Indirect Effect of Insecticides Used in Pecan Orchards to Larvae of *Chrysoperla rufilabris* (Neuroptera: Chrysopidae)[1]

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ABSTRACT Eight insecticides at two concentrations (low and high) were tested for toxicity to first, second, and third instars of *Chrysoperla rufilabris* (Burmeister). Lindane (0.65 and 1.3 g actual insecticide AI/l), endosulfan (0.375 and 0.75 g AI/l), carbaryl (1.2 and 2.4 g AI/l), azinphos-methyl (1.0 and 2.0 g AI/l, malathion (0.9 and 1.8 g AI/l), methomyl (0.225 and 0.45 g AI/l), phosmet (0.375 and 0.75 g AI/l), and esfenvalerate (0.0.15 and 0.03 g AI/l) treated cowpea aphids (*Aphis craccivora* Koch) were fed to the lacewing larvae in the laboratory. Among tested insecticides, azinphos-methyl was the most toxic insecticide to larvae at the low and high rates and was classified as moderately harmful. Lindane and carbaryl were slightly harmful; endosulfan, malathion, methomyl, phosmet, and esfenvalerate were harmless. In most cases the first instar larvae were the most susceptible to the insecticides tested. Both rates caused similar mortality of *C. rufilabris* larvae after 48 h of feeding with the exception of azinphos-methyl and methomyl which caused higher mortality at the high rate.

KEY WORDS *Chrysoperla rufilabris,* insecticides, aphids, toxicity.

Chrysoperla rufilabris (Burmeister) commonly occurs in a variety of habitats throughout most of the United States (Burke and Martin 1956, Muma 1959, Edelson and Estes 1987). The larvae are predaceous and attack most any soft-bodied insects and mites they encounter (Angew et al. 1981, Tauber and Tauber 1983). Predators such as *C. rufilabris,* which can feed on a wide variety of prey, have potential as biological control agents, in part, because their population can be maintained on alternate prey during periods of low pest density (Ehler and van den Bosch 1974). *C. rufilabris* is the most abundant predator of pecan aphids *Monelliopsis pecanis* Bissell and *Monellia caryella* (Fitch) (Edelson and Estes 1987).

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Among natural enemies, the preimaginal stages of Chrysopidae are considered, in general, to be relatively tolerant of chlorinated hydrocarbons and pyrethroid insecticides, and intolerant of carbamates and organophosphates when insecticides are applied directly or when insects contact fresh or dry residue (Bartlet 1964, Wilkinson et al. 1975, Plapp and Bull 1978, Shour and Crowder 1980, Grafton-Cardwell and Hoy 1985). Closely allied species may respond differently to the same pesticide (Putman 1956, Lingren and Ridgway 1967). In addition, the same species may respond differently to different pesticides within the organophosphate and carbamate groups. One-day-old residues of azinphosmethyl, carbaryl, and ethion caused 80, 65, and 0% mortality, respectively, to third instars of *C. rufilabris* after 48 h of exposure (Lawrence 1974). Residues of chlorinated hydrocarbons (lindane and endosulfan) and pyrethroids (cypermethrin, fenvalerate, and fluvalinate) were not toxic to first- and second instars of *C. rufilabris,* but eight organophosphates and carbamates (carbaryl and methomyl) were found to be toxic (Mizell and Schiffhauer 1990).

Predators feeding on treated prey also may be affected indirectly by insecticides. Demeton had very little effect on the first instars of *C. rufilabris* when fed for 7 d on dead or dying *Aphis gossypii* Glover (Ahmed et al. 1954). Second instar *Antocoris nemorum* (L.) and *A. confusus* Reuter, feeding on pea aphids that had been killed by the systemic insecticide phorate, grew into normal adults and suffered no mortality (Elliot 1970). In contrast, three species of Syrphidae were highly affected when fed on cotton aphids killed by demeton (Ahmed et al. 1954). Endosulfan, carbaryl, phosmet, methomyl, and esfenvalerate were very toxic to larvae and adults of *Hippodamia convergens* Guerin-Meneville when coccinellids were fed insecticide-treated *Monelliopsis pecanis* Bissell (Hurej and Dutcher 1994). Our objective was to study the indirect toxicity of eight contact insecticides used in pecan orchards to the first, second, and third instars of *C. rufilabris* when fed on insecticide-treated aphids.

