# Effect of Selected Insecticides on the Natural Enemies *Coleomegilla maculata* and *Hippodamia convergens* (Coleoptera: Coccinellidae), *Geocoris punctipes* (Hemiptera: Lygaeidae), and *Bracon mellitor*, *Cardiochiles nigriceps*, and *Cotesia marginiventris* (Hymenoptera: Braconidae) in Cotton

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**ABSTRACT** We evaluated the toxicity of three insecticides (lambda cyhalothrin, spinosad, and S-1812) to the natural enemies *Bracon mellitor* Say, *Cardiochiles nigriceps* Viereck, *Coleomegilla maculata* De Geer, *Cotesia marginiventris* (Cresson), *Geocoris punctipes* (Say), and *Hippodamia convergens* Guérin-Méneville, in topical, residual, and field assays. Lambda cyhalothrin exhibited the greatest toxicity to the natural enemies. In topical toxicity tests, lambda cyhalothrin adversely affected each natural enemy species studied. Residues of lambda cyhalothrin on cotton leaves were toxic to *B. mellitor*, *C. nigriceps*, *C. maculata*, and *G. punctipes*. Interestingly, residues of this insecticide were not very toxic to *C. marginiventris* and *H. convergens*. *Geocoris punctipes* and *C. maculata* numbers in the field generally were significantly lower for lambda cyhalothrin treatments than for the other four treatments, substantiating the previous tests. Although cotton aphids began to increase over all treatments around the middle of the test period, the number of cotton aphids in the lambda cyhalothrin plots was significantly higher than the number in any of the other treatments. As cotton aphids increased in lambda cyhalothrin field plots, the predator *H. convergens* also increased in number, indicating that lambda cyhalothrin did not adversely affect it in accordance with the residual tests. Spinosad exhibited marginal to excellent selectivity, but was highly toxic to each parasitoid species and *G. punctipes* in topical toxicity tests and to *B. mellitor* in residual tests. Spinosad generally did not affect the number of *G. punctipes*, *H. convergens*, and *C. maculata* in the field except for one day after the second application for *G. punctipes*. S-1812 exhibited good to excellent selectivity to the natural enemies. Some reduction of *G. punctipes* occurred for only a short period after the first and second application of this insecticide in the field. *H. convergens* and *C. maculata* were affected very little by S-1812.

**KEY WORDS** insecticides, natural enemies, cotton

PREDOMINANT SPECIES OF natural enemies over a range of cotton insect pests include *Bracon mellitor* Say, *Cardiochiles nigriceps* Viereck, *Coleomegilla maculata* De Geer, *Cotesia marginiventris* (Cresson), *Geocoris punctipes* (Say), and *Hippodamia convergens* Guérin-Méneville. The parasitoid *C. marginiventris* plays a prominent role in biological control of the beet armyworm, *Spodoptera exigua* (Hübner) (Ruberson et al. 1994), whereas *B. mellitor* (Cross 1973) and *C. nigriceps* (Lewis et al. 1972) are important parasitoids of boll weevil larvae, *Anthonomus grandis grandis* Boheman, and tobacco budworm larvae, *Heliothis virescens* (F.), respectively, in cotton. *G. punctipes* is an important predator of lepidopteran pests in cotton (Bell and Whitcomb 1962, Lingren et al.1968), and *C. maculata* and *H. convergens* are important predators of the cotton aphid, *Aphis gossypii* Glover (Flint and Dreistadt 1998).

These key natural enemies can be important in suppressing insect pest populations and thus their conservation is a valuable integrated pest management (IPM) approach in cotton. Selective insecticides that target pest species could play a role in conserving this wide diversity of natural enemies associated with cotton.

Generally, one of three methods has been used to determine the toxicity of insecticides to natural enemies: (1) topical application of insecticides in the laboratory, (2) exposure to residues of insecticides applied to leaves, and (3) monitoring natural enemy populations before and after applications of insecticides in the field. The first method is a good measure of the effect an insecticide will have when it is directly sprayed on a natural enemy in the field. The second method is the best one for assessing the effect of insecticide residues on natural enemies. The third method is best for evaluating the impact of insecticides

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on populations of insects in the field, but the first two techniques can provide valuable information on expected and observed impact of these insecticides on natural enemies in the field.

