

COMPARISON OF SUSCEPTIBILITY OF *GEOCORIS PUNCTIPES*<sup>1</sup> AND *LYGUS LINEOLARIS*<sup>2</sup> TO INSECTICIDES FOR CONTROL OF THE TARNISHED PLANT BUG

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ABSTRACT

Comparison of the susceptibility of *Geocoris punctipes* (Say) and the tarnished plant bug (TPB), *Lygus lineolaris* (Palisot de Beauvois) to selected insecticides was determined in topical, tarsal contact, and field studies. In both topical and tarsal contact studies, *L. lineolaris* was more susceptible to imidacloprid and oxamyl residues than *G. punctipes*. However, oxamyl was more toxic to the pest than imidacloprid. Both insect species responded very similarly to fipronil, acephate, dicotophos, and lambda-cyhalothrin, all of which were very toxic to these insects. In our field study, lambda-cyhalothrin had an equally negative impact on populations of TPB and *G. punctipes* concurring with previously published field studies. Results from our laboratory and other field studies indicate that oxamyl and imidacloprid would be effective against TPB while conserving populations of *G. punctipes* for biological control of lepidopteran larvae in cotton.

INTRODUCTION

The tarnished plant bug (TPB) *Lygus lineolaris* (Palisot de Beauvois) (Hemiptera: Miridae) is often a serious tissue-sucking pest of cotton, *Gossypium hirsutum* L. causing abnormal plant growth, fruit damage, delay in fruiting, and delayed boll maturity (Hanny et al. 1977). The big-eyed bug, *Geocoris punctipes* (Say) (Hemiptera: Lygaeidae), is a predator of many pest species including *H. virescens* and *Helicoverpa zea* (Boddie) eggs and small larvae (Lingren et al. 1968). *Geocoris punctipes* also feeds on plants, increasing the likelihood of their survival during the absence of invertebrate hosts (Eubanks and Denno 1999).

Since the TPB and *G. punctipes* can occur in cotton fields concurrently, selectivity of insecticides with respect to these two insect species is an important issue in an integrated pest management program because insecticides recommended for *L. lineolaris* control may be harmful to *G. punctipes*. TPB and *G. punctipes* can be affected by insecticides through various routes of administration: topical contact on their bodies, tarsal contact with residues of insecticides, and feeding on insecticide treated plants and prey (for predator). The organophosphate, acephate, recommended for use in cotton for TPB control in 1977, provides effective TPB suppression (Bannister et al. 1995, Reed et al. 1997, Robbins et al. 1998). The pyrethroid insecticides were first registered for use in cotton in 1978, and lambda-cyhalothrin was used very effectively against TPB (Graham and Gaylor 1988, Leonard et al. 1987). Another organophosphate insecticide, dicotophos (Burris et al. 1986, Graham and Gaylor 1988, Leonard

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<sup>5</sup>Mention of a proprietary product does not constitute an endorsement or recommendation for its use by USDA.

et al. 1987, Langston and Schuster 1989), and the carbamate, oxamyl (Micinski 1983) also were used successfully for TPB control during this time. Pyrethroid resistance was first detected in 1993 in a field population of TPB in the Mississippi Delta, and resistant insects also were found to have multiple resistance to some organophosphate and carbamate insecticides (Snodgrass and Elzen 1995). Level of control with organophosphate, carbamate, and pyrethroid insecticides has decreased over the past several years in some areas of cotton production where resistance to all these insecticides has been reported. However, dicofol, cyfluthrin, oxamyl, and lambda-cyhalothrin, are still used effectively against susceptible TPB populations (Bannister et al. 1995, Pankey et al. 1996, Reed et al. 1997, Robbins et al. 1998, Russell et al. 1998). The new insecticides imidacloprid, an imidazolidinimine, and fipronil, a phenylpyrazole, have shown excellent activity on TPB even against TPB populations that are highly resistant to other classes of insecticides (Burris et al. 1994, Bannister et al. 1995, Scott and Snodgrass 1996, Shaw and Yang 1996, Teague and Tugwell 1996).

