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# INTEGRATED PEST MANAGEMENT OF *LIRIOMYZA TRIFOLII*: INFLUENCE OF AVERMECTIN, CYROMAZINE, AND METHOMYL ON LEAFMINER ECOLOGY IN CELERY

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ABSTRACT

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The impact of weekly applications of avermectin, cyromazine and methomyl on *Lyriomyza trifolii* (Burgess) and an associated complex of six parasite species was evaluated in celery, *Apium graveolens* L. Avermectin suppressed leafminer populations, but did not adversely affect (1) seasonal per cent parasitism, (2) adult parasite mortality, or (3) survival and emergence of immature parasites from treated foliage. Although cyromazine use also reduced *L. trifolii* density, significant reductions in survival and emergence of immature parasites greatly diminished the potential for biological control by lowering the seasonal per cent parasitism and increasing the *L. trifolii*:parasite ratio. Methomyl application for control of lepidopterous larvae increased leafminer density and reduced the seasonal percent parasitism by reducing survival of adult parasites.

Species composition of the parasite complex was least affected by avermectin and methomyl. Cyromazine significantly reduced the relative abundance of some key parasite species. Major parasite species included species in the family Eulophidae: *Diglyphus intermedius* (Girault), *D. begini* (Ashmead), *Chrysonotomyia* (*Achrysocharella*) *punctiventris* (Crawford), *Chrysocharis parksi* Crawford and *C. ainsliei* Crawford, and the family Pteromalidae: *Halticoptera circulus* (Walker). The potential for incorporation of these compounds into an integrated pest management program for celery and tomatoes, *Lycopersicon esculentum* Mill., is discussed.

## INTRODUCTION

The relatively recent introductions of the polyphagous agromyzid, *Liriomyza trifolii* (Burgess), into Africa, Europe and western North America have resulted in serious economic losses on a variety of commercially produced vegetables and ornamentals (Spencer, 1973, 1981; Parrella, 1982). In response to the loss of effectiveness of many agricultural chemicals (Leibee, 1981), and the potential for rapid development of resistance to new compounds (Keil and Parrella, 1983), interest in the implementation of inte-

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grated pest management (IPM) programs which utilize biological control agents has increased.

The appeal of an IPM approach has been enhanced by reports of modern pesticides generating major outbreaks of *Liriomyza* species by disrupting the natural enemy complex. Hills and Taylor (1951) first documented this problem when they reported *Liriomyza* sp. populations (probably *L. sativae* Blanchard) increased and parasite numbers decreased following applications of DDT. Similar results were presented by Wene (1955) for DDT, methoxychlor, dieldrin, endrin and lindane, and by Getzin (1960) for parathion, ethion and diazinon. More recently, the disruptive influence of permethrin (Poe et al., 1978), methomyl (Oatman and Kennedy, 1976; Johnson et al., 1980a), and a variety of other compounds (Pohronezny et al., 1978; Lange et al., 1980) on parasite survival has been determined.

Since the introduction of *L. trifolii* into the celery-producing regions of western North America in the mid-1970s, economic losses attributable to pesticide-induced outbreaks have escalated to unacceptable levels (Trumble and Toscano, 1983). Therefore, the study reported here was conducted to determine if two promising new compounds for leafminer suppression, cyromazine and avermectin, could effectively be interfaced with natural control agents in an IPM program.

## MATERIALS AND METHODS

Experiments were conducted in two autumn plantings of celery (variety 5270-R) at the University of California's South Coast Field Station in Orange County, California, during 1982 and 1983. This coastal field station is located within one of the major celery-producing regions in the United States. Celery seedlings were transplanted into double row beds, sprinkler irrigated for two weeks, and drip-irrigated thereafter. Individual plants were separated by 15 cm, and row centers were 100 cm apart. The 1982 planting was transplanted on 4 August and harvested during the second and third weeks of November. In 1983, seedlings were transplanted on 10 August and harvested on 21 and 22 November.

