Proc. Fla. State Hort. Soc. 120:170–177. 2007.

Comparative Effectiveness of New Insecticides in Controlling Armyworms (Lepidoptera: Noctuidae) and Leafminers (Diptera: Agromyzidae) on Tomato

DAKSHINA R. SEAL[1*], DAVID J. SCHUSTER[2], AND WALDEMAR KLASSEN[1]

[1]*University of Florida, IFAS, Tropical Research and Education Center, 18905 SW 280 Street, Homestead, FL 33031*

[2]*University of Florida, IFAS, Coast Research and Education Center, 14625 C.R. 672, Wimauma, FL33598*

ADDITIONAL INDEX WORDS. *Liriomyza trifolii*, *Spodoptera* spp., insecticide, fermentation product, differential toxicity, predatory spiders

Armyworms (*Spodoptera* spp.) and leafminers (*Liriomyza* spp.) are important pests of tomato in Florida. Studies on the effectiveness of new insecticides in protecting tomato were conducted at the Gulf Coast Research and Education Center, Wimauma, FL and the Tropical Research and Education Center, Homestead, FL in 2003, 2005, 2006, and 2007. Leafminers were suppressed most effectively on tomato by abamectin (Agri-Mek®), spinetoram (Radiant®), and chlorantraniliprole (Coragen®), but most consistently by spinetoram. Significant reduction of armyworms on tomato was provided by metaflumizone (Alverde™ 240SC), chlorantraniliprole, indoxacarb (Avaunt™ 30WG), spinetoram, spinosad (SpinTor™ 2SC), and novaluron (Rimon™0.83EC). All of these insecticides resulted in fewer armyworm-damaged fruit, as did emamectin benzoate (Proclaim™ 5SG), pyridalyl (Tesoro™ 4EC), flubendiamide (Synapse 24WG), and spinetoram in rotation with methoxyfenozide (Intrepid™). In Fall 2005, predatory spider populations initially were considerably lower immediately following application of metaflumizone, indoxacarb, novaluron, spinetoram, and spinosad, but the populations treated with metaflumizone, indoxacarb, and spinosad had fully recovered by the seventh day after treatment. In Spring 2006, at 14 days after treatment with metaflumizone, indoxacarb, or with emamectin benzoate, *Geocoris* spp., *Orius* spp., and spiders were about as numerous as in the untreated plots. The availability of several effective insecticides with only mild toxicity to certain important predators is of great importance for the development of sustainable integrated pest management systems. This information is valuable for managing armyworms and leafminers on tomato by applying the above mentioned insecticides either alone, in combination, or in rotation.

Armyworms [*Spodoptera* spp. including southern armyworm, *Spodoptera eridania* (Cramer); beet armyworm, *Spodoptera exigua* (Hübner), *Spodoptera dolichos* (F.), and *Spodoptera latifascia* (Walker)] and leafminers (*Liriomyza* spp.) are common insect pests of vegetable production in Florida. They are polyphagous and cause serious economic damage to vegetables and ornamentals (Capinera, 2001; Minkenberg and Van Lenteren, 1986). *Liriomyza trifolii* (Burgess) is an especially serious pest of tomato in North America (Schuster and Everett, 1983).

Chemical insecticides continue to be the major means of controlling leafminers (Cox et al., 1995) and armyworms (Cobb and Bass, 1975; Meinde and Ware, 1978). Nevertheless, the injudicious use of broad-spectrum insecticides has caused the destruction of beneficial natural enemies and the development of insecticide resistance, which is a major factor in the emergence of these insects as major pests (Graham et al., 1995; Parrella and Keil, 1984; Ruberson, 1993; Ruberson et al., 1994; Smith, 1989, 1994; Stoltz and Stern, 1978).

In order to counter the development of insecticide resistance, it is essential to devise a management program against leafminers and armyworms. The foundation of this program is the rotation of effective insecticides belonging to different mode of action classes [Insecticide Resistance Action Committee (IRAC), 2007; McCord et al., 2002], all of which are benign to natural enemies of these pests. Such a program was developed in celery production to counter cyromazine resistance in *L. trifolii* in Florida (Florida Fruit and Vegetable Association , 1991). In this program cyromazine was rotated with abamectin, and two consecutive applications of the same product were never made. To combat *L. trifolii* on ornamentals in California (Parrella, 1982), a new class of insecticides was rotated every 1 to 2 months (University of California Integrated Pest Management, 2000).

In the present study, new insecticides of various chemical classes were evaluated to control *Liriomyza* leafminers and *Spodoptera* armyworms on tomato in two widely separated agricultural regions in Florida, i.e., at the Gulf Coast Research and Education Center (GCREC), Wimauma, and at the Tropical Research and Education Center (TREC), Homestead. The purpose of this study was to provide information to pest managers and growers on the efficacy of various new chemicals against leafminers and armyworms. This information should assist growers in countering the development of resistance in leafminers and armyworms against any insecticide in part by the judicious rotation of these important tools.