Most of the reported insecticide research on *G. punctipes* concentrates on residual toxicity of insecticides which has been low for some insecticides such as spinosad and oxamyl and high for other insecticides such as malathion and fipronil (Boyd and Boethel 1998, Elzen et al. 1998, Elzen and Elzen 1999, Tillman and Mulrooney 2001). The few topical toxicity studies conducted have demonstrated that malathion and other organophosphates, fipronil, and cyfluthrin are highly toxic to *G. punctipes* (Lingren and Ridgway 1967, Tillman and Mulrooney 2001). The single study reported on effect of feeding on dried residues of an insecticide on cotton leaves demonstrated that both species were susceptible to feeding on indoxacarb-treated plants (Tillman et al. 2001). Few studies have investigated the effect of insecticides on feeding by *G. punctipes*. Elzen (2001) reported that consumption of *H. zea* eggs by this predator was lower in malathion, profenofos, endosulfan, fipronil, azinphos-methyl, and imidacloprid treatments compared with the untreated control. Tillman et al. (2001) reported that indoxacarb-treated eggs were highly toxic to females feeding on these eggs.

Few studies have compared the effect of insecticides on both TPB and *G. punctipes*. In one field study, survival of *G. punctipes* was high for carbaryl and spinosad, moderately high for indoxacarb, and low for methyl parathion, lambda-cyhalothrin, and imidacloprid+cyfluthrin (Leverage)(Muegge and Payne 2001). Our research, conducted to compare susceptibility of *L. lineolaris* and *G. punctipes* to selected insecticides with current or potential usage in TPB control, involved bioassaying both insects via topical and tarsal contact routes of administration and evaluating the effect of lambda-cyhalothrin on field populations of these insect species.

## MATERIALS AND METHODS

*G. punctipes* were collected from untreated cotton in the hill section of Mississippi and kept in plastic food containers with *H. virescens* eggs for food. *L. lineolaris* were collected from wild host plants in the Mississippi Delta (Washington Co.), kept in cardboard ice-cream cartons, and fed fresh green beans. 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 Bioassay.** This test included the following six treatments and rates: (1) acephate (Orthene 75 wettable soluble powder [0.56 kg (AI)/ha], Valent USA Corporation, Walnut Creek, CA), (2) lambda-cyhalothrin (Karate 1 emulsifiable concentrate [0.028 kg (AI)/ha], Zeneca, Wilmington, DE), (3) dicofol (Bidrin 8 emulsifiable concentrate [0.56 kg (AI)/ha], Novartis Crop Protection, Greensboro, NC), (4) fipronil (Regent 2.5 emulsifiable concentrate [0.056 kg (AI)/ha], Rhone-Poulenc Agric. Co., Research Triangle Park, NC), (5) imidacloprid (Provado 1.6 flowable [0.053 kg (AI)/ha], Bayer, Inc., Kansas City, MO), and (6) oxamyl (Vydate 2.76 concentrated low volume [0.28 kg (AI)/ha], Dupont Agricultural Products, Wilmington, DE). The recommended rate for *L. lineolaris* control in Mississippi was used for

all insecticides. 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 TX-8 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. A water control was included in the test.

Insects were aspirated into a new plastic petri dish (100 x 15 mm), anesthetized lightly (until slight knockdown or approximately 3-5 sec) with CO<sub>2</sub> and then placed uncovered in the spray chamber for treatment. Control insects were treated in the same manner to eliminate CO<sub>2</sub> knockdown as a source of mortality. 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<sub>2</sub> into the dish from a CO<sub>2</sub> cylinder. A treatment replicate consisted of ten insects per species. Each treatment was replicated six times for a total of 60 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 (green beans for *L. lineolaris* and *H. virescens* eggs for *G. punctipes*) and placed in an environmental chamber maintained at 25 ± 2°C, 50 ± 5% RH, and a photoperiod of 14:10 (L:D) h. All insects were checked for mortality 48 h after treatment.

**Residual Toxicity Bioassay.** Bollgard cotton (Monsanto, St. Louis, MO) was planted in plots 4 (1.02 m/row) rows x 61 m and were replicated four times. All insecticides were applied with a spray system pressurized by compressed air mounted on a John Deere 600 high clearance sprayer. The application parameters were: speed - 4.8 kph; pressure - 358 kPa; volume - 93.4 L/ha; and nozzles - TX-12 (Spraying systems, Wheaton, IL). In 1996, a test was repeated on 24, 25, and 28 June and included the following six treatments with the same rates as in the previous test: (1) acephate (2) dicotophos, (3) fipronil, (4) imidacloprid, (5) oxamyl, and (6) untreated control. A randomized complete block design with four replications was used. On 27 June 1997 a second test was done in conjunction with the field study below and included the insecticide lambda-cyhalothrin at the rate in the previous test and an untreated control. For both tests, ten cotton leaves from the fourth node down from the terminal were collected from each treatment replicate for bioassay immediately after the insecticide dried (approximately 1 h after treatment). Leaves were placed in plastic bags, transported to the laboratory on ice, and placed in 15 x 100 mm petri dishes. One *G. punctipes* and one *L. lineolaris* were placed in each of the ten plastic petri dishes containing a treated cotton leaf. All insects were checked for mortality after 48 h.

