Impact of Type and Timing of Southern Corn Rootworm Treatments on Predaceous Arthropods in Peanut[1]

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ABSTRACT At-flowering and at-pegging treatments of soil-applied insecticides for southern corn rootworm, *Diabrotica undecimpunctata howardi* Barber, control were examined to determine if type and/or timing of insecticide affected the abundance of predaceous arthropods in reproductive-stage peanuts. *Orius insidiosus* (Say) and spiders comprised the majority of predators captured during the study. Effects of timing were variable, but indicated that earlier, at-flowering pesticide application may allow for better re-establishment of some predators (e.g., *O. insidiosus*), and for the total number of predators, than later, at-pegging pesticide applications. There was no consistent effect of chlorpyrifos or fonophos applied at flowering, or chlorpyrifos or ethoprop applied at pegging, on predator abundance in reproductive-stage peanuts.

KEY WORDS Soil insecticides, peanuts, southern corn rootworm, predators, *Diabrotica undecimpunctata howardi, Orius inidiosus*

The southern corn rootworm, *Diabrotica undecimpunctata howardi* Barber (Coleoptera: Chrysomelidae), is a key pest of peanuts, *Arachis hypogea* L., in the southeastern United States (Smith and Barfield 1982). In the North Carolina-Virginia peanut growing area, adult southern corn rootworms emerge from corn in late June and early July and begin moving into flowering peanuts (Hunt and Baker 1982). Populations of southern corn rootworms are highest in late July to early August when beetles are ovipositing. Eggs are laid in the top 5-10 mm of soil near the base of host plants (Arant 1929, Brust and House 1990ab). Eggs hatch in 6-13 d and the young larvae begin feeding on subterranean plant parts (Long and Dogger 1955). Oviposition and survival are dependent on a number of environmental factors (Campbell and Emory 1967), the most important of which is soil moisture content (Grayson and Poos 1947). When soil moisture is less than 5%, little oviposition occurs (Brust and House 1990b). Eggs and early instars suffer extensive mortality when soil moisture drops below 2.5% (Krysan 1976, Lummus et al. 1983, Brust and House 1990a). Although adult feeding on peanut foliage occurs (Arant 1929), economic injury is caused by larvae feeding on the subterranean roots and pegs (Smith and Barfield 1982).

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Integrated pest management strategies for southern corn rootworm have been difficult to develop (Brandenburg and Herbert 1991). Because the damaging larval stage is soil-inhabiting, scouting is time-consuming and unreliable (Smith and Barfield 1982, Krysan and Miller 1986). In addition, the wide host range and high mobility of adult and narrow ranges of soil types and conditions required for survival of larvae, have made prediction of pod damage on the basis of adult detection schemes unproductive (Brandenburg and Barbour 1992). Currently, southern corn rootworm is controlled only through the prophylactic use of granular insecticides applied in bands over the peanut rows. Because it is essentially too late to treat an infestation once it has been discovered, these insecticides have been traditionally applied in mid-July when peanuts are pegging, and before rootworm damage can occur. While this treatment is effective, it poses problems for growers. Most of the commonly used insecticides specify soil incorporation at application. However, vines from adjacent rows are overlapping at this time and growers are hesitant to incorporate due to the associated vine damage and potential for spreading disease organisms (Brandenburg and Herbert 1991).

Brandenburg and Herbert (1991) proposed that soil insecticides for southern corn rootworm applied at flowering in mid-June, rather than at pegging in mid-July. Because plants are smaller, this early treatment allows insecticide incorporation with minimal vine damage, and reduces the risk of spreading pathogens. There are other potential benefits as well. More complete insecticide incorporation can reduce environmental hazards, particularly the risk of avian toxicity. Because insecticides used for rootworm control also control other insect pests of peanut, such as the potato leafhopper, *Empoasca fabae* (Harris), and the lesser corn stalk borer, *Elasmopalpus lignosellus* (Zeller), earlier application may reduce the total number of pesticide applications required for insect control (Brandenburg and Herbert 1991). Finally, detrimental effects on some natural enemies have been associated with at-pegging insecticide applications for control of arthropod pests in peanut (Funderburk et al. 1990, Mack et al. 1992). Chlorpyrifos is the insecticide most commonly used for southern corn rootworm control in North Carolina (Brandenburg 1990). It is possible that earlier, at-flowering treatment with chlorpyrifos, or the use of other granular insecticides applied at flowering or pegging, might allow natural enemy populations to become better established on pegging peanuts than the traditional at-pegging application of chlorpyrifos. This may reduce problems with outbreaks of secondary pests, such as twospotted spider mites, *Tetranychus urticae* (Koch), or the corn earworm, *Helicoverpa zea* (Boddie) (Brandenburg and Kennedy 1982). The objective of this research was to determine the effects of type and/or timing of pesticide application on the abundance of predaceous arthropods in pegging peanuts.