Materials and Methods

LEAFMINER CONTROL EXPERIMENTS. In the first experiment leafminer control was evaluated on 'Solar Set' tomato seedlings planted on 28 Dec. 2006 at TREC in Krome gravelly loam (loamy-

*Corresponding author; email: dseal3@ufl.edu

skeletal, carbonatic hyperthermic lithic Udorthents), which consists of about 33% soil and 67% pebbles (>2 mm). Experimental plots were randomly selected 30-ft-long segments of three adjacent raised beds 3 ft wide, 0.5 ft high, and 6 ft between bed centers and covered with 1.5-mil-thick black polyethylene mulch. The beds were fumigated 2 weeks prior to setting transplants with a mixture containing 67% methyl bromide and 33% chloropicrin at 220 lbs/acre. Seedlings were placed 18 inches apart within rows and drip irrigated and fertigated with 4–0–8. Plots were arranged in a randomized complete-block design with four replications. A 5-ft-long nontreated planted area separated each replicate. Treatments evaluated were: 1) abamectin (10 oz/acre, Agri-Mek 0.15EC, Syngenta Crop Protection); 2) metaflumizone (16 oz/acre; Alverde 240SC, BASF AgProducts); 3) indoxacarb (3.5 oz/acre; Avaunt 30WG, DuPont); 4) chlorantraniliprole (5.1 oz/acre; Coragen 5SC, DuPont Crop Protection); 5) spinetoram (7.0 oz/acre; Radiant 120SC, Dow AgroSciences); 6) novaluron (12.0 oz/acre; Rimon 0.83EC, Chemtura Corporation); 7) flubendiamide (3.0 oz/acre; Synapse 24WG, Bayer CropScience); 8) pyridalyl (6.4 oz/acre; Tesoro 4EC, Valent USA); and 9) a nontreated control. Treatments were applied by using a backpack sprayer at 30 psi with two nozzles/row delivering 70 gpa. Treatments were made at weekly intervals on four dates: 24 Mar., 1 Apr., 9 Apr., and 16 Apr. 2007. Treatments were evaluated at 48 h after each application by collecting 10 randomly selected leaves, one leaf/plant, from each treatment plot. The 10 leaves from each plot were placed in a cup and transported to the laboratory to record the number of mines (irrespective of length of mine) with the aid of a binocular microscope at 10×. The leaves were then stored in the laboratory at room temperature for 7 d to obtain and record the number of leafminer pupae per sample.

Leafminer control was evaluated in two experiments at the GCREC in a spring trial and in a fall trial in 2006. Experimental plots of Myakka fine sand were single 18-ft-long rows in the spring and three, 24-ft-long rows in the fall on raised beds 32 inches wide, 8 inches high, and 5 ft between bed centers and covered with white polyethylene mulch in the spring trial and with metallized polyethylene mulch in the fall trial. On 21 Mar. in the spring trial and on 22 Sept. in the fall trial, 'Sunleaper' and 'Tygress' tomato transplants, respectively, were set 18 inches apart in a single row on each bed. Treatments evaluated were: 1) metaflumizone 240SC at 16 oz/acre in combination with Penetrator Plus; 2) indoxacarb 30WG at 3.5 oz/acre in combination with Kinetic at 0.1% v/v (alternated with spinosad 2SC at 7.25 oz in combination with Dyne-Amic at 0.1% v/v in the fall trial); 3) chlorantraniliprole 200SC at 5.1 oz/acre (combined with Kinetic at 0.1% v/v in the fall trial); 4) emamectin benzoate (4 oz/acre, Proclaim 50SG, Syngenta Crop Protection; spring trial only); 5) spinetoram 120SC at 6.0 oz/acre (fall trial only); 6) novaluron 0.83EC at 12.0 oz/acre; 7) flubendiamide 24WG at 3.0 oz/acre; 8) pyridalyl 4EC at 6.4 oz/acre; and 9) a nontreated control. Treatments were replicated four times in the spring and two times in the fall, and randomized complete-block designs were used in both experiments. Applications in the spring were made with a 2.5-gal, hand-held CO_2-powered sprayer operated at 60 psi and fitted with a single D-5 disk and #45 core. The sprayer delivered 60 gpa on 25 Apr., and 10 and 23 May; and 90 gpa on 6 June. Applications in the fall were made with a high clearance, self-propelled sprayer operated at 200 psi and 3.4 mph. It was fitted with eight Albuz orange nozzles per row and delivered 60 gpa (four nozzles open) on 1 Nov., and 90 gpa (six nozzles open) on 17 and 29 Nov. Evaluations of various treatments in controlling *L. trifolii* were made on 24 May and 29 Nov. by counting all leafmines ≥0.5 inch long on tomato leaves during a 1-min search of each plot by two individuals, and the numbers were totaled for analysis.

Armyworm control experiments. Armyworm control was evaluated on 'Solar Set' tomato seedlings transplanted on 28 Jan. at TREC. All materials and methods used in this study were as described in the first study at TREC. Treatments were: 1) metaflumizone 240SC at 16 oz/acre; 2) indoxacarb 30WG at 3.5 oz/acre; 3) novaluron 0.83EC at 12.0 oz/acre; 4) spinetoram 120SC at 7 oz/acre; 5) spinosad 2SC at 8.0 oz/acre; 6) pyridalyl 4EC at 6.4 oz/acre; and 7) a nontreated control. A pre-treatment sample was collected on 3 Mar. 2007. Treatments were made on 4, 11, 18, and 25 Mar. 2007 in the same manner as described in the first study. Treatments were evaluated by thoroughly checking five randomly selected plants per treatment plot for armyworm larvae 48 h after each application. The larvae were then separated into small, medium, and large categories.

