Planning ahead for leafminer control

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Rotating control compounds may delay development of resistance

California celery growers lost approximately $20 million in the last half of 1984 as a result of the leafminer, *Liriomyza trifolii* (Burgess). Two factors were related to this unusually severe economic impact: (1) no chemicals registered in California during this period offered reliable suppression of the leafminer populations, and (2) studies on celery growth and development clearly documented an unexpected increase in time to harvest, which was attributable directly to the leafminer.

Leafminers were previously believed to cause economically significant damage to celery only at very high population densities. When large populations occurred on transplants, the fields were disked under, resulting in substantial losses. More typically, high densities caused enough leafmining to require trimming the plants shorter than normal or removing damaged stalks before marketing the celery. Research at the University of California, Riverside, however, has shown that even moderate infestations can significantly increase the time needed for the plants to reach harvestable size. Since many California growers plant immediately after the celery-free period in order to harvest for the high-price markets during the Thanksgiving and Christmas holidays, delays of more than a week or two can be extremely costly.

In studies investigating the influence of the leafminer on celery physiology, the photosynthetic activity of leaves on 20 celery plants was "mapped" by a dual-isotope porometer. These tests showed that uniformly grown greenhouse plants were not comparable. In fact, different petioles or stalks within the same plant were often significantly different in rates of photosynthesis. Fortunately, the first and second opposite pairs of leaves on the young, vertical stalks were comparable, and these were used to measure the physiological effects of feeding/egg-laying punctures by adults and mining by larvae.

In the first experiment, pre-egg-laying females were confined to one of a pair of opposite leaves and allowed to feed on them for various time intervals. Analysis (paired comparison t-test) of over 120 comparisons indicated that photosynthesis was significantly reduced when punctures exceeded about 20 per square centimeter.

In the second test, females were allowed to lay eggs for only a brief period on one of a pair of leaves; only one larva was permitted to develop subsequently. Statistical analysis of 60 pairs of damaged-undamaged leaves showed that a single leafmine reduced photosynthesis by approximately 40 percent.

Field experiments

Field trials were then begun to determine if this large reduction in photosynthetic activity led to reduced plant growth and development. Leafminer densities were manipulated with selected pesticides in an experimental planting of 52-70HK celery at the UC South Coast Field Station, Irvine. Previous research had shown that application of methomyl, a broad-spectrum carbamate, would increase the number of mined leaves per plant by more than 75 percent, as compared with applications of methamidophos, an organophosphate. Methomyl was therefore applied weekly at 1 kilogram per hectare to increase leafminer populations, and methamidophos at 1.1 kilograms per hectare to reduce their density. Small plugs and bare-root transplants were included in the trial, since these represent the smallest and largest forms of celery that have been transplanted in California.

Each chemical treatment and plant size was replicated four times in a randomized complete block design. Replicates were four beds wide (two rows of celery per bed) by 20 meters. Plant growth was evaluated weekly for the first eight weeks, and then weight and size classes were recorded at harvest (16 to 19 weeks).

Leafminer density, as measured with pupal trays, was significantly higher on all sampling dates in the replicates treated with methomyl (fig. 1). Plant growth was significantly slowed for both plugs and transplants exposed to the moderate leafminer infestations that developed (table 1). The first plants to reach harvestable size were the bare-root transplants protected from leafmining with methamidophos. Plugs in this chemical treatment reached an equivalent size two weeks later. Within each transplant technique, plants exposed to higher pest populations achieved an equivalent size only after an additional three weeks.

The results were striking enough that a test was designed to determine if the chemicals themselves could be increasing or decreasing photosynthesis. Since neither compound affected photosynthesis at 1.5 hours or seven days following application, plant growth differences have been ascribed to the effects of leafminers.

Alternative control measures

Losses associated with leafminer damage escalate dramatically when chemical resistance develops or effective pesticides are not available. In Florida, where leafminers have reduced celery production by nearly 50 percent in the past five years,

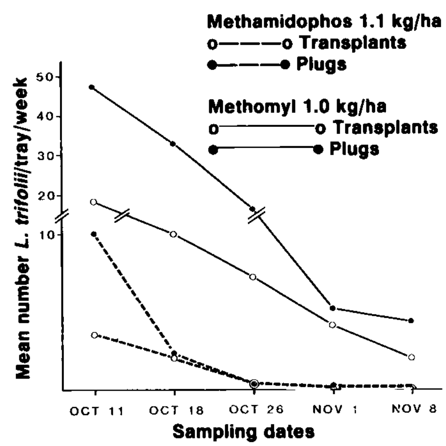

Fig. 1. Leafminer density was significantly higher in methomyl-treated plots than in methamidophos plots.

they have demonstrated high levels of resistance to pesticides in most of the major chemical groups, including chlorinated hydrocarbons, organophosphates, carbamates, and pyrethroids. Experience in Florida has also shown that the exclusive use of a single chemical causes resistance to develop rapidly, often within two years.

