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Population Changes of *Heterodera glycines* and Soybean Yields Resulting from Soil Treatment with Alachlor, Fenamiphos, and Ethoprop[1]

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Abstract: The population dynamics of *Heterodera glycines* as influenced by alachlor, fenamiphos, and ethoprop alone and in herbicide–nematicide combinations were studied in the field. Numbers of *H. glycines* juveniles and eggs were higher at midseason and harvest where nematicides were applied. Fenamiphos alone or in combination with alachlor provided better control of *H. glycines* and greater seed yields than treatments with ethoprop. Numbers of *H. glycines* eggs at harvest in 1980 were positively correlated with numbers of juveniles at planting in 1981 and negatively related to seed yield in 1981.

Key words: chemical control, *Glycine max*, herbicide, soybean cyst nematode, organophosphate nematicide, pesticide interaction, population dynamics.

Applications of both the herbicide alachlor and the organophosphate nematicides to soil frequently result in higher nematode populations at harvest than when the pesticides are used alone (3,15,16). Alachlor is used for grass and small-seeded broadleaf weed control in soybean and other field crops. Fenamiphos (systemic) and ethoprop (nonsystemic) are organophosphate nematicides. Although many pesticide interactions affect nontarget organisms (8,12,14), research has been directed primarily toward effects on the crop plant (14).

Herbicide–nematicide interactions are receiving increasing attention, but are still poorly understood (1,3,9,11,13,15,16). The herbicide cycloate applied in combination with aldicarb to fields of *Beta* spp. infested with *Heterodera schachtii* Schmidt affected neither nematicide efficacy nor the nematode (1). Cotton (*Gossypium hirsutum* L.) plants stressed by nematodes were more susceptible than nonstressed plants to damage from the herbicides trifluralin and prometryn; nematicide–herbicide combinations, however, were not different (no herbicide injury) from the nematicide alone (11). The herbicide sodium azide, although having some nematicidal activity, may reduce the efficacy of carbofuran (13). Fewer *Heterodera glycines* Ichinohe (SCN) juveniles were recovered from soils treated with vernolate, trifluralin, or metribuzin in combination with aldicarb than with aldicarb alone (9). Alachlor applied in combination with several nematicides resulted in increased numbers of nematodes in the soil at harvest, compared with the nematicides alone (3,15,16).

Enhanced late-season resurgence of *H. glycines* populations often occurs in soils treated with fenamiphos + alachlor (3,15,16). This phenomenon was first ob-

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served in fields with relatively low populations of *H. glycines* (race 1) planted to soybean (*Glycine max* (L.) Merr.) cultivars susceptible to SCN, especially 'Ransom' (15). However, subsequent experiments in fields with high initial nematode densities failed to demonstrate the enhanced resurgence.

The objectives of this research were to determine 1) the effects of alachlor, fenamiphos, and ethoprop alone and in herbicide–nematicide combinations on the population dynamics of *H. glycines* in fields with different initial nematode densities and 2) the yield response of soybean to these various pesticide combinations and *H. glycines* population densities.

MATERIALS AND METHODS

Four experiments were conducted in North Carolina in fields naturally infested with *H. glycines*: one on the Central Crops Research Station (CCRS) near Clayton, another on a private farm near Smithfield, and two on a private farm near Chadbourn. Average *H. glycines* preplant population densities (Pi) were 5,000, 3,200, 900, and 80 eggs/500 cm^3 soil. The soil at CCRS was a Varina loamy sand (85% sand, 9% silt, 6% clay, 1% organic matter); at Smithfield, a Norfolk loamy sand (81% sand, 16% silt, 3% clay, 0.8% organic matter); and at the two Chadbourn sites, a Wagram loamy sand (78% sand, 10% silt, 12% clay, 0.8% organic matter). The treatments were nontreated control, alachlor, fenamiphos, ethoprop (CCRS and Smithfield only), fenamiphos + alachlor, and ethoprop + alachlor (CCRS and Smithfield only).