A randomized complete block design incorporated four replicates of each treatment. Each plot was six rows wide by 15 m long and separated from other plots by 2 m of untreated celery. Weekly samples of the uppermost and lowermost mined leaves from each of four randomly selected plants per plot (32 leaves/treatment/week) were sealed in plastic containers and transported to the laboratory. This sampling design was patterned after previous research (Trumble and Nakakihara, 1983), which demonstrated that: (1) sampling unmined leaves containing oviposition punctures was unnecessary since no egg parasites were found, (2) sampling pupae was unnecessary since pupal parasites at this location accounted for less than 0.5% of the parasite-induced mortality, and (3) species composition was accurately reflected by sampling selected leaves. Each leaf was then examined for numbers of live larvae, dead larvae, parasitized larvae, and empty mines under a dissecting microscope equipped with substage lighting. Following examination, leaf samples were replaced in plastic containers and stored in the laboratory at 22—26°C. After 4 weeks, all emergent insects were identified and recorded.

When plants reached ca. 25 cm in height, four styrofoam trays (10 × 20 cm) were inserted between the two rows of celery plants in the center bed of each plot. Numbers of dead leafminer parasites of all species were recorded in trays on 27 October and 3 November during 1982, and weekly from 18 October to 8 November during 1983. Fewer samples were available during 1982 as rain interfered with collection by washing some insects from the trays.

Cyromazine (0.28 kg ai $ha^{-1}$ in 1982; 0.14 kg ai $ha^{-1}$ in 1983), avermectin $B_1$ (0.01 kg ai $ha^{-1}$), and methomyl (1.0 kg ai $ha^{-1}$), a pesticide commonly used in celery, were applied weekly using a tractor-mounted boom sprayer. As plant height and foliage density increased, nozzle number varied from 1 to 3 per row and carrier ($H_2O$) increased from 467 to 935 l $ha^{-1}$. All treatments except avermectin included 0.04% spreader-sticker. Both plantings received 11 applications.

## RESULTS AND DISCUSSION

Leafminer populations were significantly affected by chemical applications (Table I). In both plantings, the chitin inhibitor cyromazine and the suspected GABA inhibitor avermectin reduced leafminer density as compared to the untreated control, while methomyl use resulted in significantly higher larval numbers. Generally, more dead larvae and fewer empty mines were found in leaves from plants treated with avermectin and cyromazine than in leaves exposed to methomyl. The high numbers of empty mines occurring in leaves from plants where methomyl was applied reflected the success rate of the leafminer; more dead and parasitized larvae in the other treatments reduced the capacity for increase.

The seasonal per cent parasitism values, calculated by dividing the numbers of parasitized larvae in leaf samples by the number of live larvae plus parasitized larvae per sample, indicated that avermectin was the only chemical which did not adversely affect the biological control agents. Although dead larvae present in the leaf samples may have been killed as a result of adult parasite host-feeding, these larvae would produce neither leafminers nor parasites and were therefore excluded from the analysis. In 1983, when both leafminer and parasite populations were higher than in 1982, cyromazine applications significantly reduced the parasitism rates as compared to all other treatments.

Analogous results were produced when the insects were allowed to emerge from the leaf samples: the mean numbers of parasites per sample were lowest in the cyromazine treatments (Table II). However, since this simply may

TABLE I

Impact of pesticides on population development and parasitism of *Liriomyza trifolii* (Burgess) infesting celery in California, U.S.A., during 1982 and 1983[1]

| Treatment | Rate kg/ha | $\bar{X}$ no. live larvae/sample | $\bar{X}$ no. dead larvae/sample | $\bar{X}$ no. empty mines/sample | $\bar{X}$ no. parasitized larvae/sample | % parasitism[2] |
|---|---|---|---|---|---|---|
| 1982 | | | | | | |
| Cyromazine | 0.28 | 0.53 c | 2.92 a | 0.22 b | 0.05 b | 8.62 b |
| Avermectin | 0.01 | 0.61 c | 2.05 b | 0.11 b | 0.13 ab | 17.57 a |
| Methomyl | 1.00 | 1.66 a | 1.82 b | 0.37 a | 0.15 ab | 8.29 b |
| Control | — | 1.20 b | 2.10 b | 0.16 b | 0.21 a | 14.89 a |
| 1983 | | | | | | |
| Cyromazine | 0.14 | 2.30 bc | 3.46 a | 0.30 c | 0.11 c | 4.78 c |
| Avermectin | 0.01 | 1.94 c | 2.43 b | 0.40 bc | 0.42 b | 17.80 a |
| Methomyl | 1.00 | 3.17 a | 2.26 b | 0.98 a | 0.41 b | 11.45 b |
| Control | — | 2.78 b | 2.51 b | 0.55 b | 0.77 a | 21.69 a |

[1]Sample = 2 trifoliates/plant, 16 plants/treatment/week for 11 weeks of sampling; means in columns within the same year followed by the same letter are not significantly different at the $P \leqslant 0.05$ level, Duncan's new multiple range test.
[2]Arcsine transformation prior to analysis.