**Field Study.** Bollgard cotton (Monsanto Company, St. Louis, MO) was planted in large plots, 40 rows (1.02 m/row) wide by 39.6 m long (0.162 ha), to minimize insect migration. A John Deere 600 high-clearance sprayer equipped with a conventional spraying system was calibrated to deliver 46.8 liters/ha using TX-8 nozzles (Spraying Systems, Wheaton, IL) and 275 kPa pressure. The test began 26 June 1997 and included two treatments: 1) lambda cyhalothrin at 0.0128 kg (AI)/ha, and 2) untreated control. A randomized complete block design with four replications was used. Sampling was done immediately before each application. Post application samples were made at 1, 3, and 5 days after application. Samples (four rows) were taken using a KISS sampler (Beerwinkle et al. 1997). This sampling method was used in preference to other sampling techniques to obtain sufficient insects to make comparisons between treatments.

Percentage mortality for topical and 1996 residual data were converted by arcsine transformation and then analyzed using PROC MIXED followed by a least significant difference test (LSD) (SAS Institute 2001) where appropriate. In the 1997 residual and field experiments, *t*-tests were used for comparisons of means between treatments and species.

## RESULTS AND DISCUSSION

**Topical Toxicity Study.** A statistically significant difference was detected between species ( $F = 4.32$ ;  $df = 1, 65$ ;  $P = 0.042$ ) and insecticide treatments ( $F = 117.7$ ;  $df = 6, 65$ ;  $P =$

0.0001) when insects were exposed to topical applications of selected insecticides (Table 1).

TABLE 1. Topical Toxicity of Selected Insecticides to *G. punctipes* and *L. lineolaris* Adults in a Spray Chamber Bioassay.

Treatment	Kg (AI)/ha	% Mortality <sup>a</sup>	
		<i>G. punctipes</i>	<i>L. lineolaris</i>
Lambda-cyhalothrin	0.028	100.0 ± 0.0 a, 1	100.0 ± 0.0 a, 1
Dicrotophos	0.56	100.0 ± 0.0 a, 1	100.0 ± 0.0 a, 1
Acephate	0.56	96.5 ± 0.0 a, 1	94.7 ± 0.0 a, 1
Fipronil	0.056	93.3 ± 2.5 a, 1	93.3 ± 4.1 a, 1
Oxamyl	0.28	83.3 ± 7.1 b, 2	96.7 ± 4.0 a, 1
Imidacloprid	0.053	53.3 ± 15.8 c, 2	66.7 ± 10.6 b, 1
Water		0 d, 1	10.0 c, 1

<sup>a</sup>Means were assessed 48 h after treatment. Means within a column and row followed by the same letter and number, respectively, are not significantly different ( $P > 0.05$ ; LSD).

Both oxamyl and imidacloprid were less toxic to *G. punctipes* than to *L. lineolaris* even though oxamyl was more toxic than imidacloprid to the former species. Imidacloprid was the least effective insecticide against *L. lineolaris* in this topical contact test. Lambda-cyhalothrin, dicrotophos, acephate, and fipronil were very toxic to both insect species. Other researchers have also reported that topical applications of organophosphates, synthetic pyrethroid, and fipronil are toxic to *G. punctipes* (Lingren and Ridgway 1967, Tillman and Mulrooney 2001).

**Residual Toxicity Study.** A statistically significant difference was detected between species ( $F = 19.29$ ;  $df = 1, 12$ ;  $P = 0.0009$ ) and insecticide treatments ( $F = 20.11$ ;  $df = 5, 11.9$ ;  $P = 0.0001$ ) when insects were exposed to residues of the selected insecticides (Table 2). *L.*

TABLE 2. Residual Toxicity of Selected Insecticides to *G. punctipes* and *L. lineolaris* in a Field-treated Cotton Leaf Bioassay.