Three additional experiments for armyworm control were conducted at the GCREC in Fall 2003, Fall 2005, and in Spring and Fall 2006. The 2003 experiment was conducted at Bradenton, FL. 'Sunleaper' tomato transplants were set 10 Sept., 18 inches apart within the row on 8-inch-high and 32-inch-wide beds of EauGallie fine sand covered with white polyethylene mulch. Each plot consisted of a single 18-ft-long row with rows on 5-ft centers. Treatments were 1) indoxacarb 30WG at 3.5 oz/acre combined with Kinetic at 0.1% v.v; 2) chlorantraniliprole 200SC at 5.1 oz/acre; 3) novaluron 0.83EC at 12.0 oz/acre; 4) spinosad 2SC at 4 oz/acre; 5) flubendiamide 24WG at 3.0 oz/acre; 6) methoxyfenozide (8.0 oz/acre, Intrepid 2F, Dow AgroSciences); and 8) a nontreated control. Treatments were replicated four times in a randomized complete-block design and were applied with a 2.5-gal, hand-held CO_2-powered sprayer at 60 gpa on 22 and 30 Oct., and at 90 gpa on 4 and 18 Nov., and 1 Dec. The sprayer was fitted with a D-5 disk and #45 core and was operated at 60 psi. Fruit were harvested on 13 and 24 Nov. and 9 Dec., and the number of undamaged fruit and the number of armyworm-damaged fruit were determined.

The 2005 experiment was conducted at GCREC's new location at Wimauma, FL. On 8 Sept., 'Sunleaper' tomato transplants were set 18 inches apart within the row on 8-inch-high and 32-inch-wide beds of Myakka fine sand covered with white polyethylene mulch. Each plot consisted of a single 18-ft-long row with rows spaced 5 ft apart across the beds and 6.5 ft down the beds. Treatments were 1) metaflumizone 240SC at 16 oz/acre combined with Penetrator Plus at 0.5% v/v; 2) indoxacarb 30WG at 3.5 oz/acre combined with Dyne-Amic at 0.1% v.v; 3) novaluron 0.83EC at 12.0 oz/acre combined with Dyne-Amic at 0.1% v/v; 4) spinetoram 120SC at 7 oz/acre combined with Dyne-Amic at 0.1% v/v; 5) spinosad 2SC at 4 oz/acre combined with Dyne-Amice at 0.1% v/v; and 6) a nontreated control. Treatments were replicated four times in a randomized complete-block design and were applied with the above hand-held sprayer at 60 gpa on 30 Sept., 14 Oct., 10 Nov., and 1 Dec. The numbers of armyworm larvae and predators were evaluated on the middle 10 plants of each plot by either examining all leaves of each plant or by shaking the plants and counting dislodged insects on the soil mulch. Sampling was conducted 3 to 14 d after treatment (DAT).

The Spring 2006 armyworm experiment at GCREC was the same as for the leafminer study. On 10 May the middle 10 plants of selected plots were shaken and the numbers of beneficial insects dislodged were counted. Fruit were harvested on 31 May from the middle 10 plants of each plot and the number of undamaged fruit and the number of fruit damaged by armyworm larvae were determined.

In the Fall 2006 experiment, 'FL 47' tomato transplants were set on 15 Aug., 18 inches apart within the row on 8-inch-high and 32-inch-wide beds of Myakka fine sand covered with white polyethylene mulch. Each plot consisted of a single 18-ft-long row with rows spaced 5 ft apart across the beds and 7 ft down the beds. Treatments were replicated four times in a randomized complete-block design and were applied as in 2003 at 60 gpa on 26 Sept. and 10 and 26 Oct. Treatments evaluated were: 1) indoxacarb 30WG at 3.5 oz/acre combined with Kinetic at 0.1% v/v; 2) chlorantraniliprole 200SC at 5.1 oz/acre alternated with indoxacarb 30WG at 3.5 oz/acre combined with Kinetic at 0.1% v/v; 3) spinetoram 120SC at 7.0 oz/acre; 4) spinosad 2SC at 8.0 oz/acre combined with Dyne-Amic at 0.1% v/v; 5) pyridalyl 4EC at 6.4 oz/acre; 6) deltamethrin (16 oz/acre; Battalion 0.2EC, Arysta LifeScience), 7) methoxyfenozide 2F at 8 oz/acre combined with Dyne-Amic at 0.1% v/v; 8) lambda cyhalothrin (3.8 oz/acre; Warrior ICS, Syngenta Crop Protection); 9) betacyfluthrin (2.8 oz; Baythroid XL, Bayer CropScience); and 10) a nontreated control. On 27 and 29 Sept.; 2, 11, 13, 16, 27, and 30 Oct.; and 9 Nov., 10 plants in the middle of selected plots were shaken and the numbers of armyworm larvae and predators dislodged were counted. Fruit were harvested on 25 Oct. and 7 Nov. and the number of undamaged fruit and the number of fruit damaged by armyworm larvae were determined and were totaled over both harvest dates.

Data analyses. The data from the TREC studies were transformed using the square-root of $X + 0.25$ before analyses. All data were analyzed using software provided by the Statistical Analysis System (SAS Institute, 1999). When significant ($P < 0.05$) F values were found in the analysis of variance (ANOVA); the means were separated by the least significant difference (LSD).

Results and Discussion

Leafminer control experiments. *Liriomyza* leafminer populations in the TREC experiment were high initially and decreased as the season progressed (Tables 1 and 2). On the first sampling date, the number of leafmines per 10-leaf sample, when compared with the nontreated control, was significantly reduced by spinetoram, followed by abamectin, but not by the other treatments (Table 1). The spinetoram and abamectin treatments were consistently effective on all sampling dates, but none of the other treatments was effective on any single sampling date; nor when means across the sampling dates were considered.

The numbers of leafminer pupae obtained from samples taken on the first sampling date in all treatments except novaluron were significantly less than in the nontreated control (Table 2). In

Table 1. Mean numbers of leafmines/10 leaf sample of 'Solar Set' tomato treated with various insecticides at the Tropical Research and Education Center, 2007.