Novel insecticides with new chemistry or modes of action have been discovered. Spinosad is currently available for control of various Lepidoptera. S-1812 is an experimental insecticide in the new chemical class dihalopropenyloxy benzene and targets Lepidoptera and Thysanoptera pests. It is important to determine the selectivity of these new insecticides to understand their impact on the key natural enemies in cotton. Previous laboratory and field research studies have shown that spinosad is a valuable IPM tool because of its selectivity, but it can have some toxic effects on parasitoids (Murray and Lloyd 1997, Ruberson and Tillman 1999). It is also known that the pyrethroid lambda cyhalothrin, a grower standard for control of Lepidoptera, is generally toxic to beneficial insects (Tillman 1995, Ruberson and Tillman 1999). However, very little has been published on the effect of S-1812 on natural enemies. This research was conducted to evaluate the toxicity of the new insecticides to the predominant species of natural enemies (noted above) using topical, residual, and field tests.

## Materials and Methods

**Insects.** Females of *B. mellitor, C. nigriceps,* and *C. marginiventris* used in this test were young adults (1–2 d old) reared by USDA-ARS at Mississippi State, MS. The *C. marginiventris* colony was obtained from cocoons from a virus-free colony in Tifton, GA. The *C. nigriceps* colony originated from *H. virescens* larvae collected from cotton in the summer of 1996. The *B. mellitor* colony originated from boll weevil larvae collected from cotton squares in the fall of 1996. Fresh, vigorous females of *C. maculata, G. punctipes,* and *H. convergens* were collected from an untreated cotton field at Stoneville, MS. Immature stages were monitored biweekly in the field so that adults could be collected when they were no older than 1–1.5 wk old.

**Topical Toxicity Study.** This test included the following three treatments and rates: (1) S-1812 4 EC ([0.168 kg (AI)/ha], Valent USA Corporation, Walnut Creek, CA), (2) spinosad (Tracer 4 EC [0.1 kg (AI)/ha], Dow Agrosciences, Indianapolis, IN), and (3) lambda cyhalothrin (Karate 1 EC [0.028 kg (AI)/ha], Zeneca, Wilmington, DE). Because lambda cyhalothrin was used as a grower standard, the standard field rate for *H. virescens*/*Helicoverpa zea* (Boddie) control was used. The highest rate of spinosad recommended for *H. virescens*/*Helicoverpa zea* control was used to determine the greatest effect on beneficial insects that could possibly occur. The potentially highest rate for the experimental S-1812 for control of these worms was used for the same reason. Treatments were applied with water at high volume (93.5 liters/ha). A water control was included in the test.

A laboratory spray chamber was used to treat adult insects topically. The spray chamber used to apply the treatments was equipped with a conventional spraying system that was calibrated to deliver 93.5 liters/ha, using a single 8001E nozzle (Spraying Systems, Wheaton, IL), while maintaining 138 kPa pressure. The height and speed of the nozzle above the spray surface were 35.6 cm and 6.4 km/h, respectively.

Predators or parasitoids were aspirated into a new plastic petri dish (100 by 15 mm), anesthetized lightly with $CO_2$, and placed uncovered in the spray chamber for treatment. Before the test, a hole (55 mm in diameter) was cut in the top of the petri dish and covered with organdy mesh to increase movement of the $CO_2$ into the dish from a $CO_2$ cylinder. A treatment replicate consisted of five insects in a single petri dish. Each treatment was replicated six times for a total of 30 insects per treatment for each species. Only adult females were sprayed. After spraying, the insects were transferred to a clean petri dish. Sprayed insects were provided food (honey water for parasitoids and *H. virescens* eggs for predators) and placed in an environmental chamber maintained at 25 ± 2°C, 50 ± 5% RH, and a photoperiod of 14:10 (L:D) h. For lambda cyhalothrin and spinosad, all insects were checked for survival after 48 h, which was sufficient time to observe full toxicity for each insecticide. For S-1812, all insects were checked for survival 72 h because this insecticide is slow acting on target species.