Materials and Methods

The indirect effect of insecticides on mortality of *C. rufilabris* larvae was studied in laboratory tests. Eggs were obtained from a culture managed by W. L. Tedders of the USDA Southeastern Fruit and Tree Nut Laboratory at Byron, GA and held in a rearing room at 23 ± 2°C with 55 ± 5% RH and a photoperiod of 16:8 (L:D) h. A new *C. rufilabris* gene pool is started in Byron each year from a pecan orchard that is sprayed with pesticides based upon the University of Georgia standard recommendations. Newly-hatched larvae were placed individually in 29.6-ml cups sealed with paper lids. The larvae were fed frozen eggs of *Sitotroga cerealella* (Oliver) at 2-d intervals until they reached the desired life stage.

Eight contact insecticides in four chemical classes were tested at two concentrations (low and high): lindane - a chlorinated hydrocarbon - (Lindane, Ford's Chemical & Service, Inc., Pasadena, TX, 0.65 and 1.3 g actual insecticide AI/l), endosulfan - a chlorinated hydrocarbon - (Phaser, Hoechst Roussel, Somerville, NJ, 0.375 and 0.75 g AI/l), carbaryl - a carbamate - (Sevin 80S [80% Soluble Powder] Rhone-Poulenc, Research Triangle Park, NC, 1.2 and 2.4 g

AI/l), azinphos-methyl - an organophosphate - (Guthion 2S [Emulsifiable Insecticide, 2 lbs./gallon] Mobay Chemical Corporation, Kansas City, MO, 1.0 and 2.0 g AI/l), malathion - an organophosphate - (Cythion, American Cyanamid Company, Wayne, NJ, 0.9 and 1.8 g AI/l), methomyl - a carbamate - (Lannate LV [Low Volume], E. I. duPont de Nemours & Co., Wilmington, DE, 0.225 and 0.45 g AI/l), phosmet - an organophosphate - (Imidan 50WP [50% Wettable Powder] ICI Americas, Inc., Wilmington, DE, 0.375 and 0.75 g AI/l), esfenvalerate - a pyrethroid - (Asana XL 0.66 EC [Emulsifiable Concentrate, 0.66 lbs./gallon], E. I. duPont de Nemours & Co., Wilmington, DE, 0.015 and 0.03 g AI/l).

Cowpea aphids (*Aphis craccivora* Koch) were reared on cowpea seedlings in the greenhouse. Cowpea leaves heavily infested with aphids were dipped in each insecticide solution or water for 5 s and dried under a fume hood. An overabundance of insecticide or water-treated aphids were added by brush twice a day to each cup containing lacewings. New groups of aphids were treated with each insecticide on each day of the test. Five replications of ten lacewings each were tested for each larval stage at the low and high concentrations of each insecticide. Response of lacewings to insecticide-treated aphids at these rates were compared with their response to water-treated aphids. Mortality was recorded 1, 24, and 48 h after first aphids were added to the cups. Mortality of the test insects was corrected for control mortality by Abbott's (1925) formula. Percentages were subjected to analysis of variance (ANOVA) and Fisher's Least Significant Difference (LSD) (SAS Institute 1989).

Results and Discussion

Azinphos-methyl, both at the low and high rates, was the most toxic insecticide to larvae of *C. rufilabris* when they fed for 48 h on insecticide-treated *A. craccivora.* The final mortality of the first and second instars at the low rate was 75 and 76%, respectively, and 95 and 96%, respectively, at the high rate of application (Table 1). Third instars exhibited much lower mortality (30 and 42%) at the low and high rates, respectively. This insecticide acted slowly on lacewing larvae. Only a single larva was recorded dead after 1 h of feeding. Mortality significantly ($P < 0.05$) increased after 24 h and was the highest after 48 h. Azinphos-methyl, at the high rate, caused significantly ($P < 0.05$) higher mortality than at the low rate to first and second instar larvae after 24 and 48 h of feeding ($F = 13.5$ and 18.2 for the first instar, and 13.0 and 34.4 for the second instar, respectively, df = 1,9). Azinphos-methyl also was highly toxic to first, second, and third instars of *C. rufilabris* when they contacted residues of the insecticide (Lawrence 1974, Mizell and Schiffhauer 1990). Our tests demonstrated that third instars were much more tolerant of the insecticide than the first and second instars when they fed on treated aphids.

Lindane and carbaryl were less toxic to *C. rufilabris* than azinphos-methyl: 67 and 51% mortality at the low rate and 71 and 72%, at the high rate for the first instars after 48 h (Table 1). Second and third instars exhibited tolerance to carbaryl and lindane. Mortality was highest (18%) for the second instars after 48 h of feeding on lindane-treated aphids. Low mortality for the first instars was observed when they fed for 1 h on lindane and carbaryl treated aphids.

