Sequential Sampling Plans with Fixed Levels of Precision for *Liriomyza* Species (Diptera: Agromyzidae) in Fresh Market Tomatoes

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ABSTRACT Taylor's power law and Iwao's patchiness regression were used to determine the relationship between the mean and variance of leafminer counts obtained from yellow sticky traps and pupal trays in fresh market tomatoes. Taylor's regression method provided a better fit at low mean densities of adults. Unlike Iwao's technique, there were no significant differences between Taylor's regression slopes or *Y* intercepts for *Liriomyza sativae* Blanchard and *L. trifolii* (Burgess) numbers on sticky traps during the growing seasons of 1981 and 1982. Constant-precision-level sequential sampling plans, therefore, were developed for leafminer adult and pupal stages based on Taylor's power law. The minimum number of traps that must be counted to estimate various mean densities of adult leafminers at fixed levels of precision also were calculated.

THE LEAFMINERS *Liriomyza sativae* Blanchard and *L. trifolii* (Burgess) cause damage to tomatoes when larvae feed in leaf mesophyll tissue. *L. trifolii* became a serious pest of chrysanthemum and celery in California after its introduction into the state in the late 1970's (Parrella et al. 1981, Trumble 1981) and has since moved to fresh market tomatoes where high population densities have been recorded (Zehnder and Trumble 1984). *L. sativae* has been recognized as a pest of tomatoes in California for over 35 years (Lange 1949, Parrella 1982).

Leafminer outbreaks in tomatoes can occur when the natural enemy complex is reduced by insecticide treatments applied for control of lepidopterous pests such as the tomato pinworm, *Keiferia lycopersicella* (Walsingham), and the tomato fruitworm, *Heliothis zea* (Boddie) (Johnson et al. 1980a). Extensive leafmining activity reduces the photosynthetic capability of plants (Johnson et al. 1983) and can result in defoliation and sunscorched, unmarketable fruit.

Development of a practical leafminer management program depends on sampling methods that are easy to implement and can accurately detect leafminer population increases. Musgrave et al. (1975) found that yellow sticky traps could be used for rapid detection of adult *Liriomyza* population fluctuations. An advantage of the sticky-trap technique is that migratory leafminer populations can be monitored at the onset of infestation. The pupal tray survey developed by Johnson et al. (1980b) is a fast and accurate method of estimating pupal density. Sequential sampling plans that reduce sampling time when insect densities are low or high relative to economic threshold levels have been developed for leafminers based on the proportion of mined leaflets sampled (Wolfenbarger and Wolfenbarger 1966) and the number of live larvae per leaflet (Johnson et al. 1982). These methods are based on predetermined damage thresholds, which can vary during the growing season or between geographic locations (Kogan and Herzog 1980).

An alternative sequential sampling plan developed by Kuno (1969) and Green (1970) estimates the mean density of a population relative to a predetermined level of precision. Use of this constant-precision-level sampling technique requires sequential samples to be taken until the fixed level of precision has been reached. Such a sampling plan was developed by Parrella and Jones (1984) to estimate adult *L. trifolii* density in chrysanthemum greenhouses. The purpose of this study was therefore to develop constant-precision-level sequential sampling plans to estimate leafminer adult and pupal populations in fresh market tomatoes using yellow sticky traps and pupal trays, respectively. A technique for determining the number of sticky traps needed to estimate adult population densities within desired precision levels also is discussed.

Materials and Methods

Data were collected from an experimental planting of trellised tomatoes 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 no. 7718VF) were transplanted 9 June 1981 and 8 June 1982 on 2.1-m centers and grown according to local commercial practices. The field was divided into four randomized blocks, each 10 m long by three rows.

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Blocks were sprayed weekly with methomyl (1.0 kg [AI]/ha) to maintain high leafminer populations (Oatman and Kennedy 1976, Trumble and Toscano 1983).

Flies were sampled 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 Tack-Trap. Reflectance of the yellow sheets was measured using an ISCO Model SR spectroradiometer equipped with a remote probe placed 7 cm in front of the test surface. Two 650-W quartz halogen lamps, used as illuminators, were placed at a 45° angle, 55 cm away from the surface.

Cardboard backing (28 by 15 cm) was attached to each plastic sheet with a 50-cm binder clip. Plastic sheets with cardboard supports (hereafter referred to as traps) then were vertically fastened to wooden stakes immediately adjacent to tomato plants. Along each of the three, 10 m rows per block, stakes were placed at 1, 5, and 9 m, and cut to different lengths so that traps were randomly placed at the bottom or middle of, or immediately above the plants. Three traps were used per row, with one trap at each plant height. Because of a high correlation (1981: $r = 0.98$; 1982: $r = 0.99$) demonstrated between middle trap counts and counts taken at all three plant heights (Zehnder and Trumble 1984), only counts from traps placed at the middle height were used for analysis. The middle height was determined each week by taking the average height of 36 plants, dividing by two, then centering the trap at this height on the plant.