Treatment	Year	Kg (AI)/ha	% Mortality <sup>a</sup>	
			<i>G. punctipes</i>	<i>L. lineolaris</i>
Dicrotophos	1996	0.56	89.2 ± 2.9 a, 1	98.3 ± 1.3 a, 1
Fipronil		0.056	88.3 ± 4.2 a, 1	93.3 ± 3.8 a, b, 1
Acephate		0.56	85.8 ± 5.6 a, 1	83.2 ± 5.0 b, 1
Oxamyl		0.28	70.8 ± 7.0 b 2	91.7 ± 3.5 a, b, 1
Imidacloprid		0.053	45.0 ± 8.8 c, 2	65.0 ± 7.3 c, 1
Control			0 d, 1	4.2 d, 1
Lambda-cyhalothrin	1997	0.028	87.5 ± 6.3 a, 1	87.0 ± 5.4 a, 1
Control			0 b, 1	0 b, 1

<sup>a</sup> Means were assessed 48 h after exposure to residues on leaves collected 1 h after insecticide application. For 1996, means within a column and a row followed by the same letter and number, respectively, are not significantly different ( $P > 0.05$ ; LSD). For 1997, means within row and column followed by the same number are not significantly different ( $P > 0.05$ ; *t*-test).

*lineolaris* was more susceptible to imidacloprid and oxamyl residues than *G. punctipes*. However, oxamyl was more toxic to the pest than imidacloprid. Both insect species responded very similarly to fipronil, acephate, dicrotophos, and lambda-cyhalothrin, all of which were very toxic to these insects.

For *G. punctipes*, residual toxicity was highest for dicrotophos, fipronil, lambda-cyhalothrin, and acephate. Toxicity of oxamyl to *G. punctipes* was lower than that of the four former insecticides, but oxamyl was still intermediate in toxicity to this predator. For *L. lineolaris*, residual toxicity was high for all insecticides except imidacloprid.

The pattern of the response between insecticides and species to prolonged tarsal contact with dried insecticide residues and topical contact with sprayed insecticides was similar for both insect species. Even though toxicity of insecticides administered topically appears to be higher than that of toxicity from prolonged contact to dried insecticide residues, the general pattern of toxicity between the insecticides remains similar for both methods of application. Since the entry of these insecticides likely would be through the exoskeleton for both types of administration, the pattern of toxicity between these insecticides should be similar for both application methods. Topical applications of insecticides may have resulted in higher toxicity than exposure to insecticide residues because more of the active ingredient could enter the insect with wet versus dry insecticides. Unfortunately, quantifying amounts of insecticides in treated insects was beyond the scope of this particular study.

Residual toxicity of imidacloprid to *G. punctipes* in this study was the same as that reported by Boyd and Boethel (1998), a little higher than that reported by Elzen et al. (1998), and a little lower than that reported by Mizell and Sconyers (1992). These variances in toxicity between tests are probably due to differences in amount of exposure of the insects to the insecticide (entire surface treated versus top of leaf treated) and level of coverage on substrates (sprayed versus dipped insecticide). Each study, nevertheless, has shown that imidacloprid is less toxic than the organophosphates used for TPB control. Toxicity of oxamyl residues reported by Elzen et al. (1998) was much lower than the toxicity we obtained for *G. punctipes*. The reason for our differences is not clear, but may be due to differences in plant feeding during the test. Nevertheless, we both found that oxamyl was less toxic to *G. punctipes* than organophosphates. Elzen et al. (1998) not only determined, as we did, that residues of fipronil were very toxic to *G. punctipes*, but also that they acted quickly (30 min.). McCutcheon and DuRant (1999) also showed that residues of acephate on cotton plants in field cages, in comparison to residues on leaves in a petri dish, were very toxic to *G. punctipes*. Except for Boyd and Boethel (1998), all the residual toxicity tests, including ours, were conducted by exposing the insects to residues of the insecticide on leaves of a plant. A problem with this protocol is that the residual test may be compounded by feeding on treated leaves, and feeding on insecticide treated leaves can have a detrimental effect on plant-feeding insects. *Geocoris punctipes* females were susceptible to feeding through dried residues of Steward after sprayed on young cotton plants (Tillman et al. 2001). To eliminate insect feeding, insects can be exposed to residues on the inside surface of a holding container. Walking on treated leaves, though, more closely imitates field conditions. A possible solution to obtain the best of both experimental protocols would be to prevent insects from feeding on treated leaves. Thoughtful consideration of feeding behavior of pests and predators should be taken into account when conducting tests to determine the effect of tarsal contact to residues of insecticides.