Fenamiphos and ethoprop were applied at planting in 30-cm bands at 2.24 and 2.80 kg a.i./ha, respectively, and incorporated 5 cm deep with a tractor-drawn rototiller. Nematicide application and planting with 'Coker 156' soybeans (susceptible) were on 9 May 1980 (Smithfield) and 16 May 1980 (CCRS), and with 'Ransom' soybeans at Chadbourn on 12 May 1981. Alachlor (4.48 kg a.i./ha) was sprayed broadcast onto the soil surface of designated plots immediately after planting. Treatments were replicated six times in a 6 × 6 Latin square at CCRS and Smithfield; at the Chadbourn locations they were arranged in randomized complete blocks with 10 replications. The 4-row plots were 9 m long (CCRS and Smithfield) or 12 m long (Chadbourn) with 92-cm row spacing. Data were collected from the two center rows. All plots were cultivated as needed to minimize any effects of weeds on nematode populations or soybean growth.

Soil samples consisted of 500-cm^3 composites of 10–12 soil cores (2.5-cm d) taken 15–20 cm deep from the center two rows of each plot. CCRS and Smithfield were sampled at planting and at 21, 42, 56, 84, 112, and 203 days after planting; samples at Chadbourn were collected at planting and 49, 80, 136, and 191 (harvest) days after planting. Seed yields were taken at plant maturity on 2 December 1980 at CCRS and Smithfield and 10 December 1981 at Chadbourn. Soil samples were dry-sieved (3-mm-pore sieve) to remove roots and processed with a semi-automatic elutriator (4) and centrifugal–flotation (7) to remove nematodes. Counts for *H. glycines* included second-stage juveniles (J2), males, cysts, and eggs. Cysts were crushed with a Ten-Broeck tissue homogenizer to release eggs. In addition, a 0.2-g subsample of roots dry-sieved from each soil sample was stained (5), and the numbers and developmental stages of *H. glycines* within the roots were recorded. Four plants were also removed from each plot at each sampling date to determine shoot and root weights.

The effects of nematode population carryover during the subsequent growing season were assessed at CCRS by maintaining the plot locations following the 1980 harvest. The field was planted no-till with Ransom soybean on 22 May 1981. Alachlor was applied to all plots for grass control. Sampling dates were preplant (22 May), midseason (13 August), and harvest (3 December); procedures were as described in the previous paragraph.

All data were subjected to analysis of variance. Orthogonal contrasts were calculated for the comparisons: absence vs. presence of nematicides, fenamiphos alone and with alachlor vs. ethoprop alone and with alachlor (CCRS and Smithfield), fenamiphos vs. fenamiphos + alachlor, ethoprop vs. ethoprop + alachlor (CCRS and Smithfield), and alachlor vs. nontreated control. In addition, correlation coefficients and linear and (or) multiple regressions were computed.

