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CONTROL OF *LIRIOMYZA TRIFOLII* (BURGESS) (DIPTERA: AGROMYZIDAE) USING VARIOUS INSECTICIDES

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Abstract. **The leafminer, *Liriomyza trifolii* (Burgess) is an important pest affecting vegetable crops in South Florida. It is highly capable of developing resistance to insecticides. Studies were conducted with various compounds in an effort to devise the best control strategy of leafminer on vegetable crops. Abamectin and Spinosin provided excellent control of leafminers on 'Pod Squad' beans. Indoxacarb alone provided poor control of this pest; however, in combination with Agri-Dex®, indoxacarb provided significant control of leafminers larvae and pupae. Indoxacarb in combination with certain surfactants was equally effective to the first, second and third instars of leafminer on 'Pod Squad' beans. An increase in the level of leafminer control was achieved when azadirachtin was applied in combination with Agri-Dex®, Silwet® and Jointventure®. Among nonionic surfactants, Kinetic® and Cohere® significantly reduced leafminer larvae. Thiamethoxam applied at the rates of 4 and 8 oz/acre provided significant reduction of leafminers on tomatoes during 4 weeks of sampling. Indoxacarb did not affect emergence of the leafminer parasite, *Diglyphus* sp., whereas indoxacarb in combination with various surfactants significantly reduced leafminer parasites. This information has important bearings to the vegetable growers of south Florida. Based on this information, growers will be able to use environmentally benign insecticides in rotation with abamectin and spinosin to achieve better control of leafminers, protect natural enemies and retard the development of insecticide resistance.**

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The leafminer, *Liriomyza trifolii* (Burgess), is an important pest affecting tomato and other vegetable crops in south Florida although it is considered secondary in nature (Johnson et al., 1980; Oatman and Kennedy, 1976; Zoebisch et al., 1984;). *L. trifolii* is the predominant pest species on commercial freshmarket tomatoes grown on the Gulf Coast of Florida (Schuster, 1985). Up to 90% of tomato foliage may be lost if populations increase uncontrolled (Schuster, 1978).

The leafminer infests various vegetable crops each year with variable degrees of infection (Schuster, unpublished data). The vegetable growers of south Florida cope with this problem by applying chemical insecticides, e.g. abamectin, cyromazine, and azadirachtin (Seal, unpublished data). Frequent use of the same insecticides causes the target pest to develop resistance, and by the decimation of natural enemies causes the appearance of new pests. In addition, the resurgence of the target insect and the outbreak of secondary pest have been documented.

The beet armyworm *Spodoptera exigua* (Hubner) and the tomato fruitworms *Helicoverpa zea* (Boddie), primary pests of tomato, must be controlled to meet marketable standards (Oatman and Platner, 1971). Growers may use broad spectrum insecticides, such as methomyl (Lannate®, E. I. Du Pont De Nemours and Co., Wilmington, Del.) to achieve such standard (Oatman and Kennedy, 1976). Use of methomyl on tomatoes has resulted in increased numbers of leafminers due to decreased numbers of natural enemies.

An important part of the biology of *Liriomyza* is the ability to develop resistance to insecticides (Parrella, 1987), a capacity that has contribute to the failure in the control of leafminers (Genung, 1957; Parrella and Keil, 1984; Wolfenbarger, 1958). The strong capability of *L. trifolii* to develop resistance to insecticides made it possible to displace *L. sativae* on several crops (Schuster and Everett 1982; Zehnder and Trumble, 1982). It was also demonstrated that *L. trifolii* is more tolerant to insecticides than other Agromizid species (Lindquist et al., 1984; Parrella and Keil, 1985).

Spinosin and abamectin are two novel insecticides that provide satisfactory control of leafminers (Seal, 1998; Stansly and Conner, 1998). To avoid development of resistance in leafminers, other management practices need to be included in the management program against leafminers. In the present study, we evaluated effectiveness of indoxacarb (oxadiazinon insecticide) and azadirachtin (botanical insecticide) alone or in combination with various nonionic surfactants. The use of thiamethoxam and imidacloprid (two nicotinoid insecticides) at planting as a soil drench will also be evaluated in managing leafminers.

