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Occurrence, Parasitization, and Sampling of *Liriomyza* Species (Diptera: Agromyzidae) Infesting Celery in California[1]

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ABSTRACT

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Liriomyza trifolii (Burgess) and *L. sativae* Blanchard were found in all of the major celery-producing counties in California. *L. trifolii* was the dominant species and reached economically damaging populations in Orange, Ventura, and Monterey Counties in 1981. Density of *L. trifolii* increased more than 100% in experimental celery plantings in Orange County from 1980 to 1981, but ca. 90% of the larvae were parasitized at harvest in both years. Estimation of parasitism by leaf examination was more efficient than calculation of parasitism from adult emergence. *Diglyphus* species were the most common parasites reared from leafminers, but *Halticoptera circulus* Walker, predominated in samples collected with a suction machine. *L. sativae* were more numerous than *L. trifolii* in suction samples but not in concurrent rearing tests.

Liriomyza trifolii (Burgess) is a polyphagous agromyzid which mines the leaves of a variety of economically important plants, including celery, tomatoes, and chrysanthemums (Spencer 1973). This leafminer was probably introduced into California from Florida (Parrella et al. 1981, Spencer 1981) and has recently begun to cause economic losses to California's celery industry (Trumble 1981).

Previously, the only agromyzid attacking celery in California was *L. sativae* Blanchard, which reached damaging population levels on a 5- to 10-year cycle but was readily controlled with pesticides. An extensive survey of California conducted by Spencer (1981) in 1977 to 1978 found that *L. trifolii* did not occur outside of greenhouses used for chrysanthemum production. Previous reports of *L. trifolii* occurring in field crops in California (Frick 1959) have since proven incorrect (Spencer 1965, Parrella 1982). Based on this information, one objective of this study was to document the occurrence of *L. trifolii* in the major celery-producing areas in California.

Parasites are viable alternatives to pesticides for leafminer suppression in several crops. Hills and Taylor (1951) stated that leafminer pests of cantaloupes and lettuce in Arizona sustained high levels of parasitism in the absence of pesticides. Jenson and Koehler (1970) reported similar results for *L. sativae* (as *L. munda* Frick) infesting spring alfalfa in the Sacramento and San Joaquin Valleys of California. Parasites also appear promising for controlling both *L. sativae* and *L. bryoniae* Kalt. on greenhouse tomatoes (Hendricks et al. 1980, McClanahan 1980). In southern California, *L. sativae* mining tomato foliage only reached economic levels when their associated parasites were killed by the application of pesticides (Oatman and Kennedy 1976, Johnson et al. 1980). Additional objectives of our research were to document the incidence of leafminer parasites of *Liriomyza* species infesting celery, to ascertain which beneficial species were dominant, and to determine if a suction device could be used to quantitatively estimate field populations of leafminers and parasites in celery.

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Materials and Methods

Leafminer Survey

Preliminary surveys in central and southern coastal counties in California were made on an irregular basis during 1980. Although celery is grown throughout the year in California, our observations and reports of economic losses indicated that leafminer populations peak in the late summer and fall, and subsequent surveys were made during this time. A statewide survey of the major celery-producing counties was conducted during August 1981. Two or more fields in each county which were separated by at least 5 km were examined for leafminer damage. The presence of *L. trifolii* was documented by rearing flies from leaf samples. Additional weekly or monthly surveys were made during 1981 in counties where growers reported economically damaging infestations.

Field Biology Studies

Leafminer experiments were conducted in two 0.4-ha fall plantings of 'Tall Utah 5270-R' celery during 1980 and 1981 at the University of California's South Coast Field Station in Orange County. This field station is located within one of the major celery-producing areas of California. Celery seedlings were transplanted into double-row beds, sprinkle irrigated for 2 weeks, and furrow irrigated thereafter. Individual plants were separated by 15 cm, and row centers were 101 cm apart. The 1980 crop was transplanted on 13 August and harvested the third and fourth weeks of November. The 1981 crop was transplanted on 4 August and harvested the second and third weeks of November. No pesticides were applied to either crop. Maximum and minimum temperatures were monitored daily.