	Rate	Mean no. of leafmines/10-leaf sample				
Treatments	(oz/acre)	26 Mar.	3 Apr.	11 Apr.	18 Apr.	Mean
Control		147.75ab[z]	105.25a	71.00a	42.25a	91.56a
Abamectin 0.15EC	10.0	17.00c	2.25b	0.75d	0.50c	5.13b
Metaflumizone 240SC	16.0	183.25a	84.75a	44.25c	29.50ab	85.44a
Indoxacarb 30WG	3.5	138.50ab	93.00a	53.75abc	40.50a	81.44a
Chlorantraniliprole 5SC	5.1	116.50b	116.00a	59.75abc	24.00b	79.06a
Spinetoram 120SC	7.0	0.75d	5.75b	0.75d	0.25c	1.88b
Novaluron 0.83EC	12.0	139.25ab	84.25a	72.25a	28.00ab	80.94a
Flubendiamide 24WG	3.0	94.50b	85.00a	49.25bc	38.75a	87.00a
Pyridalyl 4EC	6.4	106.75b	93.25a	64.50ab	40.50a	76.25a
F	----	35.57	49.43	29.64	44.07	38.54
df	----	8,27	8,27	8,27	8,27	8,135
P-value	----	0.0001	0.0001	0.0001	0.0001	0.0001

[z]Means within a column followed by the same letter(s) do not differ significantly ($P > 0.05$; LSD).

Table 2. Mean numbers of leafminer pupae/10 leaf sample of 'Solar Set' tomato treated with various insecticides at the Tropical Research and Education Center, 2007.

	Rate	Mean no. of leafminer pupae/10-leaf sample				
Treatments	(oz/acre)	26 Mar.	3 Apr.	11 Apr.	18 Apr.	Mean
Control		104.25a[z]	78.75a	44.75bc	21.50a	62.31ab
Abamectin 0.15EC	10.0	0.25d	0.25b	0.25e	0.25c	0.25cd
Metaflumizone 240SC	16.0	63.00bc	54.25a	31.25bc	19.25ab	41.94b
Indoxacarb 30WG	3.5	56.50bc	58.75a	30.00c	14.00ab	39.81b
Chlorantraniliprole 5SC	5.1	5.00d	4.25b	4.50d	11.00b	5.10c
Spinetoram 120SC	7.0	0.25d	0.00b	0.00e	0.00c	0.06d
Novaluron 0.83EC	12.0	81.00ab	210.00a	42.75a	22.75a	89.13a
Flubendiamide 24WG	3.0	65.00bc	49.50a	30.50bc	15.50ab	40.13b
Pyridalyl 4EC	6.4	52.00c	56.25a	50.00bc	14.25ab	43.13b
F	----	47.15	6.05	28.90	20.17	27.49
df	----	8,27	8,27	8,27	8,27	8,135
P-value	----	0.001	0.0002	0.0001	0.0001	0.0001

[z]Means within a column followed by the same letter(s) do not differ significantly ($P > 0.05$; LSD).

Table 3. Number of leafmines on tomatoes sprayed with various insecticide treatments at the Gulf Coast Research and Education Center, 2006. 'Sunleaper' and 'Tygress' tomato cultivars were grown in the spring and fall, respectively.

Treatments	Rate (oz/acre)	Mean no. of mines/2-min search	
		Spring	Fall
Control	----	239a[z]	70ab
Metaflumizone 240SC			
+ Penetrator Plus	16.0		
0.25% v/v	210a	79a	
Indoxacarb 30WG	3.5	202a	38bc[y]
+ Kinetic	0.1% v/v		
Chlorantraniliprole 200SC	5.1	23d	22c[x]
Emamectin benzoate 50SG	4.0	196a	---
+ Dyne-Amic	0.1% v/v		
Spinetoram 120SC	6.0	---	33bc
Novaluron 0.83EC	12.0	208a	70ab
Flubendiamide 24WG	3.0	145b	60abc
Pyridalyl 4EC	6.4	85c	38bc
F	----	14.27	3.76
df	----	7,31	7,7
P-value	----	<0.0001	0.05

[z]Means within a column followed by the same letter(s) do not differ significantly ($P > 0.05$; LSD).
[y]Indoxacarb alternated with spinosad.
[x]Chlorantraniliprole combined with Kinetic 0.1% v/v.

samples from the second to the fourth sampling dates, only abamectin, spinetoram, and chlorantraniliprole significantly reduced the number of leafminer pupae per sample compared to the control. When the mean numbers of pupae across all sampling dates are considered, only abamectin, spinetoram, and chlorantraniliprole significantly reduced the leaf miner populations when compared with the nontreated control.

In the GCREC experiments, the mean numbers of leafmines/2-min search in Spring 2006 were significantly reduced compared to the control in the chlorantraniliprole treatment, followed by pyridalyl and flubendiamide (Table 3). In Fall 2006, only chlorantraniliprole significantly suppressed the leafminer population, while all other treatments were ineffective (Table 3).

Translaminar and systemic movement of insecticides in plants are properties that can be expected to increase the effectiveness of insecticides against leafminers. These properties are possessed by abamectin and spinetoram, which were the most effective by far of the insecticides evaluated. Significant translaminar or systemic action are not possessed by the following materials: metaflumizone (effective by ingestion with some contact activity), indoxacarb (highly lipophilic and, thus, an excellent contact poison), chlorantraniliprole (effective by ingestion), novaluron (effective by ingestion; some contact activity), flubendiamide (effective by ingestion and causes rapid cessation of feeding), and pyridalyl (contact insecticide for Lepidoptera and Thysanoptera) (Entomological Society of America, 2002).