Materials and Methods

Experiments were conducted on grower fields in Bertie and Washington cos., North Carolina during 1990, and at the Peanut Belt Research Station, in Bertie Co., North Carolina during 1991 and 1992. The cultivar 'NC7' was used in all years of the study.

There were two treatments in 1990; chlorpyrifos 15G applied at-flowering and at-pegging. Material was applied at 2.6 kg ai/ha, using a bicycle-wheel applicator with a Noble metering unit, to four-row by 20-m plots. There was 0.9 m between rows, four replicates of each treatment in each field, and two fields in each county. At-flowering applications were made 20 June. At-pegging applications were made 10 and 11 July in Bertie and Washington cos., respectively. One of the two center rows of each plot was sampled 1 Aug using a gasoline-powered D-vac. All of the foliage between two adjacent rows (i.e., from the mid-line of one row to the mid-line of the adjacent row) was sampled. The arthropods collected from each row were placed in a plastic bag and taken to the laboratory) where beneficial arthropods were counted and identified.

Larger plots were used in 1991 and 1992 to minimize, as much as possible, effects of natural enemy movement between plots. There were five treatments: two at-flowering insecticide applications (chlorpyrifos 15G and fonophos 10G), two at-pegging insecticide applications (chlorpyrifos 15G and ethoprop 10G) and an untreated check. The combination of insecticides and application times used in the study represent those most likely to be used by peanut growers in North Carolina. Materials were applied as described above to 25-row by 23-m plots in 1991, and 18-row by 15-m plots in 1992. Pesticides were applied at flowering and at pegging, 11 June and 16 July, respectively, in 1991 and 18 Jun and 23 Jul, respectively, in 1992. Plots were arranged in a randomized complete block with 5 replicates. Arthropods were collected from plots using sweep nets (1991) or a gasoline-powered D-vac (1992) and pit-fall traps. Sweep nets were used in 1991 because of mechanical failure of the D-vac. All of the foliage between two adjacent rows, within 1 m of the row ends, was sampled as described above, 23 Jul and 6 and 15 Aug 1991, and 30 Jul and 12 Aug in 1992. Frequent rains prevented sweep net sampling scheduled for the week of 31 Jul 1991. Sampled rows were not re-sampled on later sample dates.

Pit-fall traps were constructed after Lesiewicz et al. (1983) using wide-mouth mason jars (473 ml, 7.6 cm ID) with plastic (177 ml) drinking cup inserts. The jars were buried with the mouth flush with the soil level. The plastic cup was placed inside the jar and filled to about 1/2 its capacity with a 1:1 solution of ethylene glycol and water. The traps were then covered with a rain guard constructed by placing 8 penny nails in the corners of 15 cm^2 sections of corrugated plastic. The nails served as legs holding the corrugated plastic above the pit-fall traps. Three traps were placed 4 m apart in the center row of each plot, but not closer than 3 m from the end of a row. Traps were placed immediately before treatment with at-pegging applied pesticides and sampled 23 and 31 Jul and 6 and 15 Aug 1991, and 30 Jul and 12 Aug in 1992. Trap contents were strained to remove ethylene glycol, rinsed with 70% EtOH into 30 ml scintillation vials, and taken to the laboratory where the predaceous arthropods were counted and identified.

Standard agronomic practices were used for production and disease management (Sullivan 1991). Data were analyzed separately by sampling date for each year of the study using PROC GLM (SAS Institute 1988). The mean number of predators collected from at-flowering and at-pegging treated plots in 1991 was compared using the F statistic provided by analysis of variance. Orthogonal contrasts were used to compare mean number of predators in (1) at-flowering versus at pegging treated plots, (2) chlorpyrifos versus fonophos within at-flowering treated plots, (3) chlorpyrifos versus ethoprop in at-pegging treated plots, and (5) treated versus untreated plots in 1991 and 1992. Probability levels for all comparisons are provided; however, differences were declared significant at the 0.05 level.

Results

D-vac/sweep net samples. Predaceous arthropods collected from D-vac and sweep net samples included spiders (Araneida); Hemiptera, including minute pirate bugs (*Orius insidiosus* (Say), Anthocoridae), big-eyed bugs (*Geocoris* spp., Lygaeidae), damsel bugs (Nabidae), and assassin bugs (Reduviidae); Coleoptera, including lady beetles (Coccinelidae), and ant-like flower beetles (Anthicidae); Neuroptera, including lacewings (Chysopidae); and Hymenoptera, largely ants (Formicidae), but including some parasitic wasps. Only spiders, pooled as a single class, and *O. insidiosus* were collected in numbers sufficient to analyze independently. *O. insidiosus* comprised 50 to more than 90% of the predaceous arthropods collected in each year of the study. Therefore, numbers of predaceous Hemiptera other than *O. insidiosus* were pooled and analyzed as a single class. The remaining predaceous arthropods (e.g., coccinelids, chrysopids, formicids and anthicids) were pooled and classified as 'other' for analysis. The total number of predaceous arthropods collected also was calculated and analyzed as a single class.