Larvae and pupae were sampled using four 22.9-by-27.9-cm styrofoam trays per row (Mobilfoam, size 2s, Zellerbach Paper Co., Los Angeles) placed on the ground under the plants. Larvae dropping to the ground to pupate were collected. Adults emerging from pupae in trays were not identified to species.

Sticky traps and pupal trays were monitored during four separate time periods: 0700 to 1100, 1100 to 1500, 1500 to 2000, and 2000 to 0700 hours. Clean traps and trays were placed in the field at the beginning of each period and traps and trays from the preceding period were assessed for the number of adults and pupae, respectively. Adult leafminers on sticky traps also were identified to species. Only pupal counts taken during 0700 to 1100 hours were used in the analysis because 80% of all larval emergence occurred during this time period. Forty-eight traps (12 per time period) and 48 pupal trays were examined on each sampling date. Counts were recorded weekly on 12 sampling dates in 1981 and 9 sampling dates in 1982.

Means and variances of counts of adults and pupae were calculated for each date. Counts of adults also were analyzed by time period to minimize diel activity variation. Dispersion indices were calculated using Taylor's power law (Taylor 1961) and Iwao's patchiness regression (Iwao 1968). Taylor's power law relates variance (s^2) to mean density ($\bar{x}$) such that: $\log s^2 = b \log \bar{x} + \log a$, where the slope ($b$) is an index of aggregation and the intercept (a) is a computing factor related to sample size. Iwao's method is the regression of mean crowding ($\overset{*}{m}$) on the mean ($\bar{x}$), where $\overset{*}{m} = \bar{x} + [(s^2/\bar{x}) - 1]$ and the regression model is $\overset{*}{m} = \alpha + \beta\bar{x}$. The intercept ($\alpha$) is an index of basic contagion and the slope (β) has the same meaning as (b) in Taylor's power law.

Pairwise comparisons of Taylor's and Iwao's regression slopes for *L. sativae* and *L. trifolii* counts from sticky traps and pupal trays were done using Student's t test. Homogeneity of Taylor's regression slopes for counts of both species from traps in 1981 and 1982 was tested with analysis of covariance. Equality of Y intercepts at adjusted mean values was determined by a continuation of covariance analysis.

The results of Taylor's dispersion analysis were used to develop constant-precision-level sampling plans for total numbers of adults and pupae. Critical stoplines were calculated by the formula (Green 1970):

$$\log T_n = \frac{\log(D_0^2/a)}{b-2} + \frac{b-1}{b-2}\log n \qquad (1)$$

where a and b are from Taylor's regression, T_n = cumulative number of insects, n = sample size (number of sticky traps or pupal trays) and D_0 = the fixed level of precision. Estimates of population density within 25% of the mean are sufficiently accurate for use in pest management programs (Southwood 1978). Precision levels were therefore set between 0.20 and 0.30.

The number of sticky-trap samples needed at various population densities ($\bar{x}$) for fixed precision levels was calculated by rearrangement of equation 1 (Finch et al. 1975):

$$\log n = (\log a - 2\log D_0) - (2-b)\log \bar{x} \qquad (2)$$

Results and Discussion

Percentage of reflectance of the yellow PVC sheets from 425 to 750 nm is presented in Fig. 1. The reflectance peak occurred at approximately 550 nm, which agrees with previous spectral analysis of yellow traps (Moreno et al. 1984, Parrella and Jones 1984).

Both Taylor's and Iwao's methods significantly accounted for variation in total data on adults (Table 1); however, Taylor's power law provided a better fit to the very low *L. trifolii* populations recorded in 1981 (1981: 92 *L. trifolii*, 1,938 *L. sativae*; 1982: 2,915 *L. trifolii*, 1,789 *L. sativae*). Taylor et al. (1978) found that the power law provided a good fit to data for a wide range of organisms at low population densities. Student's t test revealed significant differences for Iwao's regression slope coefficient (β) between *L. sativae* and

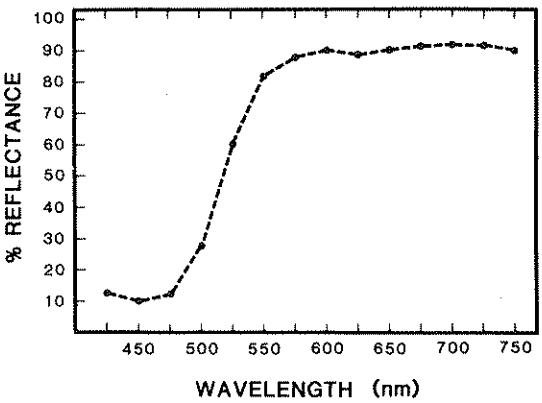

Fig. 1. Spectral reflectance curve of yellow PVC sheets used as sticky traps for adult *Liriomyza* spp.