**Residual Toxicity Study.** Bollgard cotton (Monsanto, St. Louis, MO) was planted in large plots, 40 rows (1.02 m per row) wide by 39.6 m long (0.162 ha), to minimize insect migration. A John Deere (Deere, Moline, IL) 6000 high-clearance sprayer was equipped with a conventional spraying system calibrated to deliver 46.8 liters/ha using a single TX-8 nozzle (Spraying Systems) and 275 kPa pressure. The test began 27 June 1997 and included the following treatments: (1) S-1812 at 0.112 kg (AI)/ha, (2) S-1812 at 0.168 kg (AI)/ha, (3) spinosad at 0.1 kg (AI)/ha, (4) lambda cyhalothrin at 0.0128 kg (AI)/ha, and (5) untreated control. In the field tests, a second rate of S-1812 was added because the highest recommended rate for *H. virescens*/*H. zea* control had yet to be determined. A randomized complete block design with four replications was used. Bioassays for each insect species were conducted in the laboratory. Six treated leaves from each treatment replicate were collected from the top of the plant at 0, 24, and 48 h after treatment. After leaves were collected, they were placed individually in petri dishes. Five insects were placed in a petri dish containing one treated leaf. For lambda cyhalothrin and spinosad, all insects were checked for survival after 48 h, which was sufficient time to observe full toxicity for each insecticide. For S-1812, all insects were checked for survival after 72 h because this insecticide is slow acting on target species.

**Field Study.** Both the residual and field study were conducted in the same plots as described above. Plots were sprayed at five-day intervals beginning on 27 June 1997 for three spray treatments. Insects in the field plots were sampled the morning before each spray treatment, and 1, 3, and 5 d after spraying. Natural enemies were sampled using a KISS machine (Beerwinkle et al. 1997). Four to six rows (varied

**Table 1. Percentage survival (mean ± SE) 48–72 h after treatment of *Bracon mellitor*, *Cardiochiles nigriceps*, *Cotesia marginiventris*, *Geocoris punctipes*, and *Hippodamia convergens* in topical assays with selected insecticides**

| Treatment | Rate kg (AI)/ha | *B. mellitor* females | *C. nigriceps* females | *C. marginiventris* females | *G. punctipes* adults | *H. convergens* adults |
|---|---|---|---|---|---|---|
| Water | | 100.0a | 100.0a | 96.7 ± 3.3a | 90.0 ± 4.47a | 96.7 ± 3.3a |
| S-1812 | 0.168 | 96.7 ± 3.3a | 100.0a | 93.3 ± 4.2a | 90.0 ± 6.8a | 96.7 ± 3.3a |
| Spinosad | 0.1 | 0c | 0b | 0c | 6.7 ± 4.2b | 96.7 ± 3.3a |
| Lambda cyhalothrin | 0.028 | 33.3 ± 9.9b | 0b | 53.3 ± 6.7b | 0b | 76.7 ± 6.2b |
| *F* value (df = 3) | | 88.54 | $4.06 \times 10^{15}$ | 110.86 | 118.95 | 5.63 |
| *P* | | 0.0001 | 0.0001 | 0.001 | 0.001 | 0.0058 |

Means in columns followed by the same letter are not significantly different ($P > 0.01$, Fisher LSD).

among dates) were sampled per plot. This sampling method was used in preference to other sampling techniques to obtain sufficient insects to make comparisons between treatments. Several species of natural enemies were collected, but only *C. maculata*, *G. punctipes*, and *H. convergens* occurred consistently enough to evaluate statistically. Aphids were sampled by counting the number of aphids on one fully expanded terminal leaf of 10 plants per plot.

**Statistical Analysis.** Percentage survival data were converted by arcsine transformation and analyzed using PROC MIXED (SAS Institute 1996). Means were separated by a Fisher least significant difference (LSD).

## Results and Discussion

**Topical Toxicity Study.** Lambda cyhalothrin adversely affected each predator and parasitoid species studied relative to the controls and S-1812 (Table 1). Toxicity of lambda cyhalothrin varied among the species. Lambda cyhalothrin was highly toxic to *C. nigriceps* and *G. punctipes*, moderately toxic to *B. mellitor* and *C. marginiventris*, and only slightly toxic to *H. convergens*. Tillman (1995) and Tillman and Scott (1997) reported that lambda cyhalothrin at 0.035 kg (AI)/ha was highly toxic to both *C. nigriceps* and *C. marginiventris*. Spinosad was highly toxic to each parasitoid species and *G. punctipes*. However, survival of *H. convergens* was unaffected by spinosad. S-1812 had no significant adverse effects, relative to the controls, on any species studied.