There were no significant differences in the numbers of predaceous arthropods collected from fields in Bertie and Washington cos. in 1990. Therefore, data from fields in both counties were combined for analysis (Table 1). Numbers of *O. insidiosus* and total predaceous arthropods were significantly higher in plots treated at flowering, than in plots treated at pegging with chlorpyrifos. Numbers of other predacious hemipterans, spiders, and other predators did not differ significantly between at-flowering and at-pegging treated plots.

Numbers of predaceous arthropods collected in 1991 and 1992 are shown in Table 2. The number of predators in treated plots differed significantly from the number in untreated plots only on 15 Aug 1991, when numbers of Hemiptera were higher in untreated than in treated plots. Significant differences in the numbers of predators collected from at-flowering and at-pegging treated plots were observed for several of the predator classes. Numbers of spiders were higher in at-pegging than in at-flowering treated plots on 6 Aug 1991. Numbers of *O. insidiosus* were higher in at-flowering compared to at-pegging treated plots on 30 Jul and 12 Aug 1992. Numbers of other Hemiptera also were higher in at-flowering compared to at-pegging treated plots on 30 Jul 1992. Total predator numbers were significantly higher in at-flowering than in at-pegging-treated plots for all sample dates except 23 Jul and 6 and 15 Aug 1991. Total predator numbers were numerically, but not significantly, higher in at-flowering than in at-pegging treated plots on 23 July and 15 Aug 1991 ($P < 0.06$ and $P < 0.08$, respectively), and higher in at-pegging than in at-flowering treated plots on 6 Aug 1991.

Contrasts of plots treated at-flowering with insecticides showed higher numbers of *O. insidiosus* and total predators in fonophos-treated than in chlorpyrifos-treated plots on 23 July 1991. There were no significant differences in the number of predators, in the other classes, collected from plots treated with insecticides at-flowering. Plots treated at-pegging with insecticides had higher numbers of predators in ethoprop-treated plots than in chlorpyrifos-treated plots for *O. insidiosus* on 6 Aug 1991, for spiders on 15 Aug 1991 and 30 Jul 1992, for other predators on 12 Aug 1992, and for total predators on 6 Aug 1991 and 30 Jul 1992.

Table 1. Mean number (± SEM) of arthropods captured on peanuts treated at-flowering and at-pegging with chlorpyrifos in 1990.

Time of Application	Predaceous Arthropods*				
	O. insidiosus	Hemipterans**	Spiders	Others	Total
Flowering	9.8 ± 1.95	1.3 ± 0.86	8.8 ± 1.01	0.2 ± 0.10	23.6 ± 3.08
Pegging	3.6 ± 1.26	1.1 ± 0.33	6.0 ± 1.30	0.2 ± 0.10	14.6 ± 2.92
$P \leq F$	**0.0123**	**0.8399**	**0.1167**	**1.0000**	**0.0492**

* Number of arthropods per 8 row meters: n = 16 for *O. insidiosus,* Hemiptera, and others; n = 8 for spiders. Values represent pooled means from plots in four fields.

** Values are for hemipterans other than *O. insidiosus*.

Table 2. Mean number (± SEM) of predators collected from insecticide treated and untreated peanuts in 1991 and 1992 using sweep nets and D-vac respectively.*