Height, number of petioles, and number of mined trifoliolates were recorded weekly for 50 plants, using a stratified-random sampling plan. Sampling began 4 and 2 weeks after transplanting in 1980 and 1981, respectively. One trifoliolate was removed from each of the upper and lower halves of each plant. These leaves were immediately sealed in tightly capped plastic petri dishes and transported to the laboratory. Each trifoliolate was examined under a dissecting microscope with substage lighting for number of empty mines, active larvae, dead larvae, parasitized larvae, and parasite pupae. Leaves were resealed in the petri dishes and stored at room temperature (22 to 26°C). After 1 month, all emergent leafminers and parasites were classified and counted.

Because morphological similarities have confused the taxonomic status of some members of the genus *Liriomyza* Mik (Parrella 1982), the leafminers collected during this study were identified with electrophoresis and scanning electron microscopy (Zehnder et al., in press), and representative specimens were subsequently confirmed by G. Steyskal, Systematic Entomology Laboratory, Entomology Res. Div., USDA, Washington, D. C., and by K. A. Spencer, Exwell Farm, Bray Shop, Collington PL17 8QJ, Cornwall, Great Britain. Voucher specimens have been deposited in the reference collection of the University of California, Riverside. Parasites were identified by E. E. Grisell, Systematic Entomology Laboratory, Entomol. Res. Div., USDA, Washington, D. C., and by J. Wooley and J. LaSalle, Div. Biological Control, University of California, Riverside.

Suction Sampling

Leafminers and parasites were collected weekly in 1980 from our experimental celery planting, using a D-Vac model 1A suction machine equipped with the standard 33-cm-diameter intake aperture and operated with the throttle fully open. Air intake was ca. 2.5 m^3/min. Ten collections per week, each consisting of the insects captured with 5-sec suction samples from 10 randomly selected plants, were sorted by species with a dissecting microscope, and counts were recorded.

Statistical Analysis

Means and SEs were generated by the Proc means procedure of Statistical Analysis Systems (SAS) (Helwig and Council 1979).

Percent parasitization observed in the larval stage was calculated by dividing the number of parasitized larvae by the number of parasitized larvae plus the number of active larvae. This value represents the percent parasitism for living larvae only, since dead larvae were not included. Percent parasitism based on adult emergence was assessed by dividing the total number of adult parasites by the number of emergent adult leafminers plus the total number of adult parasites. This analysis provides data similar to the "parasitism of the pupae" value suggested by Harding (1965), and serves to eliminate the effects of disease, premature larval death due to constriction of wilting leaves, or other factors which might reduce larval survival.

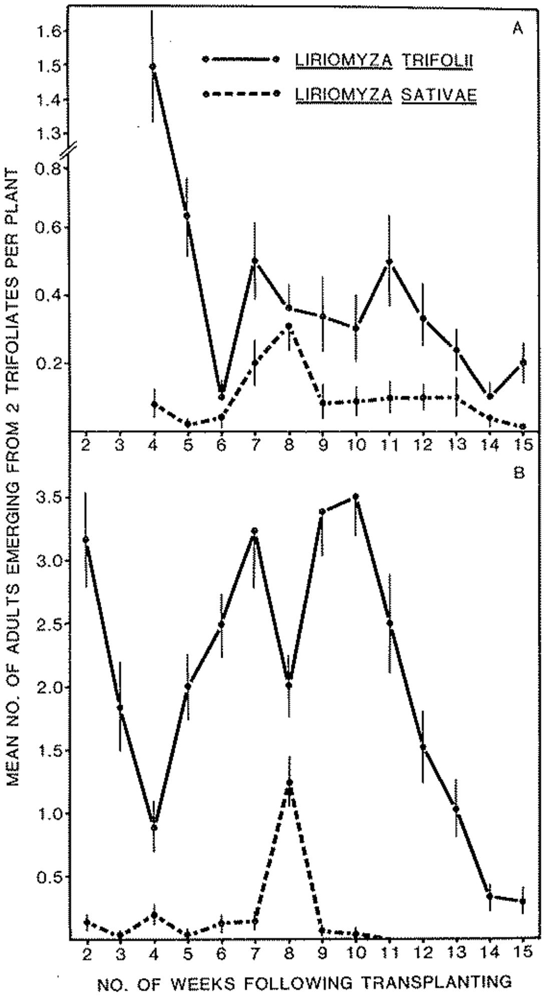

FIG. 1. Occurrence of *L. sativae* and *L. trifolii* in experimental plantings of celery in Orange County, Calif. in 1980 (A) and 1981 (B). Brackets on data points delineate SEs.