**Residual Toxicity Study.** Residual lambda cyhalothrin on cotton leaves was toxic to *B. mellitor* at 0 and 24 h after treatment and *C. nigriceps*, *C. maculata*, and *G. punctipes* at 0, 24, and 48 h after treatment (Tables 2–3). However, lambda cyhalothrin residues had limited toxicity to *C. marginiventris* or *H. convergens*. Of the six insect species studied, *B. mellitor* was the only natural enemy adversely affected by spinosad. This is

**Table 2. Percentage survival (mean ± SE) of selected parasitoids in residual assays 0, 24, and 48 h after treatment (HAT) with selected insecticides**

| Treatment | Rate (kg [AI]/ha) | 0 HAT | 24 HAT | 48 HAT |
|---|---|---|---|---|
| | | *B. mellitor* | | |
| Control | | 100.0a | 100.0a | 100.0a |
| S-1812 | 0.112 | 97.5 ± 2.5a | 97.5 ± 2.5a | 97.5 ± 2.5a |
| S-1812 | 0.168 | 100.0a | 100.0a | 100.0a |
| Spinosad | 0.1 | 0c | 7.5 ± 2.5c | 57.5 ± 17.0b |
| Lambda cyhalothrin | 0.028 | 32.5 ±b | 57.5 ± 4.8b | 80.0 ± 10.8ab |
| *F* value (df = 4) | | 97.58 | 232.5 | 4.14 |
| *P* | | 0.0001 | 0.0001 | 0.0186 |
| | | *C. nigriceps* | | |
| Control | | 97.5 ± 2.5a | 100.0a | 100.0a |
| S-1812 | 0.112 | 100.0a | 100.0a | 100.0a |
| S-1812 | 0.168 | 97.5 ± 2.5a | 97.5 ± 2.5a | 97.5 ± 2.5a |
| Spinosad | 0.1 | 97.5 ± 2.5a | 100.0a | 100.0a |
| Lambda cyhalothrin | 0.028 | 60.0 ± 9.1b | 65.0 ± 5.0b | 65.0 ± 5.0b |
| *F* value (df = 4) | | 14.3 | 38.0 | 61.0 |
| *P* | | 0.0001 | 0.0001 | 0.0001 |
| | | *C. marginiventris* | | |
| Control | | 100.0a | 100.0a | 100.0a |
| S-1812 | 0.112 | 100.0a | 100.0a | 100.0a |
| S-1812 | 0.168 | 100.0a | 100.0a | 100.0a |
| Spinosad | 0.1 | 87.5 ± 7.5a | 92.5 ± 4.8a | 100.0a |
| Lambda cyhalothrin | 0.028 | 90.0 ± 4.1a | 95.0 ± 5.0a | 97.5 ± 2.5a |
| *F* value (df = 4) | | 1.66 | 1.3 | 3.0 |
| *P* | | 0.2114 | 0.3129 | 0.0528 |

Means in columns followed by the same letter are not significantly different ($P > 0.01$, Fisher LSD).

**Table 3. Percentage survival (mean ± SE) of selected predators in residual assays 0, 24 and 48 h after treatment (HAT) with selected insecticides**