Date	*Orius*		Other Hemiptera**		Spiders		Other Predators[†]		Total	
Contrast	$\bar{X}$ ± SEM	$P > F$	$\bar{X}$ ± SEM	$P > F$	$\bar{X}$ ± SEM	$P > F$	$\bar{X}$ ± SEM	$P > F$	$\bar{X}$ ± SEM	$P > F$
23 July 1991										
Treated vs.	1.1. ±0.38		0 ± 0		1.0 ± 0.15		1.2 ± 0.28		3.2 ± 0.47	
Untreated	1.2 ± 0.58	0.8399	0 ± 0	N/A	1.2 ± 0.37	0.5190	1.8 ± 0.80	0.4236	4.2 ± 1.07	0.2709
Flowering vs.	1.7 ± 0.68		0 ± 0		1.1 ± 0.28		1.2 ± 0.42		4.0 ± 0.70	
Pegging	0.4 ± 0.22	0.0640	0 ± 0	N/A	0.8 ± 0.20	0.3894	1.2 ± 0.39	1.000	2.4 ± 0.54	0.0582
Fonophos vs.	3.0 ± 1.05		0 ± 0		1.2 ± 0.49		1.4 ± 0.75		5.6 ± 0.81	
Chlorpyrifos (at-flowering)	0.4 ± 0.40	0.0125	0 ± 0	N/A	1.0 ± 0.32	0.6822	1.0 ± 0.45	0.6709	2.4 ± 0.51	0.0108
Ethoprop vs.	0.6 ± 0.40		0 ± 0		1.0 ± 0.00		1.8 ± 0.58		3.4 ± 0.81	
Chlorpyrifos (at-pegging)	0.2 ± 0.20	0.6709	0 ± 0	N/A	0.6 ± 0.24	0.4165	0.6 ± 0.40	0.2125	1.4 ± 0.40	0.0902
6 August 1991										
Treated vs.	16.2 ± 3.34		0.3 ± 0.11		5.1 ± 0.66		9.6 ± 1.61		31.2 ± 5.15	
Untreated	23.4 ± 7.24	0.2673	0.4 ± 0.24	0.6854	3.4 ± 0.81	0.1009	4.6 ± 1.03	0.1203	31.8 ± 7.79	0.9404
Flowering vs.	10.7 ± 1.52		0.2 ± 0.13		3.5 ± 0.72		7.2 ± 1.69		21.6 ± 2.60	
Pegging (at-flowering)	21.6 ± 6.17	0.0713	0.4 ± 0.16	0.3700	6.7 ± 0.88	0.0021	12.0 ± 2.62	0.0972	40.7 ± 9.22	0.0238
Fonophos vs.	3.0 ± 1.05		0 ± 0		1.2 ± 0.49		1.4 ± 0.75		22.6 ± 3.50	
Chlorpyrifos	0.4 ± 0.40	0.7863	0 ± 0	0.2105	1.0 ± 0.32	0.1644	1.0 ± 0.45	0.5422	20.6 ± 4.20	0.8586

Table 2. Continued.

Date / Contrast	*Orius* $\bar{X} \pm$ SEM	*Orius* $P > F$	Other Hemiptera** $\bar{X} \pm$ SEM	Other Hemiptera** $P > F$	Spiders $\bar{X} \pm$ SEM	Spiders $P > F$	Other Predators[†] $\bar{X} \pm$ SEM	Other Predators[†] $P > F$	Total $\bar{X} \pm$ SEM	Total $P > F$
6 August 1991										
Ethoprop vs.	0.6 ± 0.40		0 ± 0		1.0 ± 0.00		1.8 ± 0.58		56.8 ± 14.88	
Chlorpyrifos (at-pegging)	0.2 ± 0.20	0.0103	0 ± 0	0.2105	0.6 ± 0.24	0.4301	0.6 ± 0.40	0.0661	24.6 ± 5.59	0.0089
15 August 1991										
Treated vs.	0.5 ± 0.28		0.1 ± 0.05		1.1 ± 0.28		1.6 ± 0.38		3.2 ± 1.47	
Untreated	1.2 ± 0.97	0.3267	0.4 ± 0.24	0.0289	1.8 ± 0.66	0.2644	1.2 ± 0.58	0.6304	4.6 ± 0.47	0.2508
Flowering vs.	0.8 ± 0.51		0 ± 0		1.1 ± 0.38		2.3 ± 0.63		4.2 ± 0.57	
Pegging	0.2 ± 0.2	0.3467	0. ± 0.10	0.4543	1.1 ± 0.43	1.0000	0.9 ± 0.31	0.0729	2.3 ± 0.70	0.0792
Fonophos vs.	1.2 ± 0.97		0 ± 0		1.4 ± 0.68		1.6 ± 0.51		4.2 ± 0.86	
Chlorpyrifos (at-flowering)	0.4 ± 0.40	0.3743	0 ± 0	1.000	0.8 ± 0.37	0.4446	3.0 ± 1.14	0.1935	4.2 ± 0.86	1.0000
Ethoprop vs.	0.4 ± 0.40		0 ± 0		2.0 ± 0.63		1.0 ± 0.55		3.4 ± 1.03	
Chlorpyrifos (at-pegging)	0 ± 0	0.6538	0.2 ± 0.20	0.2941	0.2 ± 0.20	0.0318	0.8 ± 0.37	0.8487	1.2 ± 0.73	0.1443
30 July 1992										
Treated vs.	22.6 ± 4.35		0.6 ± 0.18		7.85 ± 1.24		10.9 ± 2.41		41.4 ± 5.61	
Untreated	34.2 ± 10.82	0.2230	0.4 ± 0.24	0.4863	11.6 ± 2.25	0.0898	12.2 ± 5.98	0.8326	58.2 ± 9.82	0.1228
Flowering vs.	32.7 ± 4.96		1.1 ± 0.28		6.1 ± 1.09		12.3 ± 4.54		51.5 ± 6.77	
Pegging	12.4 ± 5.68	0.0252	0.1 ± 0.10	0.0011	9.6 ± 2.15	0.0778	9.5 ± 1.87	0.6121	31.3 ± 8.0	0.0437

Table 2. Continued.