Table 1. Indirect toxicity of insecticides to *C. rufilabris* larave.

		Percentage mortality ± SEM of lacewings at the indicated rates and hours.*							
		low concentration				high concentration			
Insecticide	Instar	1 h	24 h	48 h	F**	1 h	24 h	48 h	F**
Azinphos-methyl	First	2 ± 2aC	43 ± 8aB‡	75 ± 2aA†	48.4	4 ± 2aC	77 ± 4aB	95 ± 3aA	222.6
	Second	0 ± 0aC	52 ± 4aB‡	76 ± 4aA†	150.9	2 ± 2aC	70 ± 3aB	96 ± 2aA	353.4
	Third	0 ± 0aB	16 ± 7bAB	30 ± 8bA	5.8	2 ± 2aC	22 ± 7bB	42 ± 9bA	7.0
	F†	1.0	7.8	22.8		0.3	33.4	22.4	
Lindane	First	30 ± 6aB	62 ± 9aA	67 ± 8aA	6.2	24 ± 5aB	55 ± 6aA	71 ± 5aA	18.0
	Second	0 ± 0bA	6 ± 4bA	10 ± 4bA	2.1	6 ± 2bA	14 ± 5bA	18 ± 4bA	2.4
	Third	0 ± 0bA	4 ± 2bA	6 ± 2bA	2.3	0 ± 0bB	8 ± 2bA	10 ± 0bA	21.0
	F†	22.5	32.1	35.0		14.6	27.7	75.1	
Carbaryl	First	10 ± 4aB	42 ± 7aA‡	51 ± 9aA	9.9	10 ± 4aB	68 ± 7aA	72 ± 6aA	33.7
	Second	0 ± 0bB	2 ± 2bAB	10 ± 4bA	3.5	0 ± bB	4 ± 2bA	10 ± 7bA	1.1
	Third	0 ± 0bA	0 ± 0bA	0 ± 0bA	0.0	0 ± 0bA	0 ± 0bA	2 ± 2bA	1.0
	F†	5.0	35.1	22.6		5.0	72.1	45.1	
Esfenvalerate	First	6 ± 4aB	18 ± 7aB	42 ± 8aA	8.1	6 ± 2aB	14 ± 2aB	46 ± 5aA	35.4
	Second	0 ± 0aA	0 ± 0bA	4 ± 2bA	2.7	2 ± 2abB	4 ± 4aAB	14 ± 4bA	3.4
	Third	0 ± 0aA	6 ± 2abA	6 ± 2bA	3.0	0 ± 0bA	8 ± 4aA	8 ± 4bA	2.3
	F†	2.2	5.0	18.0		2.8	2.1	22.4	
Malathion	First	0 ± 0aB	18 ± 6aA†	22 ± 7aA†	5.5	8 ± 4aB	45 ± 10aA	49 ± 14aA	6.1
	Second	0 ± 0aC	14 ± 4abB	26 ± 5aA	12.1	0 ± 0bB	18 ± 6bA	30 ± 6bA	9.2
	Third	0 ± 0aA	2 ± 2bA	10 ± 7aA	1.3	0 ± 0bB	8 ± 4bB	20 ± 3bB	12.7
	F†	0.0	4.0	1.6		4.6	7.6	4.2	
Methomyl	First	10 ± 3aA	19 ± 4aA†	21 ± 6aA†	1.8	22 ± 6aB	44 ± 7bA	49 ± 7aA	5.1
	Second	2 ± 2bA	12 ± 5abA	14 ± 5abA	2.3	8 ± 4bB	24 ± 7bAB	38 ± 9aB	4.1
	Third	0 ± 0bA	2 ± 2bA	2 ± 2bA	0.5	0 ± 0bA	2 ± 2cA	6 ± 4bA	1.4
	F†	6.0	5.2	4.4		7.7	14.4	9.1	

* Lowercase letters within each column are for mean percentage mortality at the same hour for each rate; uppercase letters within the same row are for mean percentage mortality of the same stage at 1, 24, and 48 h at the 50 and 100% rates. ‡ indicate significant ($P < 0.05$) differences between percentage mortality at the 50 and 100% rates at the same stage and hr. Means were separated ($P < 0.05$) using Fisher's protected least significant difference (LSD) (SAS Institute 1989).