| Treatment | Rate (kg (AI)/ha) | 0 HAT | 24 HAT | 48 HAT |
|---|---|---|---|---|
| | | *C. maculata* | | |
| Control | | 100.0a | 100.0a | 100.0a |
| S-1812 | 0.112 | 100.0a | 100.0a | 100.0a |
| S-1812 | 0.168 | 100.0a | 100.0a | 100.0a |
| Spinosad | 0.1 | 100.0a | 100.0a | 100.0a |
| Lambda cyhalothrin | 0.028 | 7.5 ± 2.5b | 22.5 ± 9.5b | 50.0 ± 10.8b |
| *F* value (df = 4) | | 1369.0 | 67.05 | 21.43 |
| *P* | | 0.0001 | 0.0001 | 0.0001 |
| | | *G. punctipes* | | |
| Control | | 100.0a | 92.5 ± 4.8a | 100.0a |
| S-1812 | 0.112 | 97.5 ± 2.5a | 100.0a | 100.0a |
| S-1812 | 0.168 | 97.5 ± 2.5a | 90.0 ± 5.8a | 100.0a |
| Spinosad | 0.1 | 92.5 ± 7.5a | 95.0 ± 2.9a | 97.5 ± 2.5a |
| Lambda cyhalothrin | 0.028 | 12.5 ± 6.3b | 45.0 ± 2.9b | 72.5 ± 11.1b |
| *F* value (df = 4) | | 66.06 | 17.96 | 5.64 |
| *P* | | 0.0001 | 0.0001 | 0.0056 |
| | | *H. convergens* | | |
| Control | | 92.5 ± 2.5a | 100.0a | 100.0a |
| S-1812 | 0.112 | 90.0 ± 4.1a | 100.0a | 100.0a |
| S-1812 | 0.168 | 90.0 ± 4.1a | 100.0a | 100.0a |
| Spinosad | 0.1 | 97.5 ± 2.5a | 100.0a | 100.0a |
| Lambda cyhalothrin | 0.028 | 82.5 ± 4.8a | 92.5 ± 2.5b | 95.0 ± 2.9a |
| *F* value (df = 4) | | 2.14 | 9.0 | 3.0 |
| *P* | | 0.1265 | 0.0006 | 0.0528 |

Means in columns followed by the same letter are not significantly different ($P > 0.01$, Fisher LSD).

commensurate with the study conducted by Elzen et al. (1998) for *H. convergens* and *G. punctipes.* S-1812 was not toxic to any of the natural enemies at either rate.

**Field Study.** The number of *G. punctipes* per 40 m of row was significantly lower for lambda cyhalothrin treatments than for the other four treatments on every sampling date after treatment (Table 4). This reduction in number of *G. punctipes* was probably caused by the high topical and residual toxicity of lambda cyhalothrin to this insect. Spinosad did not adversely affect the number of *G. punctipes* except after the first day of the second application.

S-1812 at the higher rate adversely affected the number of *G. punctipes* 1 d after the first and second applications, 6/28 and 7/3, respectively. However, the number of *G. punctipes* was not significantly different from the control 3 and 5 d after these applications. It is unclear why the number of *G. punctipes* decreased after application of S-1812 in the field because this insecticide was selective to this natural enemy in the laboratory tests. This insecticide may have some sublethal effect on this predator that temporarily prohibited the insect from searching, or the insecticide may have repelled the insect in the field. Some sublethal effects have been observed for *G. punctipes* (Elzen and Elzen 1999).

Although the number of cotton aphids increased over all treatments over time, the number of aphids in the lambda cyhalothrin plots was significantly higher than that in any of the other treatments (Table 4). The number of *H. convergens* was not significantly affected by any treatment up to day 11 (7/7) of the test (Table 4). At that time, the number of *H. convergens* was significantly higher in the lambda cyhalothrin plots than in any of the other plots. This was probably because of the higher number of aphids in the lambda cyhalothrin plots over the other treatment plots. When the plots were sprayed on day 11, the number of *H. convergens* was not significantly different in lambda cyhalothrin plots in comparison to the other treatment plots. The reduction in number of *H. convergens* upon this application of lambda cyhalothrin was probably caused by its topical toxicity to this natural enemy. Later, on day 16 of the test, the number of *H. convergens* also was significantly higher in the lambda cyhalothrin plots than in the other treatment plots, demonstrating again that this predator increased with increases in pest numbers. Spinosad and S-1812 had very little effect on *H. convergens* in the field.

The number of *C. maculata* was significantly lower in lambda cyhalothrin plots than in untreated plots from day 7 through day 14 of the test (Table 4). The higher toxicity of lambda cyhalothrin to this insect probably accounted for the reduction of this insect observed in the field. The number of *C. maculata* was significantly lower in the S-1812 plots than in the untreated control plots for only a single day for the whole test. *C. maculata* was affected very little by spinosad in each of the three toxicity tests.