Date	*Orius*		Other Hemiptera**		Spiders		Other Predators†		Total	
Contrast	$\bar{X}$ ± SEM	$P > F$	$\bar{X}$ ± SEM	$P > F$	$\bar{X}$ ± SEM	$P > F$	$\bar{X}$ ± SEM	$P > F$	$\bar{X}$ ± SEM	$P > F$
30 July 1992										
Fonophos vs. Chlorpyrifos (at-flowering)	38.6 ± 7.85 26.8 ± 5.65	0.3251	1.2 ± 0.37 1.0 ± 0.45	0.5809	6.2 ± 2.13 6.0 ± 0.89	0.9403	9.8 ± 3.95 14.8 ± 8.61	05229	54.8 ± 9.50 48.2 ± 10.35	0.6198
Ethoprop vs. Chlorpyrifos (at-pegging)	22.2 ± 9.82 2.6 ± 0.87	0.1111	0 ± 0.20 0 ± 0	0.5809	15.4 ± 1.91 3.8 ± 0.58	0.0004	12.4 ± 2.54 6.6 ± 2.25	0.4597	50.0 ± 10.39 12.6 ± 3.19	0.0112
12 August 1992										
Treated vs. Untreated	64.0 ± 7.08 70.2 ± 13.96	0.6324	0.7 ± 0.27 1.2 ± 0.37	0.4185	11.4 ± 1.05 14.4 ± 3.98	0.2476	14.0 ± 2.24 9.0 ± 2.19	0.2840	89.1 ± 8.41 94.4 ± 17.11	0.7494
Flowering vs. Pegging	86.5 ± 7.30 41.4 ± 6.73	0.0012	0.7 ± 0.30 0.7 ± 0.47	1.0000	11.1 ± 1.35 11.7 ± 1.69	0.7919	14.5 ± 2.95 13.4 ± 3.52	0.7865	112.0 ± 9.37 66.2 ± 9.69	0.0063
Fonophos vs. Chlorpyrifos (at-flowering)	87.4 ± 4.59 85.6 ± 14.77	0.9130	0.8 ± 0.58 0.6 ± 0.24	0.7962	11.2 ± 2.48 11.0 ± 1.41	0.9504	11.6 ± 4.57 10.4 ± 3.16	0.1659	117.4 ± 9.56 106.6 ± 17.00	0.6077
Ethoprop vs. Chlorpyrifos (at pegging)	40.4 ± 3.26 42.4 ± 13.89	0.9034	0.8 ± 0.80 0.6 ± 0.60	0.7962	13.2 ± 2.63 10.2 ± 2.20	0.3569	19.8 ± 5.08 7.0 ± 3.05	0.0377	73.0 ± 8.07 59.4 ± 18.29	0.5190

* Mean numbers per 21 meters of row. Means are compared using orthogonal contrasts; n = 20 for control vs. treated, 10 for at-flowering vs. at-pegging, and 5 for insecticides with at-flowering and at-pegging.

** Hemiptera other than *Orius* spp., includes species of *Geocorus*, and *Nabis* and some Reduviids.

† Non-hemipteran predators including, Coleoptera (Coccinelidae), Neuroptera (Chrysopidae), and Hymenoptera (Formicidae)

Pit-fall samples. Beneficial arthropods collected from pit fall traps included ground beetles (Coleoptera: Carabidae), tiger beetles (Coleoptera: Cicindellidae), lady beetles, and ant-like flower beetles, ants, and spiders (Table 3). Only carabids and ants were collected in numbers sufficient to analyze as separate classes. The remaining predaceous arthropods were pooled and classified as 'others' for analysis. The total number of arthropods (carabids, ants and others) was also analyzed as a separate class. Arthropods were not collected using pit fall traps in 1990.