**Field Study.** The day before insecticide application, the number of insects was the same for treated plots and untreated controls for both species (Fig. 1). However, numbers of insects were much lower in the treated plots compared to the untreated controls 1, 3, and 5 days after insecticide application for both species. In comparison to the untreated control, a 100% reduction in TPB numbers occurred 1 day after lambda-cyhalothrin application while a 84% reduction occurred for the same treatment and time after application for *G. punctipes*. However,

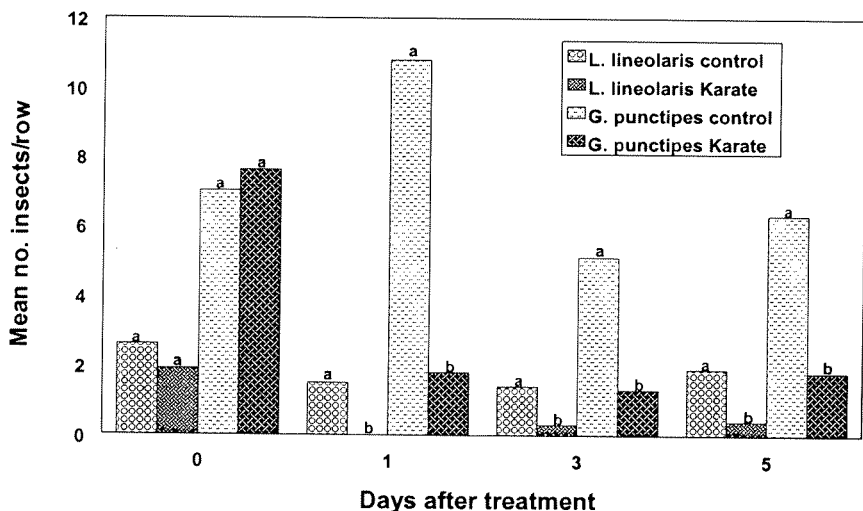


FIG. 1. Mean numbers of *G. punctipes* and *L. lineolaris* per row after application of cyhalothrin (0.028 kg/ha) on day 0. Means between treatments (untreated controls and Karate treated plots) within the same treatment day and insect species followed by the same letter are not significantly different ( $P > 0.05$ ;  $t$ -test).

percentage of reduction in number for the treated plots in comparison to untreated controls was equal (approximately 80%) for each species day 3 and 5 after application. Thus, we concluded that lambda-cyhalothrin had an equally negative impact on populations of TPB and *G. punctipes* in the field. Other studies also have shown that although lambda-cyhalothrin was very effective against TPB in field plots, it reduced populations of cotton predators, including *G. punctipes* (Graham and Gaylor 1988, Stuebaker 1997, Muegge and Payne 2001).

Acephate and dicotophos, too, have been reported to be equally detrimental to TPB and cotton predators, including *G. punctipes*, in field plots 1, 3, and 7 days after treatment (DAT) (Burris et al. 1986, Graham and Gaylor 1988, Stuebaker 1997). Logically lambda-cyhalothrin, acephate, and dicotophos should be very toxic to TPB and cotton predators in the field since these insecticides are highly toxic to both insect species through both topical and residual routes of administration. However, fipronil which was equally toxic to both insect species in the lab, was shown to be effective against TPB, but not detrimental to cotton predators, in field plots 7 DAT (Stuebaker 1997). Fipronil has feeding activity, since mortality of *G. punctipes* females was very high when they fed on fipronil-treated prey eggs (Elzen 2001). Thus, the reason for the differences in susceptibility of TPB and cotton predators to fipronil in these field tests is not apparent. It is possible that other species grouped into "cotton predators" are less susceptible to fipronil than *G. punctipes*, or a reduction in the predator population occurred before the 7 DAT sampling time. Muegge and Payne (2001) reported that imidacloprid was effective against TPB 3 and 7 DAT, but ineffective at 14 DAT at which time the population of *G. punctipes* dropped below that of the control. Since *G. punctipes* was less susceptible to imidacloprid than TPB in the lab, the differences in susceptibility between the two insect species in the field was not surprising. *G. punctipes* consumes fewer imidacloprid-treated prey than untreated prey (Elzen 2001). So the drop in population of *G. punctipes* at 14 DAT may be due to lower egg production, thus fewer nymphs would develop in the field or more simply adults died from lack