Differences in susceptibility of insects in the same family are not uncommon (Croft 1990). For example in our study, topical application of lambda cyhalothrin to *C. nigriceps* resulted in 100% mortality, whereas the same treatment killed only 46.7% of the *C. marginiventris* females. Thus, it is important that insecticide

**Table 4. Mean ± SE number of selected predators/40 m of row and aphids/leaf for S-1812, lambda cyhalothrin, spinosad, and untreated cotton field plots**

| Date | Day | Sample/Spray schedule | Treatment | Rate[a] | No. *G. punctipes* | No. *H. convergens* | No. *C. maculata* | No. aphids |
|---|---|---|---|---|---|---|---|---|
| 27/6/1997 | 1 | Prespray sample | S-1812 | 0.112 | 5.0 ± 0.58a | 0.5 ± 0.35a | 0a | |
| | | Spray 1 | S-1812 | 0.168 | 7.75 ± 1.31a | 0.13 ± 0.13a | 0a | |
| | | | Cyhalothrin | 0.1 | 7.63 ± 0.38a | 0.25 ± 0.14a | 0a | |
| | | | Spinosad | 0.028 | 6.25 ± 1.11a | 0.38 ± 0.13a | 0.13 ± 0.13a | |
| | | | Untreated | | 7.0 ± 1.26a | 0.5 ± 0.35a | 0a | |
| | | *F* value (df = 4) | | | 1.28 | 0.44 | 1.0 | |
| | | *P* | | | 0.3213 | 0.7781 | 0.438 | |
| 28/6/1997 | 2 | Postspray sample 1 | S-1812 | 0.112 | 8.5 ± 1.04b | 0.88 ± 0.24a | 0a | |
| | | | S-1812 | 0.168 | 7.25 ± 0.48b | 1.0 ± 0.61a | 0.13 ± 0.13a | |
| | | | Cyhalothrin | 0.1 | 1.75 ± 0.43c | 0.25 ± 0.14a | 0a | |
| | | | Spinosad | 0.028 | 10.25 ± 1.18a | 0.25 ± 0.14a | 0.13 ± 0.13a | |
| | | | Untreated | | 10.75 ± 1.92a | 1.25 ± 0.75a | 0.25 ± 0.25a | |
| | | *F* value (df = 4) | | | 9.88 | 0.99 | 0.58 | |
| | | *P* | | | 0.0004 | 0.4404 | 0.6795 | |
| 30/6/1997 | 4 | Postspray sample 2 | S-1812 | 0.112 | 4.5 ± 0.65a | 0.38 ± 0.13a | 0a | |
| | | | S-1812 | 0.168 | 4.0 ± 1.08a | 1.25 ± 0.14a | 0a | |
| | | | Cyhalothrin | 0.1 | 1.25 ± 0.43b | 1.25 ± 0.66a | 0.5 ± 0.5a | |
| | | | Spinosad | 0.028 | 4.75 ± 0.66a | 1.38 ± 0.47a | 0.25 ± 0.25a | |
| | | | Untreated | | 5.13 ± 0.88a | 1.38 ± 0.63a | 0.13 ± 0.13a | |
| | | *F* value (df = 4) | | | 4.04 | 0.83 | 0.67 | |
| | | *P* | | | 0.0203 | 0.5292 | 0.6249 | |
| 2/7/1997 | 6 | Prespray sample | S-1812 | 0.112 | 5.0 ± 1.27a | 0.5 ± 0.35a | 1.5 ± 1.02a | |
| | | Spray 2 | S-1812 | 0.168 | 5.63 ± 1.09a | 1.13 ± 0.31a | 1.25 ± 0.48a | |
| | | | Cyhalothrin | 0.1 | 1.75 ± 0.75b | 1.5 ± 0.35a | 1.75 ± 0.32a | |
| | | | Spinosad | 0.028 | 6.38 ± 0.75a | 0.75 ± 0.32a | 0.75 ± 0.32a | |
| | | | Untreated | | 6.25 ± 0.32a | 0.5 ± 0.2a | 0.63 ± 0.47a | |
| | | *F* value (df = 4) | | | 11.32 | 1.89 | 0.68 | |
| | | *P* | | | 0.0002 | 0.1637 | 0.6171 | |
| 3/7/1997 | 7 | Postspray sample 1 | S-1812 | 0.112 | 4.63 ± 0.52ab | 1.0 ± 0.54a | 0.75 ± 0.6ab | |
| | | | S-1812 | 0.168 | 3.25 ± 0.6b | 0.75 ± 0.25a | 0.5 ± 0.2ab | |
| | | | Cyhalothrin | 0.1 | 0.25 ± 0.14c | 0.75 ± 0.25a | 0b | |
| | | | Spinosad | 0.028 | 3.75 ± 0.52b | 1.13 ± 0.24a | 1.83 ± 0.33a | |