Results and Discussion

Leafminer Survey

L. trifolii was found in all of the major celery-producing counties in California. Growers and pest control advisors in some geographically isolated areas such as Oceana, Calif., reported that pesticide applications for leafminer suppression were unnecessary before the summer of 1981 when *L. trifolii* appeared. In Orange County, which is separated from other celery production areas by urban developments, extensive outbreaks of the new leafminer species occurred. Celery fields in Los Angeles County were not inspected, but *L. trifolii* was reared from transplants originating from commercial nurseries. In all areas except the northernmost county of San Benito, *L. trifolii* was more numerous than *L. sativae*. *L. trifolii* infestations in parts of the Salinas Valley, Ventura County, and Orange County required multiple pesticide applications, and in some fields celery petioles were mined. Feeding in the petioles is generally more destructive than mining leaves, since contaminated or damaged portions of the plant must be removed to ensure marketability.

Field Biology Studies

L. trifolii was the dominant leafminer species in fall celery plantings in Orange County, Calif., in both 1980

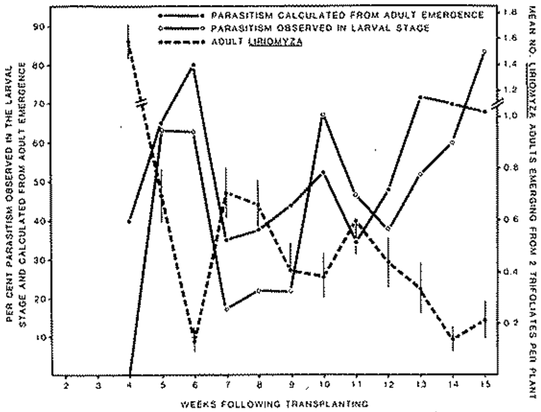

FIG. 2. Impact of parasitism on emergence of *Liriomyza* spp. adults from celery in Orange County, Calif., in 1980. See text for description of calculations. Brackets on data points delineate SEs.

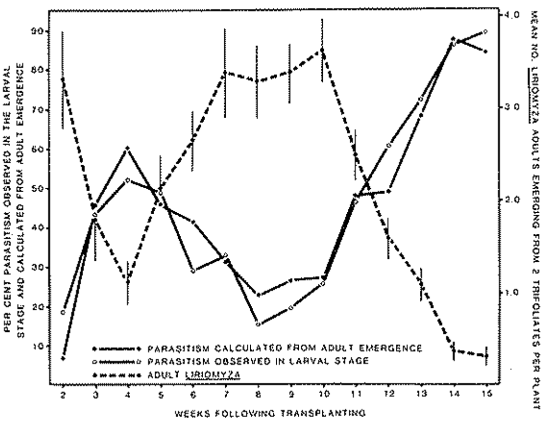

FIG. 3. Impact on parasitism on emergence of *Liriomyza* spp. adults from celery in Orange County, Calif., in 1981. See text for description of calculations. Brackets on data points delineate SEs.

and 1981 (Fig. 1). Populations of this species increased over 100% in 1981, reflecting a general increase in leafminer activity observed throughout the celery-producing areas in California. Some of the increase in field populations in 1981 can be attributed to an increased infestation in the transplants. However, since the transplants, the most advanced stage of growth retained by the nursery operation, contained only eggs and 1st-instar larvae at the time of planting, the celery was probably infested by flies migrating from nearby fields rather than by populations indigenous to the greenhouse. Thus, the population growth observed in 1981 was a function of the interaction between nursery stock and field populations, and it cannot be dismissed as simply a nursery problem. The rapid increase in leafminer populations in 1981 may have been due partially to warm temperatures and to the mild winter of 1981–1982.

Peak populations of *L. sativae* in celery at 7 to 8 weeks after transplanting coincided with the removal of nearby pole tomatoes (Fig. 1). The influx of *L. sativae* increased competition and cannibalism and may have caused the corresponding decrease in *L. trifolii* density. Similar intercrop migrations occurred in 1981 in Ventura County, where a field of tomato transplants was damaged by *L. trifolii* after harvest of an adjacent celery field (P. Phillips, personal communication).

The potential magnitude of leafminer migration after harvest was reduced in experimental celery plantings by hymenopterous parasites which parasitized ca. 84% of *Liriomyza* larvae in 1980 and ca. 90% in 1981 (Fig. 2 and 3). Percent parsitism calculated from adult emergence was similar to the percent parasitism observed during the larval stage, but an additional month was required before the data were available. Additionally, losses due to diseases or other factors suggested by Harding (1965) were minimal. Thus, the larval observation technique was more efficient, and therefore more suitable for the rapid decision-making process required by modern integrated pest management programs.