TABLE II

Influence of cyromazine, avermectin and methomyl on the emergence of *L. trifolii* and associated parasites from celery

| | 1982 | | | 1983 | | |
|---|---|---|---|---|---|---|
| Treatment | $\bar{X}$ parasites/sample[1] | $\bar{X}$ *L. trifolii*/sample | Ratio of emergent *L. trifolii*/parasites[2] | $\bar{X}$ parasites/sample[1] | $\bar{X}$ *L. trifolii*/sample | Ratio of emergent *L.trifolii*/parasites[2] |
| Cyromazine | 0.039 b | 0.046 c | 1.18 b | 0.097 c | 0.715 c | 7.37 a |
| Avermectin | 0.125 b | 0.176 c | 1.41 b | 0.276 bc | 1.051 c | 3.80 b |
| Methomyl | 0.480 a | 2.231 a | 4.65 a | 0.431 b | 3.363 a | 7.80 a |
| Control | 0.577 a | 1.771 b | 3.07 ab | 0.624 a | 2.593 b | 4.16 b |

[1]Sample = 2 trifoliates/plant, 16 plants/treatment/week for 11 weeks of sampling; means in columns followed by the same letter are not significantly different at the $P \leqslant 0.05$ level, Duncan's new multiple range test.
[2]Arcsine transformation prior to analysis.

have been a function of fewer leafminers in the foliage providing hosts for fewer parasites, the ratio of emergent leafminers to emergent parasites also was calculated. In 1982, best results were found in the treatments cyromazine and avermectin with ratios of nearly 1:1, and 1.5:1, respectively. In 1983, when the rate of cyromazine application was reduced to the level currently recommended for celery in the United States, the ratio of emergent *L. trifolii*:parasite was much less favorable, reaching ca. 7.4:1. Since both avermectin and the control generated significantly lower ratios than cyromazine, these data suggest a differential susceptibility to cyromazine for leafminers and parasites, with relatively more leafminers surviving at the lower dosage. These ratios of leafminers to parasites are of considerable importance as indicators of what level of biological control can be expected, and, combined with efficacy data, will translate ultimately into the number of applications that will be needed.

Information on live larvae per sample from Table I and the numbers of dead parasites per tray from Table III indicate that the action of methomyl was primarily on the adult parasites, while cyromazine affected only the immature stages. Thus, while avermectin has the broadest overall promise for integration into a pest management program, the activity of the other compounds on specific life stages suggests alternative uses. For example, applications of methomyl for lepidopterous pests could be followed 24—48 h later with inundative or inoculative releases of parasites. Cyromazine might be used to control irregular or periodic outbreaks of leafminers in greenhouse or field situations where interference in systems with other unaffected insects such as *Spodoptera* sp. or *Heliothis* sp. is undesirable (Schuster and Everett, 1983; Waddill, 1983).

TABLE III

Effect of pesticides on mortality of adult parasites of *L. trifolii* in experimental plantings of celery in 1982 and 1983[1]

| Treatment | 1982 | | 1983 | | | |
|---|---|---|---|---|---|---|
| | Oct. 27 | Nov. 3 | Oct. 18 | Oct. 26 | Nov. 1 | Nov. 8 |
| Cyromazine | 1.5 b | 4.5 b | 0.0 b | 0.0 b | 0.0 b | 0.0 b |
| Avermectin | 1.5 b | 2.5 b | 0.5 b | 0.4 b | 0.0 b | 0.3 b |
| Methomyl | 5.9 a | 9.7 a | 4.6 a | 2.0 a | 7.1 a | 5.6 a |
| Control | 0.6 b | 3.2 b | 0.5 b | 0.7 b | 0.4 b | 0.4 b |

[1]Values are mean numbers of dead parasites in 16 trays/treatment/date; includes all species of adult parasites of *L. trifolii*, see Tables IV and V for species; means in columns followed by the same letter are not significantly different at the $P \leqslant 0.05$ level, Duncan's new multiple range test.