| | | | Untreated | | 6.0 ± 0.94a | 0.88 ± 0.13a | 1.5 ± 0.46a | |
| | | *F* value (df = 4) | | | 12.72 | 0.27 | 3.54 | |
| | | *P* | | | 0.0001 | 0.8919 | 0.034 | |
| 5/7/1997 | 9 | Postspray sample 2 | S-1812 | 0.112 | 4.13 ± 0.58a | 0.69 ± 0.26a | 1.56 ± 0.26a | |
| | | | S-1812 | 0.168 | 4.19 ± 0.47a | 0.69 ± 0.21a | 0.63 ± 0.24bc | |
| | | | Cyhalothrin | 0.1 | 0.13 ± 0.13b | 1.13 ± 0.16a | 0c | |
| | | | Spinosad | 0.028 | 3.13 ± 0.6a | 0.69 ± 0.24a | 1.06 ± 0.06ab | |
| | | | Untreated | | 3.5 ± 0.2a | 1.13 ± 0.48a | 1.44 ± 0.48a | |
| | | *F* value (df = 4) | | | 14.32 | 0.67 | 5.66 | |
| | | *P* | | | 0.0001 | 0.6227 | 0.0056 | |
| 7/7/1997 | 11 | Prespray sample | S-1812 | 0.112 | 4.88 ± 1.03a | 1.13 ± 0.33b | 1.69 ± 0.16a | 1.5 ± 0.29b |
| | | Spray 3 | S-1812 | 0.168 | 6.19 ± 1.57a | 1.0 ± 0.2b | 1.13 ± 0.43a | 1.5 ± 0.29b |
| | | | Cyhalothrin | 0.1 | 0.19 ± 0.06b | 2.81 ± 0.4a | 0.13 ± 0.07b | 2.5 ± 0.29a |
| | | | Spinosad | 0.028 | 4.69 ± 0.98a | 0.56 ± 0.06b | 1.13 ± 0.07a | 1.0 ± 0.41b |
| | | | Untreated | | 6.31 ± 0.33a | 1.0 ± 0.23b | 1.69 ± 0.56a | 1.0 ± 0b |
| | | *F* value (df = 4) | | | 6.79 | 10.36 | 3.82 | 4.5 |
| | | *P* | | | 0.0025 | 0.0003 | 0.0247 | 0.0138 |
| 8/7/1997 | 12 | Postspray sample 1 | S-1812 | 0.112 | 2.25 ± 0.77a | 0.5 ± 0.23a | 1.19 ± 0.26a | |
| | | | S-1812 | 0.168 | 2.75 ± 0.85a | 0.75 ± 0.18a | 1.13 ± 0.31a | |
| | | | Cyhalothrin | 0.01 | 0b | 0.75 ± 0.18a | 0.19 ± 0.19b | |
| | | | Spinosad | 0.028 | 3.94 ± 0.74a | 0.88 ± 0.16a | 1.88 ± 0.3a | |
| | | | Untreated | | 3.75 ± 0.37a | 0.56 ± 0.16a | 1.44 ± 0.37a | |
| | | *F* value (df = 4) | | | 6.24 | 0.71 | 4.48 | |
| | | *P* | | | 0.0037 | 0.5985 | 0.014 | |
| 10/7/1997 | 14 | Postspray sample 2 | S-1812 | 0.112 | 3.77 ± 0.37b | 0.94 ± 0.39ab | 2.63 ± 0.48a | 3.5 ± 0.29b |
| | | | S-1812 | 0.168 | 5.25 ± 0.57a | 0.25 ± 0.1b | 2.38 ± 0.26a | 1.5 ± 0.29b |
| | | | Cyhalothrin | 0.1 | 0.38 ± 0.13c | 2.33 ± 0.08a | 0.81 ± 0.21b | 8.75 ± 3.04a |
| | | | Spinosad | 0.028 | 4.81 ± 0.28a | 0.94 ± 0.31ab | 2.69 ± 0.51a | 3.5 ± 1.44b |
| | | | Untreated | | 5.25 ± 0.37a | 0.63 ± 0.26b | 3.5 ± 0.23a | 2.5 ± 0.87b |
| | | *F* value (df = 4) | | | 29.61 | 7.2 | 7.27 | 3.39 |
| | | *P* | | | 0.0001 | 0.0023 | 0.0018 | 0.0363 |
| 12/7/1997 | 16 | Postspray sample 3 | S-1812 | 0.112 | 4.78 ± 0.87a | 0.69 ± 0.19b | 1.69 ± 0.43a | 7.0 ± 1.41b |
| | | | S-1812 | 0.168 | 4.69 ± 0.28a | 0.75 ± 0.1b | 1.94 ± 0.36a | 7.0 ± 2.0b |
| | | | Cyhalothrin | 0.1 | 0.44 ± 0.19b | 2.19 ± 0.45a | 0.69 ± 0.26a | 22.75 ± 8.93a |
| | | | Spinosad | 0.028 | 4.81 ± 0.67a | 0.81 ± 0.28b | 2.38 ± 0.52a | 5.25 ± 0.25b |
| | | | Untreated | | 6.25 ± 0.84a | 1.0 ± 0.18b | 1.56 ± 0.36a | 6.5 ± 0.87b |
| | | *F* value (df = 4) | | | 11.88 | 5.51 | 2.5 | 3.1 |
| | | *P* | | | 0.0002 | 0.0062 | 0.0864 | 0.0477 |