L. trifolii in 1982 (1981: $t = 0.35$, df = 69; 1982: $t = 3.49$, df = 70). There were no significant differences for Taylor's slope coefficient (b) between species (1981: $t = 0.89$, df = 69; 1982: $t = 1.40$, df = 70) indicating similar variance-to-mean relationships. Further analysis of the four Taylor's regression lines for *L. sativae* and *L. trifolii* in 1981 and 1982 found no significant differences between slopes (F = 2.26, df = 3,139, $\alpha = 0.05$) or Y intercepts (F = 0.45, df = 3,139, $\alpha = 0.05$). A common Taylor's power law regression then could be fitted to the data for the total number of *Liriomyza* adults trapped in 1981 and 1982 (Zar 1974). Constant-precision-level stoplines therefore were calculated using equation 1 based on Taylor's power law regression of total counts of adults combined from 1981 and 1982 (Fig. 2). Sticky-trap samples are taken sequentially until the cumulative number of trapped flies exceeds stopline values for the number of samples taken. At this time, the mean density, can be estimated as the quotient of the cumulative number of flies divided by the number of samples.

Taylor's power law and Iwao's regression method both provide a good fit to the pupal tray counts with no significant differences in slope coefficients between years (Table 2). Constant-precision-level stoplines for estimating mean *Liriomyza* (*L. sativae* plus *L. trifolii*) pupal density (Fig. 3) were calculated using equation 1 with a and b values obtained from Taylor's power law regression of 1981 and 1982 combined pupal counts. Use of pupal stoplines is the same as described for adult stoplines in Fig. 1. This method can be used to obtain a fast and accurate estimate of *Liriomyza* larval density since pupal tray counts have been correlated with larval density in foliage (Johnson et al. 1980b).

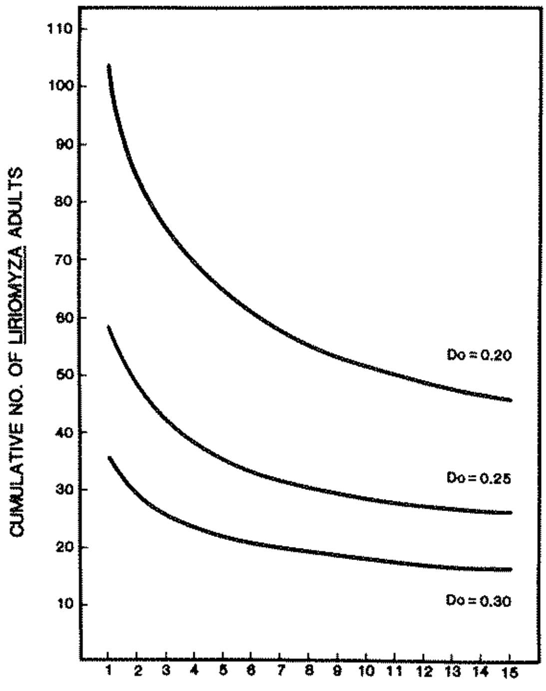

Fig. 2. Stoplines for constant-precision sequential samples for *Liriomyza* adults at three levels of precision (D_0) of 0.20, 0.25, and 0.30.

An approximate method for determining the number of sticky traps needed to estimate various adult mean densities is shown in Fig. 4. Because Iwao's regression parameters for adult *Liriomyza* were not comparable between years, optimum

Table 1. Regression statistics from dispersion analysis of adult *Liriomyza* caught on sticky traps in fresh market tomatoes[a]

Category	Year	Iwao's patchiness regression			Taylor's power law		
		α	β	R^2	Log a	b	R^2
L. sativae	1981	0.06	1.23	0.93	0.16	1.17	0.93
L. trifolii		0.04	1.39	0.27	0.09	1.09	0.88
L. sativae	1982	0.21	1.15	0.99	0.18	1.21	0.97
L. trifolii		−0.16	1.23	0.99	0.15	1.29	0.96
L. sativae	1981 and 1982	0.22	1.17	0.98	0.17	1.19	0.95
L. trifolii		−0.04	1.23	0.99	0.18	1.25	0.97
Total		0.57	1.09	0.99	0.16	1.23	0.94

[a] Data were collected from 48 sticky traps per week; 12 weeks of sampling in 1981 and 9 weeks of sampling in 1982.