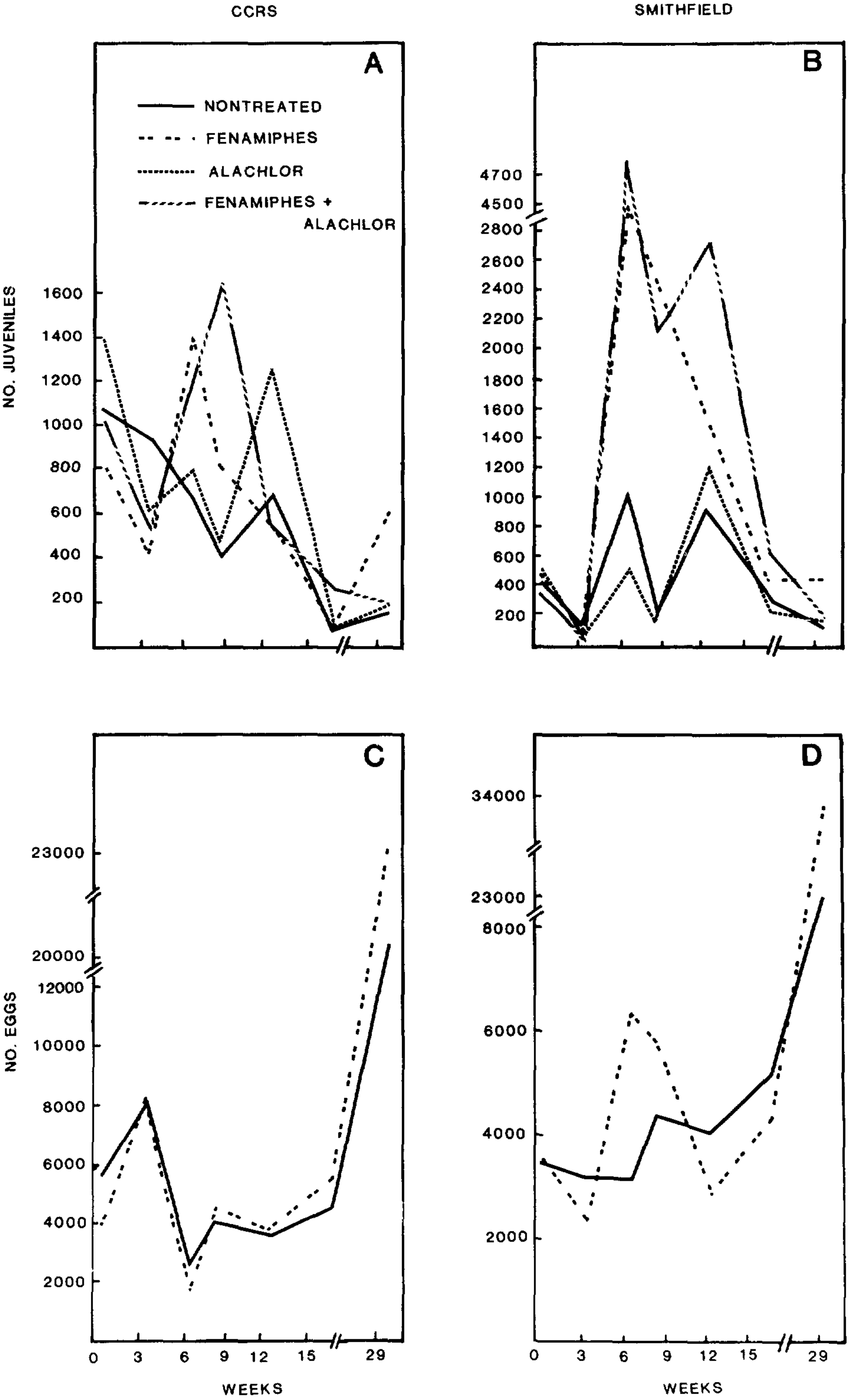

FIG. 1. *Heterodera glycines* juveniles and eggs per 500 cm^3 soil as affected by alachlor, fenamiphos, or both. A) Central Crops Research Station (CCRS), N.C., juveniles. B) Smithfield, N.C., juveniles. C) CCRS eggs. D) Smithfield eggs.

RESULTS AND DISCUSSION

The population dynamics of *Heterodera glycines* were significantly altered by pesticides at few sampling periods. Numbers of *H. glycines* J2 decreased in the soil at 3 weeks in all plots (Fig. 1A, B). At CCRS this decrease continued in the nontreated control through 8 weeks; however, treatments with nematicides resulted in increased numbers of J2 at 6 and 8 weeks (Fig. 1A). Greater numbers of J2 ($P = 0.05$) occurred at 8 weeks with fenamiphos + alachlor than with fenamiphos. Numbers of J2 per 500 cm^3 soil were greater with alachlor (1,273; $P = 0.05$) and ethoprop + alachlor (885; $P = 0.10$) treatments than with the nontreated control (685) or ethoprop (398) alone at 12 weeks.