Armyworm control experiments. In the Spring 2007 experiment at TREC, population densities of armyworms were low (Tables 4–7). All treatments provided significant reductions of

Table 4. Mean numbers of *Spodoptera* small larvae per 'Solar Set' tomato plant treated with various insecticides at the Tropical Research and Education Center, 2007.

Treatments	Rate (oz/acre)	Mean no. of small larvae/plant					
		3 Mar.	6 Mar.	13 Mar.	20 Mar.	27 Mar.	Mean
Control		0.60a[z]	1.95a	2.35a	1.10a	0.60a	1.50a
Metaflumizone 240SC	16.0	0.60a	0.00c	0.20c	0.00b	0.0b	0.05c
Indoxacarb 30WG	3.5	0.90a	0.00c	0.00c	0.00b	0.0b	0.00c
Novaluron 0.83EC	12.0	0.65a	0.10bc	0.25c	0.05b	0.0b	0.10bc
Spinetoram 120SC	7.0	0.90a	0.00c	0.00c	0.00b	0.0b	0.00c
Spinosad 2SC	8.0	0.75a	0.00c	0.00c	00.0b	0.0b	0.00c
Pyridalyl 4EC	6.4	0.55a	0.25b	0.30b	0.05b	0.20b	0.20b
F	----	0.49	50.62	41.05	19.41	7.47	38.11
df	----	6,132	6,132	6,132	6,132	6,132	6,689
P-value	----	0.81	0.001	0.0001	0.0001	0.0001	0.0001

[z]Means within a column followed by the same letter(s) do not differ significantly ($P > 0.05$; LSD).

Table 5. Mean numbers of *Spodoptera* medium larvae per 'Solar Set' tomato plant treated with various insecticides at the Tropical Research and Education Center, 2007.

Treatments	Rate (oz/acre)	Mean no. of medium-size larvae/plant					
		3 Mar.	6 Mar.	13 Mar.	20 Mar.	27 Mar.	Mean
Control		0.30a[z]	1.25a	1.05a	0.55a	0.25a	0.77a
Metaflumizone 240SC	16.0	0.20a	0.00c	0.15bc	0.00b	0.05a	0.05c
Indoxacarb 30WG	3.5	0.25a	0.00c	0.00c	0.00b	0.00a	0.00c
Novaluron 0.83EC	12.0	0.30a	0.15bc	0.10bc	0.00b	0.05a	0.08c
Spinetoram 120SC	7.0	0.20a	0.00c	0.00c	0.00b	0.00a	0.00c
Spinosad 2SC	8.0	0.20a	0.00c	0.00c	0.00b	0.00a	0.00c
Pyridalyl 4EC	6.4	0.25a	0.25b	0.40b	0.15a	0.15ab	0.24b
F	----	0.21	33.21	12.74	8.58	2.91	30.59
df	----	6,134	6,132	6,132	6,132	6,132	6,689
P-value	----	0.21	0.0001	0.0001	0.0001	0.01	0.0001

[z]Means within a column followed by the same letter(s) do not differ significantly ($P > 0.05$; LSD).

Table 6. Mean numbers of *Spodoptera* large larvae 'Solar Set' tomato plant treated with various insecticides at the Tropical Research and Education Center, 2007.

	Rate	Mean no. of large larvae/plant					
Treatments	(oz/acre)	3 Mar.	6 Mar.	13 Mar.	20 Mar.	27 Mar.	Mean
Control		0.00a[z]	0.20a	0.40a	0.40a	0.60a	0.40a
Metaflumizone 240SC	16.0	0.00a	0.00b	0.00b	0.00b	0.05b	0.01b
Indoxacarb 30WG	3.5	0.00a	0.00b	0.00b	0.00b	0.00b	0.00b
Novaluron 0.83EC	12.0	0.00a	0.00b	0.05b	0.00b	0.00b	0.01b
Spinetoram 120SC	7.0	0.00a	0.00b	0.00b	0.00b	0.00b	0.00b
Spinosad 2SC	8.0	0.00a	0.00b	0.00b	0.00b	0.00b	0.00b
Pyridalyl 4EC	6.4	0.00a	0.00b	0.10b	0.05b	0.00b	0.04b
F	----	0	4.71	4.97	6.34	12.18	69.36
df	----	6,134	6,132	6,132	6,132	6,132	6,689
P-value	----	0.01	0.002	0.0001	0.0001	0.001	0.001

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

Table 7. Mean numbers of all sizes of *Spodoptera* larvae per 'Solar Set' tomato plant treated with various insecticides at the Tropical Research and Education Center, 2007.