Materials and Methods

Several experiments were conducted in both laboratory and field conditions to determine effectiveness of indoxacarb (Avaunt® WG, E.I. Du Pont De Nemours and Co., Wilmington, Del.), azadirachtin (Neemix® 4.5, Thermo Trilogy Corp., Columbia, Md.) and thiamethoxam (Platinum™ 2SC, Syngenta Crop Protection, Inc., Greensboro, N.C.) in controlling leafminers on beans and tomatoes. Effect of various nonionic surfactants in combination with indoxacarb and azadirachtin in causing differential mortality of leafminers was also studied. In the first study, 'Pod Squad' beans (*Phaseolus vulgaris* L.) were directly seeded on 10 Dec. 2001 at a commercial farm located at Homestead, Fla. Soil type was Rockdale fine gravely loam with pH 7.0 - 7.3. Seeding operation was conducted using a tractor-mounted two-row seeder planting 8 seeds per ft. Plots consisted of three rows 30 ft. long and were arranged in a randomized complete block design with four replications. A 5 ft. unplanted buffer zone separated each replication. Treatments evaluated were: 1) Indoxacarb (0.065 lb. [a.i.]/acre); 2) Indoxacarb (0.065 lb.[a.i.]/acre) in combination with Kinetic® (0.09%, Helena Chemical Co., Memphis, Tenn.); 3) Indoxacarb (0.065 lb.[a.i.]/acre) in combination with Silwet L-77® (0.06%, Helena Chemical Co., Memphis, Tenn.); 4) Indoxacarb (0.065 lb.[a.i.]/acre) in combination with Agri-Dex® (0.5%, Helena Chemical Co., Memphis, Tenn.); 5) Indoxacarb (0.065 lb.[a.i.]/acre) in combination with Cohere® (0.25%, Helena Chemical Co., Memphis, Tenn.); 6) Indoxacarb (0.065 lb.[a.i.]/acre) in combination with Joint Venture® (0.25%, Helena Chemical Co., Memphis, Tenn.); 7) Indoxacarb (0.065 lb.[a.i.]/acre) in combination with Induce® (0.125%, Helena Chemical Co., Memphis, Tenn); 8) Abamectin (Agri-Mek® 0.15EC, 8 oz/acre, Syngenta Crop Protection, Inc., Greensboro, N.C.); and 9) a nontreated control.

All treatments were applied on three dates on 22 Dec. 2001, 1 and 5 Jan. 2002 using a backpack sprayer with two nozzles per row delivering 70 gal/acre at 30 psi. Treatments were evaluated 24-48 h after each application by randomly collecting 10 leaves, one leaf per plant, from the middle stratum of each plant located in the center row of each treatment plot. The leaves were then checked within 48 h of collection in the laboratory for leafminer larvae and mines using a binocular microscope (10X). After checking, leaves were placed in Petri dishes at room temperature (28 ° ± 1.5 °C) for 7-10 d for further development into pupae and adults. The numbers of parasitoid adults emerged were also recorded.

In the second study, simultaneously with the field study, a bioassay of various treatments as described above was conducted in the laboratory. A 16-d-old 'Pod squad' bean field with leafminer infestation was used for the bioassay study. The beans were maintained following recommended management practices. No insecticides were used for controlling insects to avoid any unwanted impact on the present study. Ten leaves in four replicates for a treatment, each with variable instars of leafminer, were collected and brought to the laboratory for use in the bioassay study. Variable instars of leafminer were identified based on the black sclerotized mouthhooks which were left within the mines after molt (Tauber and Tauber, 1968).

Four ounces of each treatment solution were prepared using distilled water and applied at appropriate rate of each insecticide using a dilution factor of 100 gal/acre. Each set of 40 leaves for each treatment were then dipped into the insecticide solution and placed separately on a polyethylene sheet to air-dry the leaves. The leaves (10 per Petri dish) were then placed in Petri dishes (9.5 cm diam.) with the bottom covered with a moistened filter paper to avoid desiccation of the leaves. The Petri dishes were placed on a table at a room temperature (28 ° ± 1.5 °C) in a randomized complete block design with four replications. The leaves were checked at 24-h intervals to ensure that there was no desiccation due to laboratory environment. The numbers of pupae and adults emerged were also recorded at the time of daily observation.

In the third study, the 'Pod Squad' bean planting was directly seeded on 6 Jan. 2002 at a commercial farm located at Homestead, Fla. Soil type and all management practices were as described in the first study. Treatments evaluated were: 1) Azadirachtin (4.5, 8 oz/acre) in combination with Kinetic® (0.09%); 2) Azadirachtin (8 oz/acre) in combination with Agridex® (0.5%); 3) Azadirachtin (8 oz/acre) in combination with Joint Venture® (0.25%); 4) Azadirachtin (8 oz/acre) in combination with LI-700 (0.5%, Loveland Industries, P.O. Box 1289, Greeley, Co); 5) Azadirachtin (8 oz/acre) in combination with Latron B-1956® (3 oz/acre, Rohm and Haas Co., Philadelphia, Pa.); 6) Azadirachtin (8 oz/acre) in combination with Tactic™ (8 oz/acre, Helena Chemical Co., Memphis, Tenn.); 7) Azadirachtin (8 oz/acre) in combination with Trilogy (1%, Thermo Trilogy Corp., Columbia, MD.) and a nontreated control. All treatments were applied on three dates (17 and 23 Dec. 2001 and 2 Jan. 2002) using a backpack sprayer with a single nozzle per row delivering 70 gal/acre at 30 psi. Treatments were evaluated 48 h after each application by randomly collecting 10 leaves, one leaf per plant, from the middle stratum of each plant located in the center row of each treatment plot. The leaves were then checked within 24 h of collection in the laboratory for leafminer larvae and mines using a binocular microscope (10X). After checking, the leaves were placed in Petri dishes (9.5 cm diam.) at room temperature (28 ° ± 1.5 °C) for 7-10 d for further development into pupae.

