Population Dynamics of *Heterodera glycines* and Soybean Response in Soils Treated with Selected Nematicides and Herbicides[1]

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Abstract: Two field experiments were conducted in two locations to determine the effects of the nematicides aldicarb, phenamiphos, and ethoprop and/or the herbicides alachlor, linuron, or metribuzin on the population dynamics of *Heterodera glycines* and soybean growth and yield. Population densities of *H. glycines* were greater, at some time during the growing season, in several treatments with alachlor alone and in combination with nematicides. Numbers of *H. glycines* at harvest were greater in plots treated with aldicarb than in those treated with ethoprop or phenamiphos. The numbers in aldicarb treated plots were generally reduced when plots also received a herbicide. Soybean yields were negatively correlated with numbers of *H. glycines* eggs and juveniles in early to mid season but positively correlated with late season population densities.
Key words: control, pesticide interactions, soybean cyst nematode, *Glycine max*, phenamiphos, ethoprop, aldicarb, alachlor, linuron, metribuzin, herbicides, nematicides.

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Crop management practices, including pesticides, may have a major impact on the population dynamics of nematodes (7). While the herbicides vernolate, chloroxuron, dinoseb, and linuron did not affect nematode populations in Georgia (4), numbers of *Helicotylenchus dihystera* (Cobb) Sher in North Carolina (9) and *Heterodera glycines* Ichinohe in Illinois (5) were increased by vernolate. Metribuzin (5) and trifluralin (5,8) also increased population densities of *H. glycines*.

Combinations of pesticides may alter the effect of a single pesticide on the population of nematodes (5,9). Numbers of *H. dihystera* were greater in plots treated with the combination of the herbicide alachlor and the insecticide-nematicide fensulfothion or the insecticide phorate than in plots with either fensulfothion, phorate, or alachlor alone. Plots treated with vernolate, metribuzin, or trifluralin and aldicarb yielded more than those treated with only aldicarb (5).

Knowledge of the dynamic relationship between the nematode, host growth, and the effects of nematicides and herbicides should be helpful in the development of sound control tactics. The objectives of this research were to determine 1) the effects of nematicides and herbicides on the population dynamics of *Heterodera glycines* and 2) the impact of *H. glycines* on soybeans in plots

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treated with a herbicide and a nematicide compared with plots treated with a nematicide alone.

MATERIALS AND METHODS

Two factorial experiments were conducted in 1978 and 1979 in fields where *Heterodera glycines* was the dominant nematode species. Two organophosphate and one organocarbamate insecticide-nemticides were used (Table 1). Three preemergence herbicides—alachlor, linuron, and metribuzin—were applied broadcast within 24 hours after planting. Plots were maintained weed-free by cultivation for the first 8 weeks of the growing season.

Soil samples for nematode assay were collected from the center two rows of each plot prior to treatment and at selected intervals throughout the season. Ten to twelve 2.5-cm-d cores taken 15-20 cm deep were composited. Nematodes were extracted from 500-cm^3 soil by a combination of elutriation and centrifugation (1).

Experiment 1: A 3 × 3 + 1 factorial experiment involving three nematicide treatments and three herbicide treatments was conducted in a loamy sand (81% sand, 16% silt, 3% clay, 1% organic matter) near Smithfield, Johnston County, NC (Table 1). There was a hard pan at the 15-cm depth and a clay subsoil. Plots were four rows wide (91-cm row spacing) and 9.1 m long. The nematicides were applied 13 May 1978 in a 30-cm-wide band and incorporated 15 cm deep. Then *Glycine max* (L.) Merr. 'Ransom' was planted. Soil samples were collected on 13 May, 22 June, 3 August, and 3 November 1978. Ten plants were dug from the outermost rows and weighed 3, 5, 7, 9, 13, and 17 weeks after planting. The center two rows were harvested on 3 November 1978. A randomized complete block design with four replications was used.

Experiment 2: A 4 × 4 + 1 factorial experiment including four nematicide treatments and four herbicide treatments was conducted in a deep Wagram fine loamy sand with 1% organic matter near Chadbourn, Columbus County, NC (Table 1). One of the herbicide treatments will not be reported in this paper because it is in an-

Table 1. Yield of soybeans grown in fields near Smithfield (1978) and Chadbourn (1979), North Carolina, and treated with nematicides and herbicides.