Differences occurred at Smithfield at 6, 8, and 12 weeks. Numbers of J2 in nematicide treatments at Smithfield were higher than other treatments at 6 and 8 weeks ($P = 0.01$) and at 12 weeks ($P = 0.10$) (Fig. 1B). Juvenile numbers were 65% greater at 6 and 8 weeks and 36% greater at 12 weeks ($P = 0.01$ and 0.10, respectively) in fenamiphos-treated plots than in plots treated with ethoprop. More J2 ($P = 0.05$) were present with fenamiphos + alachlor treatments than with fenamiphos alone.

The configuration of the population density of *H. glycines* eggs was similar in all treatments at CCRS (Fig. 1C). Their numbers increased at 3 weeks, declined at 6 weeks, then increased, especially in late season. Egg numbers per 500 cm^3 soil at 16 weeks were greater ($P = 0.05$) with ethoprop + alachlor treatments (11,322) than with ethoprop (7,033). This trend persisted at harvest, but was not significant. At harvest, egg numbers were 23% greater in fenamiphos than in ethoprop treatments.

At Smithfield, numbers of eggs per 500 cm^3 soil ranged from 2,000 to 6,000 through the growing season and increased to 23,000–43,000 at harvest with few differences among treatments. At 12 weeks, more eggs ($P = 0.10$) were produced in plots treated with ethoprop + alachlor (5,383) than with the nematicide alone (3,493); the reverse was true at 16 weeks ($P = 0.10$).

Root penetrations by J2 of *H. glycines* reached a maximum at 6 weeks and declined for the remainder of the growing season at CCRS and Smithfield. More nematodes penetrated roots (per 0.2 g root; $P = 0.05$) in the fenamiphos + alachlor treatments (295) at CCRS compared with the nematicide alone (155) at 12 weeks. At Smithfield, nematode penetration was greater ($P = 0.01$) at 6 and 8 weeks with ethoprop treatments (1,230 and 555) than with fenamiphos (445 and 260). Root penetration was less ($P = 0.05$) in all nematicide treatments compared with the other treatments at 12 weeks. Generally, nematode penetration was greater at Smithfield than at CCRS throughout the growing season.

TABLE 1. Soybean yields (g/18 m) at Smithfield and Central Crops Research Station (CCRS) in North Carolina from plots treated with alachlor, fenamiphos, and ethoprop in 1980 and nontreated in 1981.

Treatment	Smithfield	CCRS (1980)	CCRS (1981)*
Nontreated control	1,682	829	1,900
Alachlor	1,197	833	1,583
Fenamiphos	2,292	1,083	1,417
Fenamiphos + alachlor	2,281	1,256	1,300
Ethoprop	1,946	652	1,717
Ethoprop + alachlor	2,467	965	1,550
Orthogonal contrasts†	A, C, E	B, e	A, b

All data are means of six replicates; Smithfield and CCRS (1980) were planted with Coker 156 soybean; CCRS (1981) with Ransom soybean.

* Pesticide treatments were not applied at CCRS in 1981 (1980 plots were maintained undisturbed and replanted in 1981).

† Letters are used to designate differences as determined by orthogonal contrasts. A, presence vs. absence of nematicides. B = fenamiphos alone and + alachlor vs. ethoprop alone and + alachlor. C = untreated control vs. alachlor. E = ethoprop vs. ethoprop + alachlor. Capital letters indicate significance at $P = 0.05$, lower case at $P = 0.10$.

Seed yields were greater from fenamiphos-treated plots ($P = 0.05$) than from ethoprop-treated plots. Ethoprop + alachlor treatments yielded more seed ($P = 0.10$) than ethoprop alone at CCRS in 1980 (Table 1). Yields at Smithfield were increased ($P = 0.01$) in plots treated with nematicides (Table 1). Yields were greater ($P = 0.05$) with ethoprop + alachlor treatments than with ethoprop; the herbicide-alone treatment yielded less ($P = 0.05$) than the nontreated controls.