In the fourth study, efforts were made to determine if various surfactants used with indoxacarb and azadirachtin in the previous studies alone can cause significant mortality to leafminer. For this purpose a field study was conducted in beans. 'Pod Squad' beans were seeded directly in a research plot. Soil type was a Rockdale fine gravely loam with Ph 7.0 - 7.3. Planting, maintaining crops, experimental design, evaluation of treatment and all other procedures were as described in the previous study in beans. Treatments evaluated were: 1) Kinetic® (0.09%); 2) Silwet L-77® (0,06%); 3) Agri-Dex® (0.5%); 3) Cohere® (0.25%); 4) Joint Venture® (0.25%);, 5) Induce® (0.125%); 6) LI 700 (0.5%); 7) Latron B-1956® (3 oz/acre); 8) Tactic™ (8 oz/acre); and 9) a nontreated control.

In the fifth study, two nicotinoid insecticides (imidacloprid and thiamethoxam) were tested against leafminers on tomatoes (*Lycopersicon esculentum* Miller 'Solar Set'). Both imidacloprid (Admire® 2F, Bayer Corporation, Kansas City, MO) and thiamethoxam (Platinum™ 2SC, Syngenta Crop Protection, Inc., Greensboro, N.C.) are highly active against silverleaf whitefly (*Bemisia argentifolii* Bellows and Perring) (Seal, unpublished data), a serious key pest of all vegetable crops.

Tomato seedlings were planted in a Rockdale fine gravely loam with pH 7.0 – 7.3 on August 26, 2001at Homestead, FL. Experimental plot consisted of three adjacent beds 6-ft. wide, 30-ft. long covered with 1.5-mil thick black polyethylene mulch. The beds were fumigated two weeks prior to setting transplants with a mixture containing 67% methyl bromide and 33% chloropicrin at 220 lb./acre. Seedlings were placed 18 in. apart within rows and 6 ft. between rows and were drip irrigated. Plots were arranged in a randomized complete block design with four replications. A 5-ft-long nontreated planted area separated each replication. Treatments evaluated were: 1) thiamethoxam (4 oz/acre) as a soil drench at planting; 2) thiamethoxam at 8 oz/acre as a soil drench at planting; 3) thiamethoxam at 8 oz/acre as a soil drench at planting followed by pymetrozine (Fulfill® 50WG, 39.27 g [a.i.]/acre, Syngenta Crop Protection, Inc., Greensboro, N.C.) as a foliar application two times at 10 d intervals; 4) thiamethoxam at 8 oz/acre as a soil drench at planting followed by foliar application of pymetrozine (39.27 g [a.i.]/acre) in combination with pyriproxyfen (Knack™ 0.86 EC, 24.29 g [a.i.]/acre., Valent USA Corporation, Walnut Creek, Calif.); 5) imidacloprid (16 oz/acre) as a soil application two times at 10 d intervals. Foliar application of insecticides was initiated 10 d after planting tomato seedlings. Treatments were evaluated by collecting all infested leaves from each plant of randomly selected five plants per treatment plot. The numbers of mines on the infested leaves were also recorded. Numbers of pupae per plant was determined by placing all infested leaves of a plant into an insect cage at room temperature (28 ± 1.5 °C) for 10 d. To determine the effect of thiamethoxam and imidacloprid on the length and width of leafminer mines, ten leaves, each width 3-8 mines, were collected from each plot of thiamethoxam (8 oz/acre) and imidacloprid. The leaves were then checked using a binocular microscope mounted with an oculo-micrometer to measure length and width of mines.

Statistical Analysis. All applicable data were transformed using square-root (X + .25) before analyses of variance. The transformed data were analyzed with one-way analysis of variance (SAS Institute, 1989). Means were then separated by Duncan's (1955) multiple range test when significant ($P < 0.05$) values were found in the analysis of variance (ANOVA).