Treatment	Rate (kg a.i./ha)	Seed yield (g/18 m) 1978	Seed yield (g/24 m) 1979
Untreated control		2,725	670
Alachlor*	4.48	2,700	520
Linuron*	3.35	3,008	1,034
Metribuzin*	0.56	2,007	698
Aldicarb (Band)†	2.24	3,355	2,438
Aldicarb (Band) + Alachlor	2.24 + 4.48	3,683	2,896
Aldicarb (Band) + Linuron	2.24 + 2.24	3,980	2,022
Aldicarb (Band) + Metribuzin	2.24 + 0.56	4,035	1,856
Aldicarb (Furrow)*	1.12	...	1,966
Aldicarb (Furrow) + Alachlor	1.12 + 4.48	...	1,936
Aldicarb (Furrow) + Linuron	1.12 + 2.24	...	2,150
Aldicarb (Furrow) + Metribuzin	1.12 + 0.56	...	1,956
Ethoprop†	2.24	3,635	690
Ethoprop + Alachlor	2.24 + 4.48	2,720	1,024
Ethoprop + Linuron	2.24 + 2.24	2,978	988
Ethoprop + Metribuzin	2.24 + 0.56	3,315	1,085
Phenamiphos†	2.24	3,988	2,282
Phenamiphos + Alachlor	2.24 + 4.48	3,738	2,070
Phenamiphos + Linuron	2.24 + 2.24	2,840	2,038
Phenamiphos + Metribuzin	2.24 + 0.56	3,713	1,652
LSD (0.05)		805	765

*Herbicides were applied preemergence.

†Nematicides. Aldicarb at 1.12 kg was applied in seed furrow; other nematicides were applied in a 30-cm band and incorporated 15 cm deep in 1978 and 5 cm deep in 1979 with a tractor powered rototiller.

other class than those being reported herein. Plots were four rows wide (91-cm row spacing) and 12.2 m long. The treatments were applied and *G. max* 'Davis' planted 16–17 May 1979. Three of the nematicide treatments were applied in a 30-cm band and incorporated 5 cm deep; one was applied in the seed furrow (Table 1). Soil samples were taken on 16 May, 3 July, 23 July, 16 August, and 29 October 1979. Ten plants were dug from the outer two rows at 2-week intervals up to 14 weeks and at 17 and 21 weeks after planting Plants in plots were harvested 29–30 October 1979. Five blocks of a randomized complete block design were used.

RESULTS

Nematode response. Experiment 1: Numbers of *H. glycines* juveniles and eggs in the soil were very low at planting and 40 days later (22 June) (Fig. 1A-B). The populations of both increased throughout the remainder of the growing season except for a decline of juveniles after 82 days (3 August) in the phenamiphos + metribuzin treatment. Aldicarb resulted in the highest populations of eggs at the end of the season (Table 2), although there was a large increase in plots treated with alachlor. Numbers of juveniles were greater ($P = 0.02$) in the phenamiphos plus linuron treatment than in other phenamiphos treatments at 40 days (Fig. 1A). There were more juveniles in phenamiphos plus alachlor than other phenamiphos treatments at 3 August and 3 November (Fig. 1A). There was a similar trend with alachlor plus ethoprop ($P = 0.09$) or aldicrab ($P = 0.07$), compared to the other respective nematicide treatments.

More eggs were recovered from alachlor plus phenamiphos treatments during mid to late season (Fig. 1B). Ethoprop plus alachlor resulted in greater nematode reproduction (12,275 eggs) at 82 days (3 August) ($P = 0.01$) compared to other ethoprop treatments (1,067–2,775 eggs). The addition of herbicides to aldicarb treated plots resulted in smaller final populations, especially with aldicarb plus metribuzin (12,525 eggs) compared to aldicarb alone (36,350 eggs).

Experiment 2: The population densities of *H. glycines* juveniles generally increased at 92 days (16 August), then decreased by harvest (Fig. 1C). In the untreated soil, numbers of juveniles increased to about 100/500 cm^3 soil in June and increased little thereafter (Fig. 1C). The numbers of juveniles were greater ($P = 0.05$) in the phenamiphos plus alachlor treatments than with phenamiphos alone or in combination with other herbicides at 68 days (23 July) and 92 days (16 August) (Fig. 1C). Their numbers were increased ($P = 0.05$) in the alachlor treatment at 48 days (3 July) (264 vs. 100 in the check) and in the metribuzin treatment at 68 days (23 July) (288 vs. 100 in the check).

Numbers of *H. glycines* eggs peaked at 68 days (23 July) and at harvest (Fig. 1D). Egg production was suppressed by all nematicides on 23 July, with the greatest effect in the aldicarb in-furrow and phenamiphos treatments. However, the greatest number of eggs at harvest occurred in the aldicarb in-furrow treatment (Table 2). The numbers of eggs were greater at 68 days (23 July) ($P = 0.08$) and 92 days (16 August) ($P = 0.06$) in plots treated with phenamiphos plus alachlor than in those treated with the nematicide alone or in combination with other herbicides (Fig. 1D).

