diptera: Agromyzidae). Can. J. Zool. 44: 793–798.

Trumble, J. T., and N. C. Toscano. 1983. Impact of methamidophos and methomyl on populations of *Liriomyza* species (Diptera: Agromyzidae) and associated parasites in celery. Can. Entomol. 115: 1415–1420.

Tryon, E. H., Jr., S. L. Poe, and H. L. Cromroy. 1980. Dispersal of a vegetable leafminer onto a transplant production range. Fla. Entomol. 63: 292–296.

Wolfenbarger, D. A., and D. O. Wolfenbarger. 1966. Tomato yields and leafminer infestation and a sequential sampling plan for determining need for control treatments. J. Econ. Entomol. 59: 279–283.

Zehnder, G. W., and J. T. Trumble. 1983. Discrimination of *Liriomyza* species (Diptera: Agromyzidae) using electrophoresis and scanning electron microscopy. Proc. Entomol. Soc. Wash. 85: 564–574.

1984. Host selection of *Liriomyza* species (Diptera: Agromyzidae) and associated parasites in adjacent plantings of tomato and celery. Environ. Entomol. 13: 492–496.

Received for publication 27 February 1984; accepted 18 June 1984.