of suitable nutrition. Our topical and residual studies indicate that imidacloprid would be ineffective against TPB in the field, and yet it was reported to be very effective in field plot tests (Stuebaker 1997, Muegge and Payne 2001). The insecticide may have feeding activity against TPB increasing effectiveness in the field. Oxamyl was very effective against TPB without reducing cotton predators in field plots (Stuebaker 1997). Oxamyl has shown very little to no feeding activity against brown and green stinkbugs (Tillman, unpublished data), and thus, may have no feeding activity against cotton predators. A possible explanation for the observed difference in susceptibility of field populations of cotton predators and TPB could be that other predators are less susceptible than TPB to tarsal contact with residues of oxamyl as shown for *G. punctipes*, and they are unaffected when feeding on cotton with residues of oxamyl. Further studies on feeding activity of these two insecticides along with fipronil and the effect of these insecticides on *G. punctipes* in field plots clearly need to be done to fully understand the impact these insecticides would have on *G. punctipes* populations in the field. Nevertheless, results from our laboratory and Stuebaker's (1997) and Muegge and Payne's (2001) field studies indicate that oxamyl and imidacloprid would be effective against TPB while conserving populations of *G. punctipes* for biological control of lepidopteran larvae in cotton fields.

#### LITERATURE CITED

- Bannister, J. M., G. L. Lentz, and N. B. Austin. 1995. Efficacy of insecticides on tarnished plant bugs in cotton. ESA Arthropod Management Test. pp. 193-194.
- Beerwinkle, K. R., J. R. Coppedge, and T. M. O'Neil. 1997. "KISS" - a new portable pneumatic "Keep-It-Simple Sampler" for row crop insects, pp. 1330 - 1333. *In Proc., Beltwide Cotton Res. Conf., National Cotton Council, Memphis, TN.*
- Boyd, M. L., and D. J. Boethel. 1998. Susceptibility of predaceous hemipteran species to selected insecticides on soybean in Louisiana. *J. Econ. Entomol.* 91: 401-409.
- Burris, G., J. B. Graves, and A. M. Pavloff. 1986. Effects of select early treatments on flowering, June bollworms, and the early pest/predator complex. ESA Insecticide and Acaricide Test. pp. 260-261.
- Burris, G., B. R. Leonard, S. H. Martin, C. A. White, J. B. Graves, R. Shaw, and W. P. Scott. 1994. Fipronil: Evaluation of soil and foliar treatments for control of thrips, aphids, plant bugs, and boll weevils, pp. 838-844. *In Proc., Beltwide Cotton Res. Conf., National Cotton Council, Memphis, TN.*
- Elzen, G. W. 2001. Lethal and sublethal effects of insecticide residues on *Orius insidiosus* (Hemiptera: Anthocoridae) and *Geocoris punctipes* (Hemiptera: Lygaeidae). *J. Econ. Entomol.* 94: 55-59.
- Elzen, G. W., P. J. Elzen, and E. G. King. 1998. Laboratory toxicity of insecticide residues to *Orius insidiosus*, *Geocoris punctipes*, *Hippodamia convergens*, and *Chrysoperla carnea*. *Southwest. Entomol.* 23: 335-342.
- Elzen, G. W., and P. J. Elzen. 1999. Lethal and sublethal effects of selected insecticides on *Geocoris punctipes*. *Southwest. Entomol.* 24: 199-205.
- Eubanks, M. D., and R. F. Denno. 1999. The ecological consequences of variation in plants and prey for an omnivorous insect. *Ecol.* 80: 1253-1266.
- Graham, L. C., and M. J. Gaylor. 1988. Effect of selected insecticides on tarnished plant bug and predaceous arthropods. ESA Insecticide and Acaricide Test. pp. 242.
- Hanny, B. W., T. C. Cleveland, and W. R. Meredith, Jr. 1977. Effects of tarnished plant bugs (*Lygus lineolaris*) infestations on presquaring cotton (*Gossypium hirsutum*). *Environ. Entomol.* 6: 460-462.
- Langston, W. C., and M. F. Schuster. 1989. Cotton pest control. ESA Insecticide and Acaricide Test. pp.121-242.