Table 2. Regression statistics from dispersion analysis of *Liriomyza* pupal tray counts in fresh market tomatoes[a]

Year	Iwao's patchiness regression			Taylor's power law		
	α	β	R^2	Log a	b	R^2
1981	3.07	1.13	0.97	0.45	1.29	0.97
1982	0.23	1.19	0.99	0.24	1.16	0.98
1981 and 1982	1.25	1.19	0.98	0.35	1.29	0.97

[a] Data were collected from 48 pupal trays per week; 12 weeks of sampling in 1981 and 9 weeks of sampling in 1982. All collections made from 0700 to 1100 hours.

sample sizes were calculated (Fig. 3) using equation 2 based on Taylor's variance-to-mean relationship. A line drawn from the expected number of adults per trap to the sample numbers curve will show the number of traps needed to estimate the population mean with the desired level of precision. If adult density is unknown, pupal tray surveys may be used as preliminary estimates, since fluctuations in pupal tray counts were correlated with catches of adults in traps occurring after a pupal development period of 2 weeks (1981: $r = 0.77$; 1982: $r = 0.97$). A weak correlation existed between adult catches and pupal tray counts taken after a 1-week period necessary for egg and larval development (1981: $r = 0.69$; 1982: $r = 0.46$). That

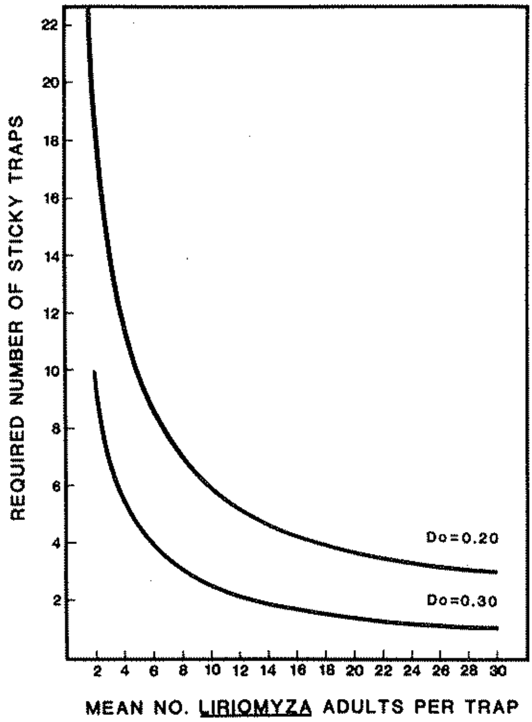

Fig. 4. Required number of sticky traps for various *Liriomyza* adult densities at two levels of precision (D_0) of 0.20, 0.30.

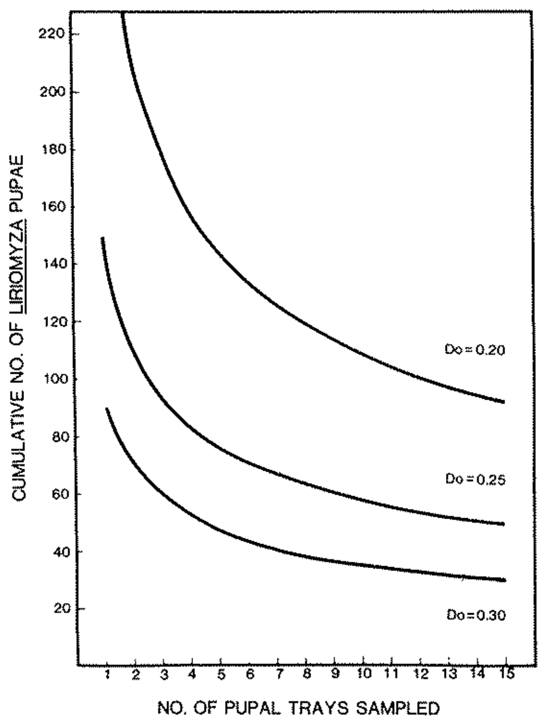

Fig. 3. Stoplines for constant-precision sequential samples for *Liriomyza* pupae at three levels of precision (D_0) of 0.20, 0.25, and 0.30.

this was not as strong as the pupal and future adult relationship was expected since external factors, such as weather and natural enemies, exert a greater influence on leafminer oviposition and larval development than on the pupal stage.

The consistent variance/mean relationships observed in this study indicated that aggregation on yellow sticky traps was similar for *L. sativae* and *L. trifolii* during the two growing seasons. Thus, this trapping technique can be used to effectively monitor mixed populations of these species in fresh market tomatoes. Similar consistent variance/mean ratios also were found for *L. trifolii* collected on yellow sticky traps in chrysanthemum greenhouses (Parrella and Jones 1984). Therefore, the use of yellow sticky traps may prove appropriate for sampling *Liriomyza* species in a variety of cropping systems. Information of this type is necessary to the development of sequential sampling plans with predetermined levels of precision, and provides an important tool for monitoring leafminer population fluctuations with a minimum of time and effort.

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