Results and Discussion

In the first study on the first sampling date, a significant reduction of leafminer larvae compared to the non-treated control was achieved by applying indoxacarb in combination with Silwet L-77®, Agri-Dex®, or Induce® (Table 1). Indoxacarb alone or in combination with other surfactants did not result in significant reduction of leafminer larvae relative to the non-treated control. On the subsequent sampling dates, all treatments provided significant reductions of leafminer larvae compared to the non-treated control, with some inconsistent results when indoxacarb was applied alone. No larvae survived the abamectin treatment on any sampling date. Indoxacarb in combination with Induce® resulted in significantly fewer leaf mines when compared with the nontreated control on the first sampling date (Table 2). Abamectin treated leaves did not have any leaf mines. On the subsequent sampling dates, all treatments except indoxacarb alone, resulted in fewer leaf mines. On the first sampling date, the numbers of larvae surviving to pupation in all indoxacarb treatments did not differ from that of the non-treated control (Table 3). On the second sampling date, indoxacarb combined with Agridex® or Joint Venture®, and abamectin provided significant reductions in the numbers of larvae surviving to pupation. The mean numbers of pupae across the sampling dates for the above treatments were also significantly lower than that of the non-treated control. Based on the mean across sampling dates, adult emergence was significantly lower from leaves treated with indoxacarb plus Agridex® or abamectin than from non-treated leaves (Table 4). Because no larvae survived treatment with abamectin, there were none surviving to pupation or adult emergence.

The mean number of parasites, primarily *Diglyphus* sp., that emerged from foliage treated with indoxacarb alone did not differ from the number emerging from non-treated foliage (Table 5). The addition of nonionic surfactants to indoxacarb resulted in reduced parasite adult emergence. Abamectin completely decimated leafminer larvae in this study and, as a result, no parasites emerged from abamectin treated leaves. Decimation of leafminer populations on potato treated with abamectin was also reported by Seal and McCord (1998).

Table 1. Effect of various surfactants on impact of foliar applications of indoxacarb on *Liriomyza trifolii* larvae on bean, 2001-02.

		Mean no. larvae per leaf			
Treatments	Rate (g [a.i.]/acre)	12/24/01	01/03/02	01/07/02	Mean
Indoxacarb	0.065 g	1.62 ac	3.70 b	4.27 a	3.16 b
Indoxacarb + Kinetic	0.065 g + 0.09%	2.12 ab	0.90 c	3.05 b	2.02 c
Indoxacarb + Silwet L-77	0.065 g + 0.06%	1.35 bc	0.52 cd	1.35 c	1.07 d
Indoxacarb + Agri-Dex	0.065 g + 0.5%	1.77 c	0.15 de	0.22 d	0.51 e
Indoxacarb + Cohere	0.065 g + 0.25%	1.85 ac	0.27 de	1.97 c	1.36 d
Indoxacarb + +Joint Venture	0.065 g + 0.25%	2.25 a	0.40 de	0.40 d	1.01 d
Indoxacarb + Induce	0.065 g + 0.125%	1.17 c	0.30 de	1.65 c	1.04 d
Abamectin	8 oz/acre	0.00 d	0.00 e	0.00 d	0.00 f
Untreated control		2.25 a	4.40 a	4.27 a	3.64 a

Means within a column followed by the same letter do not differ significantly ($P > 0.05$; DMRT).

Table 2. Effect of various surfactants on impact of foliar applications of indoxacarb on *Liriomyza trifolii* mines on bean, 2001-02.

		Mean no. mines			
Treatments	Rate (g [a.i.]/acre)	12/24/01	01/03/02	01/07/02	Mean
Indoxacarb	0.065 g	1.82 bc	5.27 a	8.42 a	5.17 ab
Indoxacarb + Kinetic	0.065 g + 0.09%	2.80 ab	3.45 b	7.22 ab	4.49 bc
Indoxacarb + Silwet L-77	0.065 g + 0.06%	2.35 ac	3.20 bc	5.92 b	3.82 cd
Indoxacarb + Agri-Dex	0.065 g + 0.5%	2.42 ab	1.07 e	2.87 c	2.12 e
Indoxacarb + Cohere	0.065 g + 0.25%	2.57 ab	2.02 cd	6.97 b	3.85 cd
Indoxacarb + Joint Venture	0.065 g + 0.25%	2.8 2a	2.95 bc	5.75 b	3.84 c
Indoxacarb + Induce	0.065 g + 0.125%	1.55 c	1.82 d	5.72 b	3.03 d
Abamectin	8 oz/acre	0.00 d	0.12 f	0.10 d	0.07 f
Untreated control		2.62 ab	5.32 a	8.45 a	5.46 a

Means within a column followed by the same letter do not differ significantly (P > 0.05; DMRT).

Table 3. Effect of various surfactants on impact of foliar applications of indoxacarb on the survival of *Liriomyza trifolii* larvae to pupae on bean, 2001-02.