- Leonard, B. R., J. B. Graves, A. M. Pauloff, and G. Burris. 1987. Evaluation of selected insecticides on tarnished plant bugs, cotton fleahopper and beneficial insects. *ESA Insecticide and Acaricide Test*. p. 233.
- Lingren, P. D., and R. L. Ridgway. 1967. Toxicity of five insecticides to several insect predators. *J. Econ. Entomol.* 60: 1639-1641.
- Lingren, P. D., R. L. Ridgway, and S. L. Jones. 1968. Consumption by several common arthropod predators of eggs and larvae of two *Heliothis* species that attack cotton. *Ann. Entomol. Soc. Am.* 61: 613-618.
- McCutcheon, G. S., and J. A. DuRant. 1999. Survival of selected generalist predaceous insects exposed to insecticide residues on cotton. *J. Cotton. Sci.* 3: 102-108.
- Micinski, S. 1983. Insecticide treatments for tarnished plant bug and cotton fleahopper control. *ESA Insecticide and Acaricide Test*. p. 195.
- Mizell, R. F., and M. C. Sconyers. 1992. Toxicity of imidacloprid to selected predators in the laboratory. *Fla. Entomol.* 75: 277-280.
- Muegge, M. A., and C. Payne. 2001. Effect of selected insecticides on *Lygus* spp. And beneficial arthropods in cotton, pp. 911-913. *In Proc., Beltwide Cotton Res. Conf., National Cotton Council, Memphis, TN.*
- Pankey, J. H., B. R. Leonard, J. B. Graves, and E. Burris. 1996. Toxicity of acephate, cypermethrin and oxamyl to tarnished plant bugs in vial bioassays and caged studies on cotton, pp. 882-887. *In Proc., Beltwide Cotton Res. Conf., National Cotton Council, Memphis, TN.*
- Reed, J. T., M. S. Howell, and C. S. Jackson. 1997. Efficacy of various insecticides against tarnished plant bugs in Mississippi. *ESA Insecticide and Acaricide Test*. p. 267.
- Robbins, J. T., F. A. Harris, and R. E. Harris. 1998. Tarnished plant bug control in the Mississippi Delta, pp. 1197-1198. *In Proc., Beltwide Cotton Res. Conf., National Cotton Council, Memphis, TN.*
- Russell, J. S., J. Goer, K. D. Torrey, and B. R. Leonard. 1998. Evaluation of insecticide treatments against tarnished plant bugs in cotton. *ESA Insecticide and Acaricide Test*. p. 244.
- SAS Institute. 2001. SAS/C online document™, Release 8.2, Cary, NC, SAS Institute, Inc.
- Scott, W. P., and G. L. Snodgrass. 1996. Efficacy of Fipronil and Provado against tarnished plant bugs in cotton. *ESA Arthropod Management Test*. p. 268.
- Shaw, R., and H. S. Yang. 1996. Performance summary of Fipronil insecticide on cotton 1996, pp. 862-865. *In Proc., Beltwide Cotton Res. Conf., National Cotton Council, Memphis, TN.*
- Snodgrass, G. L., and G. W. Elzen. 1995. Insecticide resistance in a tarnished plant bug population in cotton in the Mississippi Delta. *Southwest. Entomol.* 20: 317-323.
- Studebaker, G. 1997. Efficacy of selected insecticides on plant bugs and predatory arthropods on cotton. *ESA Arthropod Management Test*. pp. 272-273.
- Teague, T. G., and N. P. Tugwell. 1996. Efficacy of Provado when applied with feed grade molasses to control tarnished plant bugs. *ESA Arthropod Management Test*. pp. 269-270.
- Tillman, P. G., and J. E. Mulrooney. 2001. Effect of malathion on beneficial insects. *Southwest. Entomol. Supplement* 24: 13-21.
- Tillman, P. G., G. G. Hammes, M. Sacher, M. Connair, E. A. Brady, and K. Wing. 2001. Toxicity of a formulation of the insecticide indoxacarb to the tarnished plant bug, *Lygus lineolaris* (Hemiptera: Miridae), and the big-eyed bug, *Geocoris punctipes* (Hemiptera: Lygaeidae). *Pest Management Science* 58: 92-100.