Means in columns followed by the same lower case letter are not significantly different ($P > 0.05$, Fisher LSD) between insecticides for a single date.

[a] kg (AI)/ha.

bioassays be conducted using several species, and their toxicity not be based on a single species and then toxicity generalized to a group of natural enemies such as "lady beetles." Also, understanding sublethal effects of these insecticides could possibly help explain observed differences in responses of insects to insecticides. Therefore, studies on the sublethal effects of this and the other insecticides will be conducted in the future for these natural enemies.

As we have demonstrated, the assay method used to ascertain the toxicity of an insecticide for an insect can have a great effect on the outcome of the test. Spinosad and lambda cyhalothrin were very toxic to *G. punctipes* in topical assays; but in the field, spinosad had little adverse effect on this insect whereas lambda cyhalothrin greatly reduced the numbers of this insect. Part of the explanation for the differences in toxicity observed between the topical and field tests could be that the behavior of the insect, such as resting on the underside of a leaf, could reduce the possibility of the insect receiving a topical application of the insecticide in the field. The same could be true for lambda cyhalothrin. However, lambda cyhalothrin has residual activity against *G. punctipes*, and this insect must search the top of cotton leaves to find hosts. Thus, extrapolating pesticide effects at the population level from limited studies could lead to erroneous conclusions. Nevertheless, topical and residual toxicity tests should be conducted to better understand the potential effect these types of contact with the insecticide may have on the insect in the field and how this information could possibly be used to design a program to conserve natural enemies or increase the effectiveness of the insecticide against the target pest. The effect on insects of ingesting the insecticide also should be studied in the laboratory for the same reasons. Behavioral tests should be conducted to determine if any of the types of contact with the insecticide would occur in the field. For example, the insecticide may be toxic to the insect when ingested in the laboratory, but the insect may not feed on treated leaves in the field. Ultimately, the effect an insecticide may have on insect populations must be tested in large field plots.

In summary, lambda cyhalothrin was generally more toxic to natural enemies than spinosad and S-1812. Spinosad exhibited marginal to excellent selectivity, but was highly toxic to each parasitoid species and *G. punctipes* in topical toxicity tests and to *B. mellitor* in residual tests. Spinosad generally did not affect the number of *G. punctipes*, *H. convergens*, and *C. maculata* in the field. Murray and Lloyd (1997) conducted studies that showed that spinosad had no disruptive effect on populations of the predators *Nabis kinbergii* Reuter and *Harmonia octomaculata* (F.) in cotton. S-1812 exhibited good to excellent selectivity to the natural enemies. Spinosad and S-1812 should be excellent tools in conserving valuable natural enemies, and efforts should be made to incorporate such selective insecticides in IPM programs.

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