		Mean no. pupae		
Treatments	Rate (g [a.i.]/acre)	12/24/01	01/07/02	Mean
Indoxacarb	0.065 g	31.75 a	40.75 a	36.25 a
Indoxacarb + Kinetic	0.065 g + 0.09%	37.50 a	26.25 ab	31.87 ab
Indoxacarb + Silwet L-77	0.065 g + 0.06%	33.50 a	15.00 bd	24.25 ab
Indoxacarb + Agri-Dex	0.065 g + 0.5%	25.75 a	7.00 de	16.37 b
Indoxacarb + Cohere	0.065 g + 0.25%	44.50 a	37.75 ab	41.12 a
Indoxacarb + Joint Venture	0.065 g + 0.25%	41.75 a	6.75 ce	24.25 ab
Indoxacarb + Induce	0.065 g + 0.125%	31.00 a	25.25 ac	28.12 ab
Abamectin	8 oz/acre	0.00 b	0.00 e	0.00 c
Untreated control		41.75 a	32.75 ab	37.25 a

Means within a column followed by the same letter do not differ significantly (P > 0.05; DMRT).

Table 4. Effect of various surfactants on impact of foliar applications of indoxacarb on emergence of *Liriomyza trifolii* adults on bean, 2001-02

		Mean no. adults		
Treatments	Rate (g [a.i.]/acre)	12/24/01	01/07/02	Mean
Indoxacarb	0.065 g	14.50 a	20.75 a	17.62 a
Indoxacarb + Kinetic	0.065 g + 0.09%	16.75 a	9.50 bd	13.12 ab
Indoxacarb + Silwet L-77	0.065 g + 0.06%	13.75 a	4.50 ce	9.12 ab
Indoxacarb + Agri-Dex	0.065 g + 0.5%	12.50 a	2.25 ef	7.37 b
Indoxacarb + Cohere	0.065 g + 0.25%	18.75 a	13.50 ac	16.12 a
Indoxacarb+ + Joint Venture	0.065 g + 0.25%	21.75 a	2.50 df	12.12 a
Indoxacarb + Induce	0.065 g + 0.125%	15.75 a	12.00 ac	13.87 ab
Abamectin	8 oz/acre	0.00 b	0.00 f	0.00 c
Untreated control		15.25 a	18.75 ab	17.00 a

Means within a column followed by the same letter do not differ significantly (P > 0.05; DMRT).

Table 5. Effect of various surfactants on impact of foliar applications of indoxacarb on emergence of parasitoid adults of *Liriomyza trifolii* on bean, 2001-02.

		Mean no. parasitoids		
Treatments	Rate (g [a.i.]/acre)	12/24/01	01/07/02	Mean
Indoxacarb	0.065 g	4.75 ab	2.00 a	3.37 ab
Indoxacarb + Kinetic	0.065 g + 0.09%	3.00 bc	0.25 b	1.62 ac
Indoxacarb + Silwet L-77	0.065 g + 0.06%	3.00 bc	0.25 b	1.62 ac
Indoxacarb + Agri-Dex	0.065 g + 0.5%	2.00 bc	0.00 b	1.00 bc
Indoxacarb + Cohere	0.065 g + 0.25%	2.75 bc	0.25 b	1.50 bc
Indoxacarb + Joint Venture	0.065 g + 0.25%	2.00 bc	0.25 b	1.12 bc
Indoxacarb + Induce	0.065 g + 0.125%	4.75 ab	0.00 b	2.37 ac
Abamectin	8 oz/acre	0.00 c	0.00 b	0.00 c
Untreated control		8.00 a	1.00 ab	4.50 a

Means within a column followed by the same letter do not differ significantly (P > 0.05; DMRT).

In the bioassay study (second study), indoxacarb alone did not result in significantly reduced survival to pupation compared to the non-treated control when first and second instars of leafminer were treated (Table 6). Survival to pupation of larvae treated as third instars was significantly reduced by indoxacarb alone. When indoxacarb in combination with either Silwet L-77®, Joint Venture® or Induce® was applied to the first instars, the number surviving to pupation was significantly reduced compared to the non-treated control. All indoxacarb/surfactant combinations significantly reduced the numbers of larvae surviving to pupation when applied to second and third instars. All treatments, with the exception of the combination of indoxacarb and Kinetic®, significantly reduced the survival to adult emergence compared to the non-treated control when applied to first-, second- or third instars (Table 7).

In the third study, azadirachtin in combination with various surfactants provided inconsistent results in reducing leafminer larvae on different sampling dates (Table 8). Azadirachtin in combination with Agridex® consistently reduced leafminer larvae on all sampling dates. Spinosin provided significant control of leafminer larvae.