Control of *H. glycines* was better with phenamiphos and aldicarb than with ethoprop. The greatest control of most other nematodes was with phenamiphos and the poorest with aldicarb. For example: Numbers of *Paratrichodorus minor* (Colbran) Siddiqi at 92 days (16 August) in plots treated with phenamiphos, ethoprop, or aldicarb were 122, 193, and 221/500 cm^3, respectively.

Plant response. Experiment 1: Yields were greater ($P = 0.05$) in plots treated with ethoprop, phenamiphos, phenamiphos plus alachlor or metribuzin, and aldicarb plus alachlor or linuron or metribuzin than in the untreated control (Table 1). When comparing pesticide combinations to a nematicide alone, yields were less ($P = 0.05$) in combinations of ethoprop plus alachlor and phenamiphos plus linuron than with a nematicide alone (Table 1).

Experiment 2: Numbers of juveniles at 48 days (3 July) were positively correlated ($r = 0.42, P = 0.05$) with total plant weight at 2 weeks. Most of the plant weights at 12

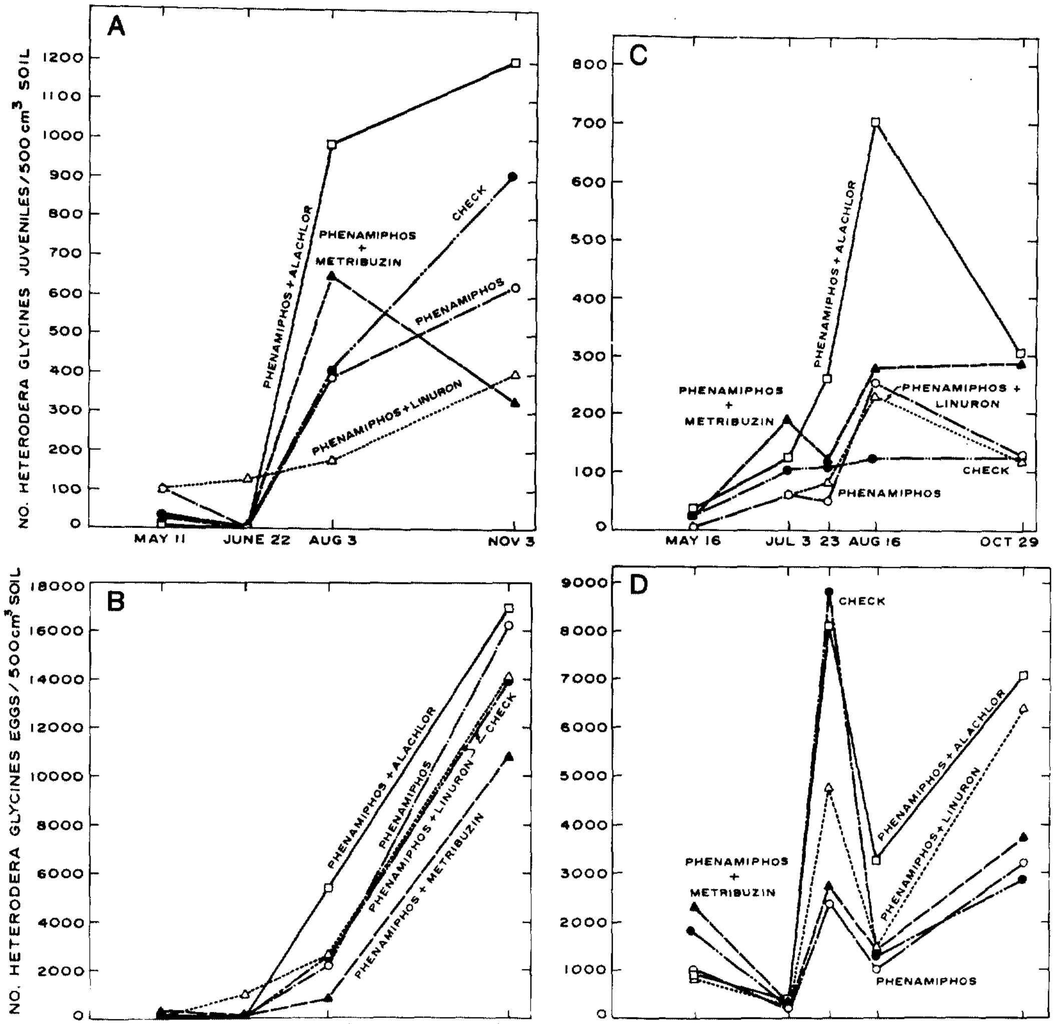

Fig. 1. Seasonal population fluctuations of *Heterodera glycines* on soybeans grown in soil treated with nematicides and/or herbicides. A–B) Ransom soybean, Smithfield, NC. 1978. A) Numbers of juveniles per 500 cm^3 soil. Jun 22: $P = 0.02$ for phenamiphos + linuron vs. others; Aug 3: $P = 0.12$ for phenamiphos + alachlor vs. others; Nov 3: $P = 0.06$ for phenamiphos + alachlor vs. others. B) Numbers of eggs per 500 cm^3 soil. Jun 22: $P = 0.01$ for phenamiphos + linuron vs. others. C–D) Davis soybean, Chadbourn, North Carolina. C) Numbers of juveniles/500 cm^3 soil. Jul 3: $P = 0.14$ for phenamiphos + metribuzin vs. others; Jul 23: $P = 0.02$ for phenamiphos + alachlor vs. others; Aug 16: $P = 0.03$ for phenamiphos + alachlor vs. others; Oct 29: $P = 0.09$ for phenamiphos + metribuzin or phenamiphos + alachlor vs. others. D) Numbers of eggs/500 cm^3 soil. Jul 23: $P = 0.08$ for phenamiphos + alachlor and check vs. others; Aug 16: $P = 0.06$ for phenamiphos + alachlor vs. others.

weeks and after were negatively correlated ($P = 0.05$) with numbers of juveniles in the soil at 48 days (3 July). Numbers of eggs at 68 days (23 July) were negatively correlated ($P = 0.05$) with yield ($r = -0.57$) and with plant weights recorded at 8 ($r = -0.41$) and 21 ($r = -0.45$) weeks. Most of the correlations of final egg numbers with plant weights and yield were positive, except root weights at 2 weeks were negatively correlated ($r = -0.54$, $P = 0.01$).

Yields were greater ($P = 0.05$) in the plots treated with aldicarb (band and infurrow) and phenamiphos than in the untreated control, most of the plots treated with herbicides alone, and most ethoprop treated plots (Table 1). Herbicides did not significantly ($P = 0.05$) alter yields from

Table 2. Numbers of *Heterodera glycines* eggs/500 cm^3 soil at harvest from plots treated with nematicides or herbicides.