The number of ants and the total number of predators were greater in untreated plots than in treated plots on 31 Jul 1991. Otherwise, no statistically significant differences in numbers of predaceous arthropods between treated and untreated plots were observed. Numbers of carabids were significantly higher in at-pegging than in at-flowering treated plots on 6 Aug 1991, but higher in at flowering than in at-pegging treated plots on 12 Aug. 1992. Contrasts between plots treated with insecticides at-flowering showed significantly higher numbers of carabids in fonophos-treated plots than in chlorpyrifos-treated plots on 31 Jul 1991, but no statistically significant differences were observed for numbers of predators in other classes during 1991 or 1992. Contrasts between plots treated at-pegging with insecticides showed higher predator numbers in ethoprop-treated plots than in chlorpyrifos-treated plots for ants on 23 and 30 Jul 1991, for carabids on 6 Aug 1991 and 12 Aug 1992, for other predators on 12 Aug 1992 and for total predator numbers on 15 Aug 1991 and 30 Jul 1992.

Discussion

Detrimental effects of traditional, at-pegging, pesticide applications in peanut have been documented (Croft and Brown 1975, Funderburk et al. 1990, Mack 1992). Funderburk et al. (1990) found lower densities of spiders in areas of commercial peanut fields treated with chlorpyrifos during the early pod stage than in untreated areas of these fields. Mack (1992), found that at-flowering application of a number of granular insecticides, including chlorpyrifos, fonophos, and ethoprop, did not consistently increase or decrease numbers of canopy-inhabiting natural enemies. However, in the same experiment chlorpyrifos was found to significantly decrease numbers of predaceous epigaeic arthropods such as spiders, earwigs (Dermaptera), and carabids. *Orius insidiosus,* the most abundant predator in this study, is known to feed on peanut pests such as *Helicoverpa* sp. occurring in other crops (Dietz et al. 1976). Although its actual impact on pest populations in peanut has not been studied, Barber (1936) found that *O. insidiosus* destroyed 14% to 53% of the *Helicoverpa* eggs deposited on corn.

In the present study, few consistent effects of time of insecticide application on predaceous arthropod numbers were observed. Numbers of *O. insidiosus* were significantly lower in plots treated at-pegging than in plots treated at-flowering with chlorpyrifos in 1990. These results are interesting because the application of granular insecticides is generally reported to have little impact on populations of predaceous Hemiptera (Smith and Jackson 1975, Morrison et al. 1979, Funderburk et al. 1990, Mack 1992). The total number of predators also was lower in plots treated at-pegging compared to plots treated at-flowering

Table 3. Mean (± SEM) number of predators collected from pesticide treated and untreated plots in peanut using pit fall traps in 1991 and 1992.*

Date	Ants		Carabids		Others		Total	
Contrast	$\bar{X}$ ± SEM	$P > F$	$\bar{X}$ ± SEM	$P > F$	$\bar{X}$ ± SEM	$P > F$	$\bar{X}$ ± SEM	$P > F$
23 July 1991								
Treated vs.	6.6 ± 1.88		2.1 ± 0.35		3.4 ± 0.53		12.2 ± 2.13	
Untreated	4.2 ± 1.07	0.4958	4.4 ± 2.29	0.0684	6.0 ± 2.21	0.0969	14.6 ± 3.62	0.6080
Flowering vs.	4.0 ± 1.03		2.9 ± 0.50		4.3 ± 0.91		11.2 ± 2.21	
Pegging	9.3 ± 3.50	0.1112	1.3 ± 0.33	0.1480	2.6 ± 0.43	0.2073	13.2 ± 3.75	0.6326
Fonophos vs.	6.4 ± 1.21				6.2 ± 1.24		16.6 ± 2.36	
Chlorpyrifos	1.6 ± 0.68	0.2963	4.0 ± 0.45		2.4 ± 0.60	0.0542	5.8 ± 1.32	0.0812
(at-flowering)			1.8 ± 0.58	0.1589				
Ethoprop vs.	14.0 ± 6.34		1.2 ± 0.58		2.6 ± 0.40		17.8 ± 6.88	
Chlorpyrifos	4.6 ± 1.96	0.0505	1.4 ± 0.40	0.8948	2.6 ± 0.81	1.0000	8.6 ± 2.29	0.1324
(at-pegging)								
31 July 1991								
Treated vs.	2.6 ± 0.62		0.4 ± 0.15		1.6 ± 0.38		4.6 ± 0.85	
Untreated	11.2 ± 5.01	0.0058	1.0 ± 0.45	0.0593	3.6 ± 1.29	0.0836	15.8 ± 6.04	0.0051
Flowering vs.	2.7 ± 0.90		0.6 ± 0.27		1.8 ± 0.68		5.1 ± 1.39	
Pegging	2.6 ± 0.91	0.09673	0.1 ± 0.10	0.1000	1.4 ± 0.37	0.6854	4.1 ± 1.03	0.7504
Fonophos vs.	3.4 ± 1.72		1.2 ± 0.37		2.0 ± 1.05		6.6 ± 3.32	
Chlorpyrifos	2.0 ± 0.63	0.6858	0 ± 0	0.0092	1.6 ± 0.98	0.7742	3.6 ± 1.49	0.5022
(at flowering)								

Table 3. Continued.