Table 6. Effect of various surfactants on impact of indoxacarb on survival of first, second and third instars of *Liriomyza trifolii* to pupae in a leaf-dip bioassay.

		Mean no. pupae			
Treatments	Rate (g [a.i.]/acre)	First instars	Second instars	Third instars	Total
Indoxacarb	0.065 g	4.33 bc	20.66 ab	3.33 bc	28.33 b
Indoxacarb + Kinetic	0.065 g + 0.09%	26.33 a	10.66 bd	5.0 bc	42.0 b
Indoxacarb + Silwet L-77	0.065 g + 0.06%	0.66 c	0.66 de	0.33 bc	1.67 de
Indoxacarb + Agri-Dex	0.065 g + 0.5%	5.0 bc	6.33 be	0.33 bc	11.67 cd
Indoxacarb + Cohere	0.065 g + 0.25%	11.0 bc	16.33 bc	6.00 b	33.33 b
Indoxacarb + Joint Venture	0.065 g + 0.25%	0.00 c	2.33 ce	0.00 c	2.33 de
Indoxacarb + Induce	0.065 g + 0.125%	5.66 c	21.66 ab	0.33 bc	27.67 bc
Abamectin	8 oz/acre	0.00 c	0.00 e	0.33 bc	0.33 e
Untreated control			45 a	31.33 a	93.33 a

Means within a column followed by the same letter or no letter no not differ significantly (P > 0.5; DMRT).

Table 7. Effect of various surfactants on impact of foliar applications of indoxacarb on emergence of Liriomyza trifolii adults in a leaf-dip bioassay.

		Mean no. adults			
Treatments	Rate (g [a.i.]/acre)	First instars	Second instars	Third instars	Total
Indoxacarb	0.065 g	3.33 c	10.33 bc	0.00 c	13.66 cd
Indoxacarb + Kinetic	0.065 g + 0.09%	21.33 a	5.66 bd	3.0 b	30.0 b
Indoxacarb + Silwet L-77	0.065 g + 0.06%	0.00 c	0.33 cd	0.00 c	0.33 f
Indoxacarb + Agri-Dex	0.065 g + 0.5%	1.66 c	4.33 bd	0.00 c	6.0 de
Indoxacarb + Cohere	0.065 g + 0.25%	9.0 bc	11.66 bc	3.33 b	24.0 bc
Indoxacarb + Joint Venture	0.065 g + 0.25%	0.00 c	1.67 bd	0.00 c	1.66 ef
Indoxacarb + Induce	0.065 g + 0.125%	3.33 c	11.0 ab	0.33 c	14.66 bd
Abamectin	8 oz/acre	0.00 c	0.00 d	0.00 c	0.00 f
Untreated control		15.66 ab	28.66 a	19.33 a	63.66 a

Means within a column followed by the same letter or no letter no not differ significantly (P > 0.5; DMRT).

Table 8. Effect of various surfactants on impact of foliar applications of azadirachtin on *Liriomyza trifolii* larvae on bean, 2002.

		Mean no. larvae			
Treatment	Rate/acre	01/19	01/25	02/04	Mean
Azadirachtin + Kinetic	8 oz + 0.09%	1.47 bc	1.72 ac	0.17 dc	1.12 b
Azadirachtin + Agridex	8 oz + 0.5%	0.70 c	1.10 c	0.22 bd	0.67 c
Azadirachtin + Joint Venture	8 oz + 0.25%	2.27 a	1.60 bc	0.17 cd	1.35 ab
Azadirachtin + LI 700	8 oz + 0.5%	1.20 bc	2.0 ab	0.50 ab	1.23 ab
Azadirachtin + Latron B-1956	8 oz + 3 oz	1.62 ab	1.30 ac	0.30 ac	1.07 b
Azadirachtin + Tactic	8 oz + 8 oz	1.60 ab	2.47 a	0.25 ad	1.44 ab
Azadirachtin + Trilogy	8 oz + 1%	1.77 ab	2.20 ab	0.55 a	1.50 a
Spinosin	6 oz	0.02 d	0.12 d	0.02 d	0.05 d
Untreated control		2.25 a	4.40 a	4.27 a	3.64 a

Means within a column followed by the same letter or no letter no not differ significantly (P > 0.5; DMRT).

Table 9. Effect of various surfactants on impact of foliar applications of azadirachtin on *Liriomyza trifolii* mines on bean, 2001-02.