	Rate	Mean no. of small + medium + large-size larvae/plant					
Treatments	(oz/acre)	3 Mar.	6 Mar.	13 Mar.	20 Mar.	27 Mar.	Mean
Control		0.90a[z]	3.40a	3.80a	2.05a	1.45a	2.68a
Metaflumizone 240SC	16.0	0.80a	0.00d	0.35c	0.00b	0.10bc	0.11bc
Indoxacarb 30WG	3.5	1.15a	0.00d	0.00c	0.00b	0.00c	0.00c
Novaluron 0.83EC	12.0	0.95a	0.25c	0.40c	0.05b	0.05bc	0.19b
Spinetoram 120SC	7.0	1.10a	0.00d	0.00c	0.00b	0.00c	0.00c
Spinosad 2SC	8.0	0.95a	0.00d	0.00c	0.00b	0.00c	0.00b
Pyridalyl 4EC	6.4	0.80a	0.50b	0.80b	0.25b	0.35b	0.48b
F	----	0.32	110.66	50.30	31.71	21.54	69.86
df	----	6,134	6,132	6,132	6,132	6,132	6,689
P-value	----	0.32	0.0001	0.0001	0.0001	0.0001	0.0001

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

small armyworm larvae on the first sampling date when compared with the nontreated control (Table 5). Insecticide treatments performed consistently on the subsequent sampling dates in reducing armyworm larvae when compared with the nontreated control. In addition, insecticide treatments significantly reduced medium-size (Table 5) and large armyworm larvae (Table 6). In addition, all insecticide treatments significantly controlled armyworm larvae on tomato in the samples collected 3, 7, and 14 d after the first application (Table 7). Similarly, all insecticide treatments reduced the numbers of armyworm larvae of all sizes combined 4 and 6 d after the second application (Table 7). The most effective materials were indoxacarb, spinetoram, and spinosad; the next most effective insecticides were novaluron and metaflumizone; and the least effective was pyridalyl.

In the experiment conducted at GCREC in Fall 2005, the armyworm population was sparse, with all of the insecticide treatments significantly reducing the numbers of armyworm larvae compared to the untreated control on three of five sampling dates (Table 8). Most of the predators observed in the experiment were various species of spiders (Table 9), but occasionally one or a few big-eyed bugs (G*eocoris* spp.), damsel bugs (Nabidae), minute pirate bugs (*Orius* spp.), stilt bugs (Berytidae), lacewing adults (*Chrysopa* spp.), and lady beetle adults (Coccinelidae) were observed (data not shown). The numbers of predatory spiders on all treated plots were significantly lower than the number on the control on 3DAT1 and on 4DAT2 (Table 9). Predatory spiders in the treated plots increased by 7DAT1 and 6DAT2, when their population densities were not significantly less than in the nontreated control.

In the Fall 2003 experiment at GCREC, the armyworm population was heavy with about 77% of the fruit in the control plots being damaged (Table 10). All treated plots yielded more nondamaged fruit than the control (data not shown). Fewer fruit damaged by armyworm larvae, relative to nonsprayed control plots, were harvested from all sprayed plots. Plots treated with spinosad yielded more damaged fruit than any other treated plot.

In the Spring 2006 experiment at GCREC, the armyworm population was low with about 12% of the fruit in the control plots being damaged (Table 10). Fewer fruit damaged by armyworm larvae, relative to nonsprayed control plots, were harvested from each of the treated plots on both harvest dates (data not shown) and for the total harvest (Table 10). Compared to the untreated control, metaflumizone, indoxacarb, and emamectin benzoate resulted in fewer *Geocoris* spp.; however, *Orius* spp. and spiders were not suppressed significantly by the insecticide treatments (Table 11).

In the Fall 2006 experiment at GCREC (Table 10), the armyworm population was moderate with about 38% of the fruit in the untreated control sustaining damage by armyworm larval feeding. Fewer fruit damaged by armyworm larvae, relative to nonsprayed control plots, were harvested from each of the sprayed plots. However, plots sprayed with deltamethrin had significantly more armyworm-damaged fruit than did plots treated with the other

Table 8. Mean numbers of *Spodoptera* larvae dislodged from 'Sunleaper' tomato plants treated with various insecticides at the Gulf Coast Research and Education Center, Fall 2005. Treatments were applied on 30 Sept., 14 Oct., 10 Nov., and 1 Dec.

Treatments	Rate (oz/acre)	Mean no. of *Spodoptera* larvae/10 plants[z]				
		3DAT1	7DAT1	14DAT1	4DAT2	6DAT2
Control	----	1a[y]	0a	2a	6a	8a
Metaflumizone 240SC	16.0	0b	0a	0a	0b	0b
+ Penetrator Plus	0.5% v/v					
Indoxacarb 30WG	3.5	0b	0a	0a	0b	0b
+ Dyne-Amic	0.1% v/v					
Novaluron 0.83EC	12.0	---	0a	1a	---	0b
+ Dyne-Amic	0.1% v/v					
Spinetoram 120SC	7.0	0b	0a	<1a	0b	0b
+ Dyne-Amic	0.1% v/v					
Spinosad 2SC	8.0	0b	7a	<1a	0b	0b
+ Dyne-Amic	0.1% v/v					
F	----	6.00	1.00	2.13	5.58	12.74
df	----	4,12	5,15	5,15	4,12	5,15
P-value	----	0.007	0.45	0.11	0.009	<0.0001

[z]DAT1 and DAT2 mean days after the first and second treatments, respectively.
[y]Means within a column followed by the same letter do not differ significantly ($P > 0.05$; LSD).

Table 9. Numbers of predatory spiders dislodged from 'Sunleaper' tomato plants sprayed with various insecticides at the Gulf Coast Research and Education Center, Fall 2005.