In research to find alternative control measures, experiments on untreated celery at the South Coast Field Station have shown that a complex of six parasites from the families Eulophidae and Pteromalidae can provide a substantial level of leafminer suppression. The parasites provided economic levels of control for a brief period early in the season and again just before harvest. Although limited in duration, this control was of considerable value. Reduction in early-season pest densities slowed the potential growth rate of the leafminer. Late-season parasitism reaching nearly 90 percent prevented the migration of large numbers of leafminers during harvest; such mass movements can cause significant losses in unharvested portions of fields or in adjoining crops.

Available chemicals were then evaluated for potential compatibility with the biological control agents and for effects on leafminers, based on weekly counts from four pupal trays per replicate (16 trays per treatment). Treatments were replicated four times in randomized complete block designs during 1981-83. Each replicate (four per treatment) was 15 meters long by six rows wide, and was treated weekly with pesticides. Leaves were collected weekly from plants in each replicate and held in the laboratory for one month to allow emergence of leafminers and parasites. Avermectin b1, methamidophos and cyromazine proved very effective for leafminer control, but cyromazine significantly reduced parasite populations.

An integrated pest management (IPM) program was then designed based on the three effective chemicals, of which only methamidophos is registered for use on celery in California. The IPM approach plans ahead for managing resistance and maximizing biological control. The three chemicals have been extensively tested in California on several crops; all have proved effective for leafminer control on celery. The current status of these pesticides in the registration process varies, but all have been used previously on celery or have been submitted for registration on other crops.

Chemicals used for leafminer suppression in the past have lasted longest when applied in rotation. The three compounds could function in a rotation system if used during the proper stage of plant growth and only "as needed." First cyromazine would be applied outside the greenhouse when plants are hardening and in the field during the first week after transplanting — a sensitive stage, when protection against leafminers in important. During this time, usually only leafminer eggs and first-stage larvae are present, neither of which are suitable hosts for the parasites.

The second chemical, methamidophos, would be used up to eight weeks after transplanting. Research has shown that this compound has only a minor impact on the leafminer parasites, so that they would continue to increase during this period. Registration for this chemical in California was withdrawn during the summer and early fall of 1984, because residue tests found levels above the legal 1 part per million. Subsequent studies in Orange County, California, have indicated that a three-week preharvest interval can reduce residues to below the legal maximum, and registration was reinstated. In the proposed rotational program, application of this chemical during the first eight weeks after transplanting, when no harvestable plant material is being produced, would provide a preharvest interval of six to eight weeks.

The celery plantings could be protected during the last seven to eight weeks with avermectin b1. This pesticide breaks down very rapidly (usually in about two days for most of the compound under field conditions), has essentially no direct toxicity or effect on the composition of the leafminer parasite complex, and shows excellent efficacy against the leafminer. These attributes allow maximum benefit from the biological control agents that inhibit the buildup of damaging leafminer populations late in the season.

Rotating these compounds can delay development of resistance in the leafminer. This combination of chemicals would also rotate the modes of action against the pest, which may prove to be critical in managing the development of resistance to insecticides. Cyromazine is believed to act as an insect growth regulator, specifically as a chitin inhibitor; leafminer larvae are prevented from developing a new outer skin and cannot molt successfully. Methamidophos, like most organophosphates, inhibits nerve-to-nerve transmission. Avermectin b1 is thought to cause paralysis by interfering with nerve-muscle communication. Thus, each compound is selecting for a different type of resistance during a specific stage of each crop.

If resistance to one of the compounds begins to develop, it is hoped that populations of leafminers with resistant genes would be reduced by the other chemicals. In addition, when the chemical in question is not used for an extended period, the pressure for maintaining the genes necessary for resistance would be eliminated, and normal attrition would help reduce the frequency of resistant individuals. Finally, since the parasites attack the leafminers independently of any genetic resistance to the pesticides, further losses of resistant stock in the leafminer population would be expected. Therefore, this system could remain effective for an extended period.

TABLE 1. Effect of leafminer density on leaf production and plant height for celery plugs and transplants

Sampling	Methomyl		Methamidophos	
date	Plugs	Transplants	Plugs	Transplants
	Mean no. leaves per plant			
Aug: 25	10	31	12	26
Sep: 1	12	37	16	40
8	15	38	24	48
15	19	62	35	86
22	37	67	44	124
29	45	123	55	166
Oct: 6	83	184	100	231
13*	113 a	212 c	163 b	240 d
	Plant height (cm)			
Aug: 25	4.0 a	14.5 b	3.5 a	15.0 b
Sep: 1	4.5 a	15.5 b	4.0 a	13.0 b
8	4.5 a	15.0 b	6.0 a	15.5 b
15	5.5 a	17.5 b	7.5 a	21.0 b
22	9.0 a	22.0 b	12.0 a	28.5 c
29	13.0 a	35.0 b	14.0 a	38.5 b
Oct: 6	18.5 a	39.5 c	22.5 b	46.0 d
13	22.5 a	49.0 c	31.0 b	53.5 d

*Means across rows followed by the same letter are not significantly different at the $P \leq 0.05$ level, Duncan's new multiple range test.

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Drs. I. P. Ting and L. Bates, Department of Botany and Plant Sciences, UC Riverside, provided information on the proper use of the porometer as well as access to the syntillation counter. The author gratefully acknowledges the help of H. Nakakihara, W. Carson, J. Feaster, T. Perring, and J. Morse. This research was supported in part by grants from the California Celery Advisory Board.