	Mean no. mines				
Treatment	Rate/acre	01/19	01/25	02/04	Mean
Azadirachtin+ Kinetic	8 oz + 0.09%	1.67 bc	2.0 ac	3.27 e	2.31 cd
Azadirachtin + Agridex	8 oz + 0.5%	0.90 c	1.45 c	5.0 de	2.45 d
Azadirachtin + Joint Venture	8 oz + 0.25%	2.37 a	1.82 bc	4.62 ce	2.94 bc
Azadirachtin + LI 700	8 oz + 0.5%	1.50 bc	2.60 ab	6.35 ac	3.48 ab
Azadirachtin + Latron B-1956	8 oz + 3 oz	1.65 bc	1.95 ac	5.57 bd	3.05 bc
Azadirachtin + Tactic	8 oz + 8 oz	1.67 ab	2.95 a	5.27 bd	3.30 ab
Azadirachtin + Trilogy	8 oz + 1%	1.87 ab	2.65 ab	8.37 a	4.30 a
Spinosin	6 oz	0.00 d	0.025 d	0.30f	0.10 e
Untreated control		1.92 ab	2.05 ac	46.35 ab	3.45 ab

Means within a column followed by the same letter or no letter no not differ significantly ($P > 0.5$; DMRT).

Leaf mines were significantly fewer on the first sampling date when leaves were treated with azadirachtin in combination with Kinetic®, Agridex®Li-700, Latron® or Trilogy® (Table 9). On the second sampling date, none of the azadirachtin treatments reduced mines on bean leaves. On the third sampling date, azdirachtin in combination with Kinetic®, Agridex®, ot Joint Venture® significantly reduced leaf mines. Over all, Kinetic® and Agridex® significantly reduced mines. Spinosin was consistent in reducing mines as in the instance of larvae. Significant reduction in the numbers of leafminer larvae and mines on tomatoes treated with Spinosin was also observed by Stansly and Conner (1998).

In the fourth study, on the first sampling date, none of the surfactants resulted in significant reduction of leafminer larvae (Table 10). Almost similar pattern of larval response to various surfactants was observed on the two subsequent sampling days with some exceptions. Mean across the sampling dates indicated that numbers of leafminer larvae on bean leaves treated with Kinetic® and Cohere® resulted in significantly lower larvae when compared with the non-treated control.

In the fifth study, thiamethoxam treated plants had significantly fewer numbers of leafminer infested leaves than the plants treated with imidacloprid and nontreated control plants (Fig. 1). In all treatments an increase in the numbers of infested leaves were observed on the subsequent sampling days, but this increase did not differ among thiamethoxam treatments. Leafminer populations suddenly disappeared after the 4th sampling date (data not shown). Mean numbers of leaf mines per plant were significantly fewer in thiamethoxam treated plants than imidacloprid and nontreated plants (Fig. 2). Mean length and width of mines on thiamethoxam treated leaves (L: 3.5 ± 0.15 cm, W: 0.5 ± 0.06 cm, n: 10 leaves) were significantly smaller than non-treated control leaves (L: 6.4 ± 0.2 cm, W: 0.2 ± 0.01 cm, n: 10 leaves). Mean numbers of leafminers pupae emerged from thiamethoxam treated leaves were also fewer than imidacloprid and nontreated leaves (Fig. 3). A high percentage (ca. 70%) of leafminer larval mortality was observed in thiamethoxam treated leaves which is a cause for the shorter length of the mines on those treated leaves.

In summary, this study provides information about the new insecticides in controlling *L. trifolii* on vegetable crops. Spinosin and abamectin are currently used and highly effective insecticide against *L. trifolii*. Judicial use of indoxacarb, azadirachtin and thiamethoxam in rotation with the current management tools will delay the development of resistance or tolerance against spinosin and abamectin. Use of Agridex®, a nonionic surfactant, in combination with indoxacarb and azadirachtin provided superior control of *L. trifolii* in the present study. Based on the present study, indoxacarb is relatively safe on natural enemy of leafminers. Use of indoxacarb in rotation with other insecticides will promote the effectiveness of natural biological agents of leafminers on vegetable crops.

Table 10. Effect of foliar applications of various surfactants on *Liriomyza trifolii* larvae on bean, 2002. Application volume was 70 gal per acre.

	Mean no. of larvae				
Treatment	Rate/acre (v/v)	01/19	01/25	02/05	Mean
Kinetic	0.09%	1.33 ab	0.70 e	0.33 bd	0.78 de
Silwet l-77	0.06%	1.93 a	3.13 ab	0.13 ce	1.73 a
Agri-Dex	0.5%	0.53 c	2.13 bc	0.53 ab	1.06 be
Cohere	0.25%	0.60 c	1.83 cd	0.20 ce	0.87 ce
Joint Venture	0.25%	1.06 bc	3.16 ab	0.16 ce	1.46 ac
Induce	0.125%	0.93 bc	3.36 ab	0.03 de	1.44 ad
LI 700	0.5%	0.90 bc	3.63 a	0.76 a	1.76 a
Latron B-1956	3.0 oz/acre	1.00 bc	3.16 ab	0.46 bc	1.54 ab
Tactic	8.0 oz/acre	0.90 bc	3.66 a	0.10 ce	1.55 ab
Untreated control		1.03 bc	3.63 a	0.40 bc	1.68 ab

Means within a column followed by the same letter or no letter no not differ significantly ($P > 0.5$; DMRT).