Date / Contrast	Ants $\overline{X} \pm SEM$	Ants $P > F$	Carabids $\overline{X} \pm SEM$	Carabids $P > F$	Others $\overline{X} \pm SEM$	Others $P > F$	Total $\overline{X} \pm SEM$	Total $P > F$
31 July 1991								
Ethoprop vs.	3.6 ± 1.69		0.2 ± 0.20		2.0 ± 0.55		5.8 ± 1.66	
Chlorpyrifos (at-pegging)	1.6 ± 0.60	0.5644	0. ± 0	0.6201	0.8 ± 0.37	0.3944	2.4 ± 0.75	0.479
6 August 1991								
Treated vs.	2.1 ± 0.69		4.2 ± 0.64		1.5 ± 0.55		7.7 ± 1.08	
Untreated	9.2 ± 8.95	0.1564	2.8 ± 0.58	0.1587	2.8 ± 1.66	0.3728	17.8 ± 10.80	0.2538
Flowering vs.	1.7 ± 0.96		2.4 ± 0.48		1.8 ± 0.94		5.9 ± 1.35	
Pegging	2.4 ± 1.02	0.8737	5.9 ± 0.91	0.0006	1.2 ± 0.59	0.6425	9.5 ± 1.56	0.5118
Fonophos vs.	2.6 ± 1.89		1.8 ± 0.58		3.2 ± 1.71		7.6 ± 2.54	
Chlorpyrifos (at flowering)	0.8 ± 0.37	0.7728	3.0 ± 0.71	0.3143	0.4 ± 0.24	0.1380	4.2 ± 0.49	0.6601
Ethoprop vs.	2.6 ± 0.93		7.8 ± 1.11		1.0 ± 0.45		11.4 ± 1.44	
Chlorpyrifos (at-pegging)	2.2 ± 1.96	0.9488	4.0 ± 0.84	0.0046	1.4 ± 1.17	0.8263	7.6 ± 2.66	0.6633
15 August 1991								
Treated vs.	0.6 ± 0.21		16.4 ± 2.92		2.1 ± 0.93		19.2 ± 3.18	
Untreated	0.6 ± 0.60	0.9222	19.8 ± 5.23	0.4522	1.2 ± 0.97	0.6452	21.6 ± 5.70	0.6426
Flowering vs.	0.3 ± 0.21		13.7 ± 2.6		1.0 ± 0.33		15.0 ± 2.74	
Pegging	1.0 ± 0.33	0.1398	19.2 ± 5.25	0.1764	3.2 ± 1.82	0.2179	23.4 ± 5.61	0.0827

Table 3. Continued.

Date	Ants		Carabids		Others		Total	
Contrast	$\overline{X} \pm$ SEM	$P > F$	$\overline{X} \pm$ SEM	$P > F$	$\overline{X} \pm$ SEM	$P > F$	$\overline{X} \pm$ SEM	$P > F$
15 August 1991								
Fonophos vs.	0.6 ± 0.40		10.0 ± 2.19		1.0 ± 0.55		11.6 ± 2.40	
Chlorpyrifos (at flowering)	0 ± 0.	0.3604	17.4 ± 4.32	0.1972	1.0 ± 0.45	1.0000	18.4 ± 4.63	0.3051
Ethoprop vs.	1.6 ± 0.40		32.6 ± 5.73		2.8 ± 1.88		37.0 ± 6.23	
Chlorpyrifos (at-pegging)	0.4 ± 0.40	0.0708	5.8 ± 1.11	0.0002	3.6 ± 3.36	0.7458	9.8 ± 3.20	0.0006
30 July 1992								
Treated vs.	2.2 ± 0.47		0.1. ± 0.06		0.5 ± 0.10		2.9 ± 0.56	
Untreated	0.8 ± 0.52	0.1449	0.1 ± 0.09	0.9665	0.7 ± 0.23	0.5211	1.6 ± 0.56	0.2170
Flowering vs.	2.0 ± 0.59		0.1 ± 0.07		0.5 ± 0.14		2.6 ± 0.61	
Pegging	2.6 ± 0.88	0.4978	0.2 ± 0.09	0.4798	0.6 ± 0.15	0.8440	3.3 ± 0.94	0.4507
Fonophos vs.	2.5 ± 0.80		0.1 ± 0.07		0.7 ± 0.25		3.3 ± 0.86	
Chlorpyrifos (at-flowering)	1.4 ± 0.87	0.3721	0.1 ± 0.13	0.6604	0.3 ± 0.13	0.2490	1.9 ± 0.86	0.3033
Ethoprop vs.	4.5 ± 1.68		0.3 ± 0.16		0.4 ± 0.14		5.2 ± 1.79	
Chlorpyrifos (at pegging)	0.7 ± 0.28	0.0054	0.1 ± 0.07	0.1572	0.7 ± 0.27	0.3903	1.5 ± 0.42	0.0097

Table 3. Continued.