The species composition of parasites emerging from celery leaves was influenced by pesticide application (Tables IV and V). Species fluctuations seen for cyromazine treatments between 1982 and 1983 may be due, in part, to the extremely low numbers of parasites reared in 1982, which caused large percentage differences for species consisting of relatively few specimens. However, in spite of the higher density of parasites in 1983, cyromazine eliminated *Chrysocharis parksi* Crawford during both years. Even though *C. parksi* is of minor importance as a biological control agent for *L. trifolii* on celery, this parasite is the primary natural control agent on tomatoes (Johnson et al., 1980b; Zehnder and Trumble, 1984). Thus, cyromazine may have less potential for incorporation into an integrated pest management program for *Liriomyza* species on tomatoes than on celery.

TABLE IV

Species composition of leafminer parasites emerging from celery treated with selected pesticides in 1982

| Treatment | Percent of total parasites[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *Diglyphus* species | | | *Chrysocharis* species | | | *Halticoptera circulus* | *Chrysonotomyia punctiventris* |
| | *D. intermedius* | *D. begini* | Total | *C. parksi* | *C. ainsliei* | Total | | |
| Cyromazine | 57.15 a | 0.00 c | 57.15 a | 0.00 b | 0.00 b | 0.00 b | 28.56 a | 14.28 a |
| Avermectin | 40.91 b | 18.18 a | 59.09 a | 18.18 a | 18.20 a | 36.38 a | 0.00 b | 4.54 bc |
| Methomyl | 57.83 a | 7.22 b | 65.05 a | 13.25 a | 16.87 a | 30.12 a | 2.41 b | 2.41 c |
| Control | 55.45 a | 7.92 b | 63.37 a | 15.84 a | 10.89 a | 26.73 a | 1.98 b | 7.92 b |

[1]Arcsine transformation prior to analysis; means in columns followed by the same letter are not significantly different at the $P \leqslant 0.05$ level, Duncan's new multiple range test.

TABLE V

Species composition of leafminer parasites emerging from celery treated with selected pesticides in 1983

| Treatment | Percent of total parasites[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *Diglyphus* species | | | *Chrysocharis* species | | | *Halticoptera circulus* | *Chrysonotomyia punctiventris* |
| | *D. intermedius* | *D. begini* | Total | *C. parksi* | *C. ainsliei* | Total | | |
| Cyromazine | 61.11 a | 22.22 a | 83.33 a | 0.00 c | 5.56 b | 5.56 c | 11.11 a | 0.00 b |
| Avermectin | 55.55 a | 25.92 a | 81.47 a | 1.85 b | 5.54 b | 7.39 bc | 1.85 b | 9.26 a |
| Methomyl | 58.54 a | 12.19 b | 70.73 a | 9.75 a | 10.98 a | 20.73 a | 0.00 b | 8.54 a |
| Control | 74.58 a | 10.17 b | 84.75 a | 4.23 b | 5.93 b | 10.16 b | 0.85 b | 4.24 a |

[1]Arcsine transformation prior to analysis; means in columns followed by the same letter are not significantly different at the $P \leqslant 0.05$ level, Duncan's new multiple range test.

Although avermectin significantly reduced the occurrence of *Diglyphus intermedius* (Girault) in 1982, losses were compensated for by an increase in the relative dominance of *D. begini* (Ashmead). The total percentage of the two species in the genus *Diglyphus*, the key parasites of leafminers on celery (Trumble and Nakakihara, 1983), was not adversely affected by any pesticide in either year. *Chrysocharis ainsliei* Crawford, *Halticoptera circulus* (Walker) and *Chrysonotomyia punctiventris* (Crawford) populations varied widely between treatments and years, but *H. circulus* proved more tolerant of cyromazine.

## CONCLUSION

Based on this research avermectin was the most suitable compound tested for integration into a pest management program for *L. trifolii* on celery. Since avermectin had a minimal effect on both the adult and larval stages of parasites, this chemical could be applied as needed in either greenhouse or field situations without inducing undesirable fluctuations in the parasite population. Although cyromazine did not adversely affect adult parasites, losses occurring following application to leaves containing immature parasites were significant. Thus, use of this compound not only reduced the potential for biological control, but could cause substantial oscillations in parasite density. Additionally, cyromazine use caused a shift in the species composition of the parasites: *Chrysocharis parksi*, the key parasite occurring in tomatoes, was eradicated. Therefore, cyromazine appears to offer even less promise for an integrated pest management program for tomatoes. The application of methomyl for control of lepidopterous larvae in celery should be minimized, as this pesticide increased leafminer survival and density by causing a high level of mortality in the adult parasites.

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