** F values for means separation for each stage at different time periods.

† F values for means separation for all stages at each time period.

Mortality increased significantly ($P < 0.05$) after 24 h and did not change after 48 h. Lindane and carbaryl, at the low and high rates, caused similar mortality when the same stage and hour were compared, with one exception; carbaryl at the high rate caused higher mortality of the first instar after 24 h of feeding ($F = 6.9$, df = 1,9). Lindane and carbaryl were similarly highly toxic to the first instars of *C. rufilabris* when they were fed insecticide-treated aphids, while lindane was not toxic and carbaryl was highly toxic to these larvae when they contacted residue of the insecticides (Mizell and Schiffhauer 1990).

Esfenvalerate, malathion, and methomyl at the high rates killed 46, 49, and 49%, respectively, of the first instars of *C. rufilabris* after 48 h of feeding. Second and third instars were more tolerant of esfenvalerate than first instars. Esfenvalerate caused similar mortality to larvae at the low and high rates after 1, 24, and 48 h of feeding. In most cases, toxicity of malathion and methomyl at the low and high concentrations to the same stage and at the same hour was similar. Significantly ($P < 0.05$) higher mortality was found only for the first instars after 24 h in the case of malathion ($F = 5.6$, df = 1,9) and for the first instars after 24 and 48 h in the case of methomyl ($F = 11.0$ and 9.8, respectively, df = 1,9). Dry residues of the pyrethroid insecticides fenvalerate, cypermethrin, and fluvalinate were safe to larvae of *C. rufilabris* (Mizell and Schiffhauer 1990). It is known that lacewing larvae exhibit high natural tolerance to pyrethroids (Shour and Crowder 1980, Grafton-Cardwell and Hoy 1985). A portion of this tolerance is attributable to detoxification by pyrethroid esterase(s) (Ishaaya and Casida 1981). Malathion and methomyl which showed low indirect toxicity to lacewing larvae in our tests were highly toxic when larvae contacted residues of the insecticides (Mizell and Schiffhauer 1990).

All three larval instars of *C. rufilabris* were extremely tolerant of endosulfan and phosmet when fed for 48 h on insecticide-treated *A. craccivora*. The highest morality found was 4% for second instars at the high rate in the case of endosulfan and 2% for the first instars at the low rate in the case of phosmet. Endosulfan also was not toxic to larvae of *C. rufilabris* when they contact residues of the insecticide (Mizell and Schiffhauer 1990) and phosmet residue was not toxic to larvae of *Chrysoperla carnea* (Stephens) (Grafton-Cardwell and Hoy 1985).

The Working Group "Pesticides and Beneficial Organisms" of the International Organization for Biological Control established four categories of direct pesticide toxicity to beneficial organisms tested in the laboratory: 1 = harmless (<50% mortality), 2 = slightly harmful (50 - 79%), 3 = moderately harmful (80 - 99%), and 4 = harmful (100%) (Hassan et al. 1991). Using the same categories for indirect toxicity, our insecticides may be classified as follows: azinphos-methyl is moderately harmful; lindane and carbaryl are slightly harmful; and, endosulfan, esfenvalerate, malathion, methomyl, and phosmet are harmless. Azinphos-methyl was moderately harmful for the first and second instars; third instars were tolerant of the insecticide. Lindane and carbaryl were slightly harmful only to the first instars. *C. rufilabris* has significant potential as a biological control agent for a number of pests, including pecan aphids. The direct toxicity results of Mizell and Schiffhauer (1990), and our test results on indirect toxicity suggest that insecticide applications in pecan may be integrated with mass rearing and release of *C. rufilabris*. In pecan orchards, *C. rufilabris* are released as eggs, first instars, and adults. If eggs are released, then carbaryl and fenvalerate should not be applied. If first instars are released, then azinphosmethyl should not be applied. If adults are released, then organophosphate and carbamate insecticides should not be applied. Pyrethroids are harmless to all life stages except the eggs. With the exceptions of endosulfan and phosmet which were harmless to all instars, aphids treated with the tested insecticides were more toxic to first instar *C. rufilabris* than to older larvae. *C. rufilabris* could be conserved with a delay in the insecticide application until released larvae have reached the second or third instar. Responses to low concentrations of the tested insecticides were similar to the response to high concentrations. Application of reduced concentrations or application of an insecticide followed by release of the *C. rufilabris* after the half-life of the residue of the insecticide probably would not reduce the indirect mortality to *C. rufilabris*.

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