Date	Ants		Carabids		Others		Total	
Contrast	$\bar{X} \pm$ SEM	$P > F$	$\bar{X} \pm$ SEM	$P > F$	$\bar{X} \pm$ SEM	$P > F$	$\bar{X} \pm$ SEM	$P > F$
12 August 1992								
Treated vs.	2.0 ± 0.38		08 ± 0.19		1.1 ± 0.15		3.9 ± 0.51	
Untreated	1.1 ± 0.52	0.8666	2.1 ± 0.59	0.4404	1.1 ± 0.34	0.8842	4.3 ± 0.78	0.6822
Flowering vs.	2.1 ± 0.0.56		1.3 ± 0.35		1.4 ± 0.23		4.8 ± 0.79	
Pegging	1.9 ± 0.53	0.7782	0.3 ± 0.09	0.0194	0.8 ± 0.19	0.0684	3.0 ± 0.62	0.0703
Fonophos vs.	2.9 ± 0.74		1.5 ± 0.55		1.5 ± 0.31		5.8 ± 1.22	
Chlorpyrifos (at-flowering)	1.3 ± 0.81	0.1300	1.1 ± 0.43	0.4856	1.3 ± 0.36	0.7588	3.7 ± 0.98	0.1257
Ethoprop vs.	2.3 ± 0.73		0.3 ± 0.12		1.4 ± 0.31		4.0 ± 0.94	
Chlorpyrifos (at pegging)	1.5 ± 0.77	0.3893	0.3 ± 0.13	0.9073	0.3 ± 0.12	0.0109	2.1 ± 0.75	0.1516

* Means represent pooled values from three traps per plot. Means are compared using orthogonal contrasts; n = 20 for control vs. treated, 10 for at-flowering vs. at-pegging, and 5 for within at-flowering and at-pegging.

plots with chlorpyrifos in 1990. This resulted primarily from application timing effects on *O. insidiosus* and spiders, which comprised nearly 80% and 66% of the predators recovered from plots treated at-flowering and at-pegging, respectively.

The larger plot experiment conducted in 1991 and 1992 showed only *O. insidious* and total predator numbers to be consistently affected by timing of insecticide applications. Numbers of *O. insidiosus* were significantly lower in at-pegging than in at-flowering treated plots for two and three of the five 1991 and 1992 sample dates at $P < 0.05$ and $P < 0.10$, respectively. However, at $P < 0.10$, numbers of *O. insidiosus*, spiders, other canopy-inhabiting predators and carabids were lower ($P < 0.0006$) in at-flowering than in at-pegging plots on 6 Aug 1991. The trend towards lower predator numbers in at-pegging than in at-flowering treated plots was most apparent for total predator numbers. This trend was influenced primarily by high numbers of *O. insidiosus* and spiders which together comprised 50 to 90% of total number of predators collected from a given sample. Again, this trend was reversed on 6 Aug 1991. No consistent effects of time of insecticide application were observed for numbers of pit-fall-collected predators. There was no evidence for a consistent, differential effect of chlorpyrifos or fonophos applied at-flowering or of chlorpyrifos or ethoprop applied at-pegging, on predator numbers.

The reasons for differences in natural enemy abundance in at-flowering and at-pegging treated plots between years of the study are not known, but may be related to variation in biotic and/or abiotic environmental factors between years or to movement of natural enemies between plots. Differences in sampling techniques between years (i. e., sweep net vs. D-vac) may have contributed to some of the between-year differences in predator numbers. However, our observations indicate that there were simply fewer arthropods present in peanut plots during 1991 compared with 1992 . Frequent heavy rains during the field season may have been a factor contributing to the low number of predators collected in 1991. In addition, standard errors associated with individual means were sometimes large, especially for smaller means, and may have limited our ability to resolve treatment differences in some instances.

Our data lend support for the hypothesis that early (at-flowering) application of soil-applied insecticides allows better establishment of predators in reproductive-stage peanut than later, at-pegging pesticide applications. In combination with additional benefits such as providing earlier control of other arthropod pests of peanut, reducing vine damage, and improved soil incorporation of insecticide, early application of insecticides provides a potentially valuable insect pest management alternative to growers. We found no strong evidence that type of insecticide, among those included in the study, significantly affected predator establishment in reproductive stage peanut. However, more research, especially large plot, multi-year studies, is needed to fully understand the effects naturally-occurring environmental factors and management effects (e.g., agronomic inputs such as pesticides) on predator populations.

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