Treatments	Rate (oz/acre)	Mean no. of spiders/10 plants[z]			
		3DAT1	7DAT1	4DAT2	6DAT2
Control	----	2a[y]	1a	5a	7a
Metaflumizone 240SC	16.0	0b	<1a	2a	5a
+ Penetrator Plus	0.5% v/v				
Indoxacarb 30WG	3.5	<1b	1a	2a	4a
+ Dyne-Amic	0.1% v/v				
Novaluron0.83EC	12.0	---	0a	---	5a
+ Dyne-Amic	0.1% v/v				
Spinetoram 120SC	7.0	1b	0a	2a	7a
+ Dyne-Amic	0.1% v/v				
Spinosad 2SC	8.0	1b	1a	1a	6a
+ Dyne-Amic	0.1% v/v				
F	----	5.62	1.42	2.81	0.43
df	----	4,12	5,15	4,12	5,15
P-value	----	0.009	0.27	0.07	0.82

[z]DAT1 and DAT2 mean days after the first and second treatments, respectively.
[y]Means within a column followed by the same letter do not differ significantly ($P > 0.05$; LSD).

insecticides. The southern armyworm population was moderate in early and late October and in early November (data not shown). Beginning on 6DAT1, all treatments evaluated resulted in fewer *S. eridania* larvae compared to the control. The beet armyworm (*S. exigua*) population was moderate in late September and early October but declined to low levels during the remainder of the experiment (data not shown). All evaluated treatments resulted in fewer *S. exigua* larvae compared to the control on all sampling dates. Other *Spodoptera* spp. populations were low to moderate throughout the experiment (data not shown). Fewer larvae were dislodged from all treated plots on all sampling dates than from the control plots. Numbers of predaceous insects were low throughout the trial (data not shown). Few treatments resulted in fewer predators being dislodged except on 3DAT1 and on 6DAT2, when fewer predators were observed in most treated plots. Spiders were the most abundant predators present, followed by *Geocoris* spp. and species of the family Reduviidae.

The experiments clearly demonstrate that new insecticide chemistries are under development that will provide control of *Liriomyza* spp. leafminers and *Spodoptera* spp. larvae compared to current insecticide standards. These standards include abamectin for leafminers; and indoxacarb, spinosad, and emamectin benzoate for armyworm larvae. Two new products, spinetoram and chlorantraniliprole, provided excellent control of armyworm larvae, and spinetoram was highly effective against leafminers. Because the products were applied on weekly or bi-weekly schedules, it is not possible in these studies to identify which life stages were affected; however, because armyworm larval numbers were reduced and because only larger leafmines were counted at GCREC, it can be assumed that at least larvae were being controlled. The results of these studies also are particularly noteworthy considering that the new insecticides performed consistently whether they were combined with adjuvants or not, and even when they were evaluated at different locations

Table 10. Fruit damaged by armyworm larvae on tomatoes sprayed with various insecticides at the Gulf Coast Research and Education Center. 'Sunleaper' tomato was used in the 2003 and Spring, 2006 studies, and 'Fl 47' was used in Fall, 2006 study.

	Rate	Fall 2003		Spring 2006		Fall 2006	
Insecticide	(oz/acre)	(no.)	(%)	(no.)	(%)	(no.)	(%)
Control	----	234a	77.3a	17a	12.0a	45a	37.6a
Metaflumizone 240SC	16.0	---	---	1b	0.5a	---	---
+ Penetrator Plus	0.25% v/v						
Metaflumizone 240SC	11.4	---	---	2b	1.0a	---	---
+ Penetrator Plus	0.25%						
+ Esfenvalerate 0.66EC	9.7						
Indoxacarb 30WG	3.5	3c	1.4c	1b	0.5a	1cd	0.8c
+ Kinetic	0.1% v/v						
Chlorantraniliprole 200SC	5.1	4c	1.7c	1b	0.5a	1cd	0.7c[y]
Emamectin benzoate 50SG	4.0	---	---	6b	3.9a	---	---
+ Dyne-Amic	0.1% v/v						
Spinetoram 120SC	7.0	---	---	---	---	1cd	0.6c
Novaluron 0.83EC	12.0	10c	4.3c	4b	2.8a	---	---
Spinosad 2SC	4.0	92b	31.4b	---	---	---	---
Spinosad 2SC	8.0	---	---	---	---	3cd	2.5c
+ Dyne-Amic	0.1% v/v						
Flubendiamide 24WG	3.0	2c	0.7c	1b	1.0a	---	---
Pyridalyl 4EC	6.4	---	---	2b	1.8a	1cd	0.5c
Deltamethrin 0.2EC	16.0	---	---	---	---	17b	13.4b
Methoxyfenozide 2F	8.0	3c	1.1c	---	---	1cd	0.5c
+ Dyne-Amic	0.1% v/v[x]						
Methoxyfenozide 2F	8.0	---	---	---	---	<1d	0.2c
+ Dyne-Amic	0.1% v/v						
Alt. spinetoram 120SC	5.0						
+ Dyne-Amic	0.1% v/v						
Methoxyfenozide 2F	5.0	---	---	---	---	1cd	1.1c
+ Spinetoram 120SC	5.0						
+ Dyne-Amic	0.1% v/v						
Lambda cyhalothrin 1CS	3.8	---	---	---	---	12bc	8.2bc
Beta-cyfluthrin 0.2EC	2.8	---	---	---	---	2cd	1c
F	----	45.86	46.86	2.46	2.03	14.41	17.12
df	----	6,18	6,18	8,23	8,23	11,33	11,33
P-value	----	<0.0001	<0.0001	0.04	0.09	<0.0001	<0.0001

[z]Means within a column followed by the same letter do not differ significantly ($P > 0.05$; LSD).
[y]35WG formulation used at 3.06 oz/acre in F03; rotated with indoxacarb 30WG at 3.5 oz/acre plus Kinetic at 0.5% v/v in F06.
[x]Dyne-Amic was not used in F03.

and under different environmental conditions and different pest population densities. Several of the new materials are effective primarily through ingestion (chlorantraniliprole, flubendiamide, and methoxyfenozide) and thus pose little hazard to natural enemies (Entomological Society of America, 2002). Thus, the new chemistries generally were nontoxic or mildly toxic to certain predators and, even when the numbers of predatory spiders were reduced, the numbers rebounded within a week following treatment. The availability of several effective, new insecticides with mild toxicity to predators is of great importance for the development of sustainable integrated pest management systems, particularly because the products represent different modes of action within the IRAC classification system (IRAC, 2007). This information generated in these experiments is valuable for managing armyworms and leafminers on tomato by applying the new insecticides either alone, in combination, or in rotation.