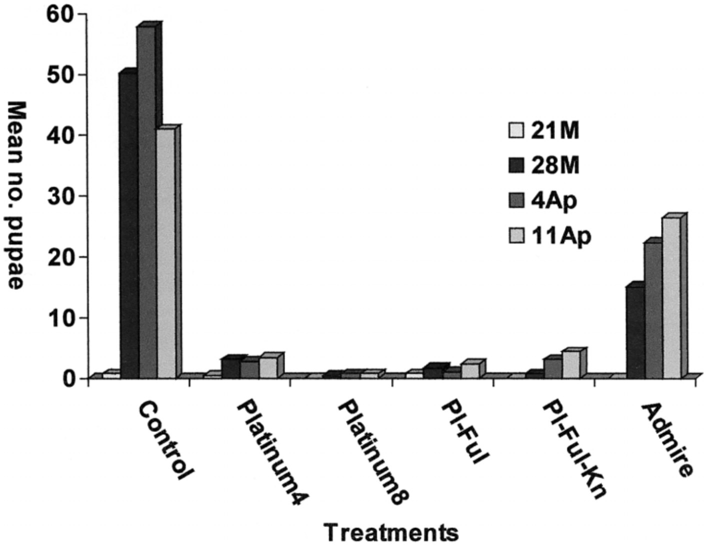

Fig. 1. Effect of various treatments on mean numbers of *Liriomyza trifolii* infested leaves per tomato plant, 2002.

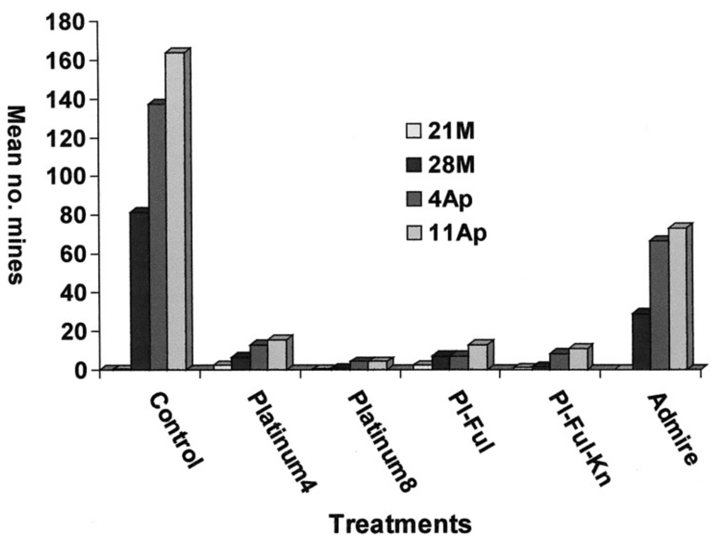

Fig. 2. Effect of various treatments on mean numbers of *Liriomyza trifolii* mines per tomato plant, 2002.

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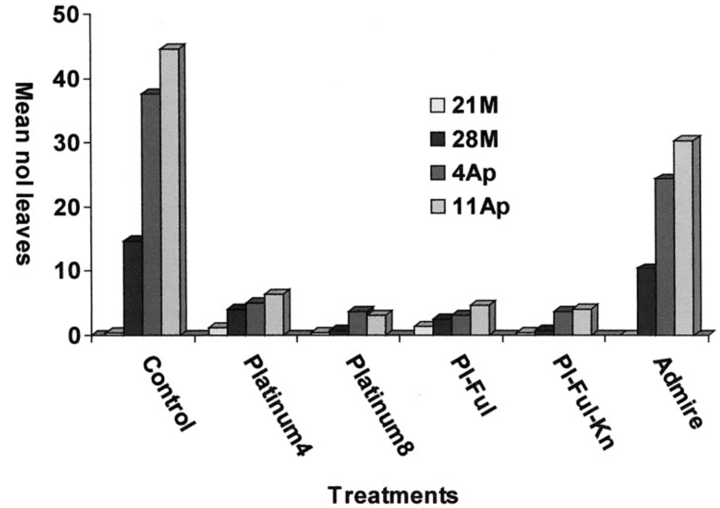

Fig. 3. Effect of various treatments on mean numbers of *Liriomyza trifolii* pupae per tomato plant, 2002.

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