Although the commercially produced celery transplants used in experimental crops were already infested with *L. trifolii* at planting, naturally occurring parasites substantially reduced *Liriomyza* population growth by 4 to 6 weeks after transplanting (Fig. 2 and 3). In 1981, leafminer density increased at 6 to 7 weeks after transplanting and was not effectively reduced until a few weeks before harvest. During this period, plant growth was rapid (Table 1), and leafminer damage was consequently not as severe as that of similar infestations on the small transplants.

The parasites reared from *L. trifolii* and *L. sativae* in celery leaves included species in the families Eulophidae: *Diglyphus intermedius* (Girault) (n = 470), *D. begini* (Ashmead) (n = 413), *Chrysonotomyia* (*Achrysocharella*) *punctiventris* (Crawford) (n = 201), *Chrysocharis parksi* Crawford (n = 116), *C. ainsliei* Crawford (n = 18); Pteromalidae: *Halticoptera circulus* (Walker) (n = 51), and Brachonidae: *Opius* spp. (n = 11). Except for *C. punctiventris*, these species were also reared from *L. sativae* mining alfalfa in northern California (Jensen and Koehler 1970). Figure 4 shows the relative abundance of each species occurring in 1980 and 1981. Since few specimens of *Opius* sp. were recovered (<1%), data on these species were not included in the analysis. Results presented here do not include the effects of *Opius* species, potential egg or pupal parasites, or predators such as chrysopid larvae, and are therefore conservative in estimation of total biological control.

Early-season (August and September) suppression of leafminers was achieved in both plantings by a complex of parasites, with no species accounting for more than 40% of the total (Fig. 4). *D. intermedius* and *D. begini* predominated in October and November. The shift in dominance from *D. intermedius* in 1980 to *D. begini* in early 1981 may have been due to an increase in acreage of adjoining tomato fields, since *D. begini* is the most abundant parasite of *L. sativae* attacking tomatoes (Johnson et al. 1980).

Table 1. Ambient temperatures and crop growth parameters for fall celery plantings in Orange County, Calif., during 1980 and 1981[a]

Year	Wk after transplanting	$\bar{x} \pm$ SD plant height (cm)	$\bar{x} \pm$ SD no. of petioles	$\bar{x} \pm$ SD weekly temp (°C)
1980	4	17.7 ± 3.7	4.0 ± 1.3	18.1 ± 0.9
	5	21.5 ± 3.5	6.7 ± 1.1	18.4 ± 1.2
	6	21.6 ± 4.7	8.7 ± 2.1	19.1 ± 2.5
	7	29.3 ± 5.7	12.4 ± 3.8	18.8 ± 1.9
	8	32.5 ± 4.5	15.7 ± 4.7	19.3 ± 1.3
	9	37.5 ± 5.2	18.5 ± 5.5	17.7 ± 1.2
	10	42.4 ± 4.4	22.0 ± 7.7	15.7 ± 2.8
	11	45.6 ± 4.0	22.0 ± 7.4	16.3 ± 2.2
	12	48.8 ± 5.9	27.3 ± 11.3	18.1 ± 1.1
	13	53.2 ± 5.1	25.0 ± 7.8	14.3 ± 1.2
	14	56.3 ± 4.7	26.5 ± 13.5	13.2 ± 1.1
	15	59.6 ± 5.1	30.8 ± 11.7	13.5 ± 1.7
1981	2	15.4 ± 3.1	2.3 ± 0.5	22.9 ± 1.8
	3	15.8 ± 4.1	2.6 ± 0.6	22.7 ± 0.6
	4	15.1 ± 3.4	3.7 ± 1.3	23.2 ± 2.0
	5	15.4 ± 3.9	5.3 ± 1.1	23.1 ± 2.5
	6	21.2 ± 3.6	8.0 ± 2.0	22.1 ± 1.2
	7	23.9 ± 5.0	11.4 ± 4.1	20.5 ± 0.6
	8	32.5 ± 5.3	18.2 ± 6.9	22.2 ± 1.7
	9	39.5 ± 5.3	23.8 ± 7.9	19.0 ± 0.6
	10	45.5 ± 5.6	25.7 ± 8.5	17.7 ± 0.6
	11	50.4 ± 4.7	29.8 ± 9.4	16.1 ± 2.5
	12	53.0 ± 5.2	28.4 ± 8.5	18.2 ± 3.4
	13	57.9 ± 4.9	32.7 ± 9.1	16.5 ± 1.1
	14	58.9 ± 5.3	26.7 ± 7.4	17.9 ± 3.8
	15	61.8 ± 4.2	36.5 ± 10.2	16.5 ± 1.3

[a]Based on samples of 50 randomly selected plants per week.