Literature Cited

Capinera, J.L. 2001. Handbook of vegetable pests. Academic Press, San Diego, CA.

Cobb, P.P. and M.H. Bass. 1975. Beet armyworm: Dosage–mortality studies on California and Florida strains. J. Econ. Entomol. 68:813–814.

Cox, D.L., M.D. Remick, J.A. Lasota, and R.A. Dybas. 1995. Toxicity of avermectins to *Liriomyza trifolii* (Diptera: Agromyzidae) larvae and adults. J. Econ. Entomol. 88:1414–1419.

Entomological Society of America. 2002. New pest management tools: Integrating biotech, new chemistry, and regulations. Rpt. on the ESA Section F Symp. held during ESA Natl. Mtg., Ft. Lauderdale, FL, 18 Nov. 2002.

Florida Fruit and Vegetable Association. 1991. Leafminer resistance management in Florida, p. 7–8. Florida Fruit and Veg. Assn. Environ. and Pest Mgt. Bul. No. 24. Dec. 1991.

Graham, F., M.J. Gaylor, and S.D. Stewart. 1995. Insect predators help control beet armyworms in cotton. Highlights of Agr. Res. 42:6. Alabama Agr. Expt. Stn., Auburn Univ.

Table 11. Predators dislodged from 'Sunleaper' tomatoes sprayed with various insecticides at the Gulf Coast Research and Education Center, Spring 2006.

Insecticide	Rate (oz/acre)	No. per 10 plants at 14DAT1[z] *Geocoris* spp.	*Orius* spp.	Spiders	Total
Control	---	5a[y]	1a	6a	12a
Metaflumizone 240SC	16.0	2b	1a	8a	11a
+ Penetrator Plus	0.25% v/v				
Indoxacarb 30WG	3.5	2b	1a	7a	10a
+ Kinetic	0.1% v/v				
Chlorantraniliprole 200SC	5.1	3ab	1a	4a	8a
Emamectin benzoate 50SG	4.0	2b	<1a	7a	10a
+Dyne-Amic	0.1% v/v				
F	----	1.52	0.52	0.55	0.34
df	----	4,12	4,12	4,12	4,12
P-value	----	0.26	0.72	0.71	0.84

[z]14DAT1 means 14 days after the first treatment.
[y]Means within a column followed by the same letter do not differ significantly ($P > 0.05$; LSD).

Insecticide Resistance Action Committee. 2007. IRAC mode of action classification, version 5.3. <www.irac-online.org>.

McCord, E., J.M. Price and C.A. Nagle. 2002. Pesticide mode of action codes to aid ornamental growers in developing control programs to manage pest resistance. Proc. Fla. State Hort. Soc. 115:130–133.

Meinde, L.J. and G.W. Ware. 1978. Tolerance of three beet armyworm strains in Arizona to methomyl. J. Econ. Entomol. 71:645–646.

Minkenberg, O.P.J.M. and J.C. van Lenteren. 1986. The leafminers, *Liriomyza sativa* and *L. trifolii* (Diptera: Agromyzidae), their parasites and host plants: A review. Agr. Univ. Wageningen 86-2.

Parrella, M.P.A. 1982. A review of the history and taxonomy of economically important serpentine leafminers (*Liriomyza* spp.) in California (Diptera: Agromyzidae) Pan-Pacif. Entomol. 58:302–308.

Parrella, M.P. and C.B. Keil. 1984. Insect pest management: The lesson of *Liriomyza*. Bul. Entomol. Soc. Amer. 30:22–25.

Ruberson, J.R. 1993. Parasitism of the beet armyworm, *Spodoptera exigua*, in South Georgia cotton, p. 993–997. Proc. Beltwide Cotton Conf., Natl. Cotton Council, Memphis, TN.

Ruberson, J.R., G.A. Herzog, W.R. Lambert, and W.J. Lewis. 1994. Management of the beet armyworm (Lepidoptera: Noctuidae) in cotton: Role of natural enemies. Fla. Entomol. 77:440–453.

SAS Institute. 1999. SAS/STAT user's guide, version 8. SAS Inst., Cary, NC.

Schuster, D.J. and P.H. Everett. 1983. New chemicals for control of leafminer on tomato. Bradenton AREC Res. Rep. BRA1983-12.

Smith, R.H. 1989. Beet armyworm on cotton. Alabama Coop. Ext. Serv. Circ. ANR-538.

Smith, R.H. 1994. Changes in secondary pests during and after boll weevil eradication, p. 796–797. Proc. Beltwide Cotton Conf., Natl. Cotton Council, San Antonio, TX.

Stoltz, R.L. and V.M. Stern. 1978. Cotton arthropod food chain disruptions by pesticides in the San Joaquin Valley, California. Environ. Entomol. 7:703–707.

University of California Integrated Pest Management. 2000. UC integrated pest management guidelines floriculture and ornamental nurseries. Univ. of California AN Publ. 392, Davis.