The field at CCRS was planted no-till to soybean in 1981 without additional treatments to determine the effect of populations on yield resulting from 1980 treatments. The numbers of *H. glycines* eggs produced in 1980 at CCRS were positively

TABLE 2. Numbers of *Heterodera glycines* at two sampling dates and seed yield of soybean as affected by fenamiphos and (or) alachlor in two field sites at Chadbourn, North Carolina.

Initial egg population density	Treatment	15 September 1981				10 December 1981				Seed yield (g)
		Juveniles	Males	Cysts	Eggs	Juveniles	Males	Cysts	Eggs	
80	Nontreated control	70	6	6	19	11	3	7	653	1,412
	Alachlor	29	7	3	5	18	0	7	615	1,910
	Fenamiphos	41	7	4	30	24	0	7	827	2,982
	Fenamiphos + alachlor	21	2	4	27	18	0	14	1,483	2,899
	Orthogonal contrasts*	NS	NS	B	NS	NS	NS	NS	NS	A, b
900	Nontreated control	128	29	29	677	192	2	125	13,243	2,680
	Alachlor	180	76	19	493	408	1	169	16,190	3,016
	Fenamiphos	164	14	28	790	260	2	125	13,117	3,757
	Fenamiphos + alachlor	118	41	28	353	262	0	113	11,197	3,722
	Orthogonal contrasts*	NS	a, B	NS	C	B	NS	NS	NS	A

All data are the means of 10 replicates; nematode numbers/500 cm^3 soil; seed yield/24 m of row.

* Letters are used to designate differences as determined by orthogonal contrasts: A = presences vs. absence of fenamiphos. B = alachlor alone vs. untreated control. C = fenamiphos vs. fenamiphos + alachlor. Capital letters indicate significance at $P = 0.05$, lower case at $P = 0.10$. NS = not significant.

correlated ($r = 0.95$, $P = 0.01$) with the J2 populations in the soil at planting in 1981. Eggs at harvest (2 December 1980) and at planting (22 May 1981) indicated an average survival rate of 13% for that winter. Seed yield in 1981 (Table 1) was negatively correlated with numbers of J2 at planting ($r = 0.94$, $P = 0.01$) and final 1980 egg populations ($r = 0.90$, $P = 0.01$). Relative plot performance at CCRS in 1981, with respect to nematode populations and seed yields, was generally the reverse of 1980 (Table 1).

In the Chadbourn field that had Pi of 80 eggs/500 cm^3 soil, few significant differences in numbers of any life stages of *H. glycines* were noted (Table 2). Seed yields were greater in fenamiphos treatments ($P = 0.01$) than in the other treatments; alachlor-alone treatments yielded more ($P = 0.10$) than the nontreated control.

Fewer eggs were present ($P = 0.05$) in the fenamiphos + alachlor treatment on 15 September than with fenamiphos alone in the field with a Pi of 900 eggs/500 cm^3 soil. At harvest, J2 were more numerous ($P = 0.05$) in plots treated with alachlor than in nontreated controls. Seed yield was greatest ($P = 0.05$) where treatments included nematicides.

The population dynamics of *H. glycines* are not altered greatly by herbicide–nematicide combinations compared with a nematicide alone in fields with relatively high population densities, especially final populations. A small or moderate Pi may be important for the herbicide alachlor to influence the activity of fenamiphos or ethoprop (3,6,10,15,16). The alachlor still may affect the nematode, even in high population density fields, because the midseason counts were greater in alachlor + nematicide treatments than with the nematicide alone. The effect may not be expressed through harvest, however, because too much inoculum is available. An important impact of pesticide application is the tendency to stimulate greater final population densities. These differences may not be statistically significant when the data are tested with an analysis of variance; however, regression models show a relationship between harvest populations and at-plant populations the subsequent growing season. Both population measurements were negatively correlated to yield the year after the pesticides were applied. Soybeans in the high Pi plots are subjected to greater probability of early season damage than those with low Pi. Thus, treatments and management tactics should be those that reduce at-plant populations and suppress late season nematode population resurgence.

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