Suction Sampling

The suction machine collected a greater proportion of *L. sativae* than of *L. trifolii*, indicating that *L. sativae* was attracted to celery. Although *L. sativae* may be collected more readily than *L. trifolii*, due to differential behavior, use of suction devices, sweep-nets or other adult collection techniques cannot be assumed to provide accurate data on the composition of *Liriomyza* species infesting the crop in locations where alternate hosts are present and intercrop migration may occur. However, adult collection techniques have proven effective in Florida, Where celery is grown in large-acreage blocks (Genung et al. 1979).

Suction sampling was effective in collecting leafminer parasites. Although the same species were captured with the suction machine as were reared from leaf samples, the numerical superiority of *Diglyphus* species recorded from leaf samples was not evident (Fig. 5). Little information is available on the field biology of these parasites, and differences in flight ability or preferred resting areas may have influenced susceptibility to collection.

H. circulus was the most common species collected by the suction machine, averaging ca. 50% of the total parasite population. As observed for leafminers, the relative abundance of parasite species cannot be accurately determined by the suction device alone, due to intercrop movement. Because parasites in some of these genera kill hosts without ovipositing (Lema and Poe 1979), the importance of large adult populations of *H. circulus* and *C. parksi* cannot be discounted due to low larval density. Therefore, the survival of all parasite species occurring in the adult or larval stages, including adult immigrants, should be considered when assessing the effects of cultural or chemical control techniques on leafminer parasites.

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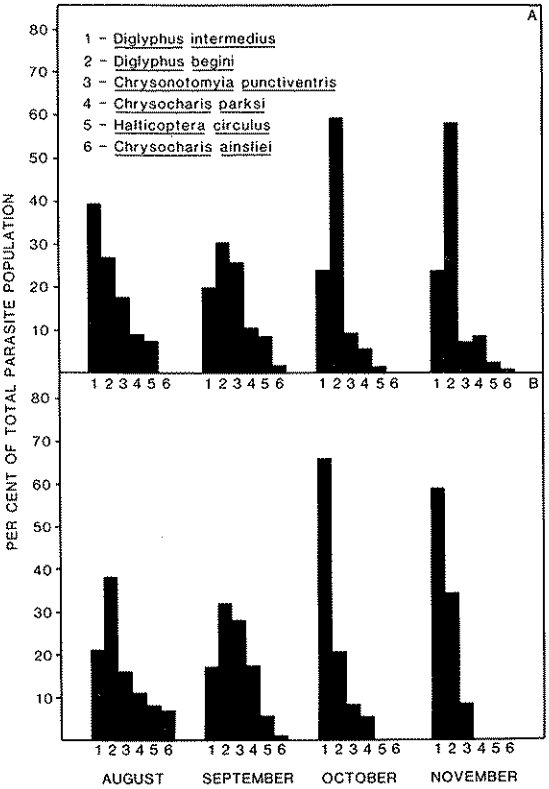

FIG. 4. Relative abundance of leafminer parasites reared from *Liriomyza* infesting celery in Orange County, Calif., in 1980 (A) and 1981 (B).

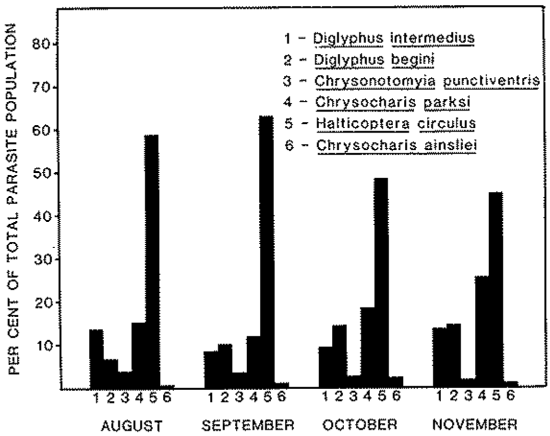

FIG. 5. Relative abundance of leafminer parasites collected by suction sampling in celery in Orange County, Calif., during 1980.

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