Treatment	Number of eggs: Smithfield (1978)	Number of eggs: Chadbourn (1979)
Check	13,925	2,860
Alachlor	25,500	2,460
Linuron	17,550	4,420
Metribuzin	16,125	2,880
Aldicarb (furrow)	...	10,900*
Aldicarb (band)	36,350*	3,520
Ethoprop	11,175	1,425
Phenamiphos	16,225	3,210

*Indicates that the number of eggs are significantly greater ($P = 0.05$) than in other treatments within columns except for alachlor in 1978.

plants in nematicide treated plots compared to those treated only with a nematicide. Soybeans treated with aldicarb (band) plus alachlor, however, yielded more ($P = 0.05$) than soybeans grown in soil treated with aldicarb (band) plus linuron or metribuzin.

DISCUSSION

The nematicides and herbicides had single and interactive effects on nematode populations. There was a greater number of juveniles and eggs of *H. glycines* at mid season with most treatments involving alachlor, especially with phenamiphos. Since the effect on nematode populations was associated with alachlor, this herbicide may stimulate hatch and/or alter the plant's physiology, possibly enhancing host suitability for the nematode. Early nematode population suppression with nematicides may be due to inhibition of hatching (3), disorientation (2), and/or, to some extent, desiccation. This suppression is usually followed by a population resurgence. Alachlor could be slightly nematicidal for a short period, which would allow some root development to occur, thus providing greater root biomass to support the nematode. This hypothesis is partially supported by the fact that final egg and juvenile populations were positively correlated with plant weights during the last half of the growing season. Overall, however, root weights were poorly correlated with nematode numbers. Also, root weights were often less in plots with larger population densities than with fewer nematodes (Fig. 2). The root effect is undoubtedly important, however, but variation and subtle effects make elucidation of factors involved difficult to determine. The effect of alachlor apparently occurs late enough not to have a significant effect on yield, but may affect the subsequent crop.

The greatest final nematode populations occur with aldicarb. The inhibitory effect of aldicarb on the nematode probably is limited to a relatively short period of time. Earlier reproduction coupled with a well-developed root system could result in larger populations near the end of the season. Physiological alteration of the plant and differential effects from decreasing concentrations of aldicarb on hatching and reproduction may also be involved. Low concentrations of aldicarb induced hatching of *Heterodera schachtii* Schmidt (3,10,11) and increased the attraction of males to females of this nematode (3). The fecundity of *Aphelenchoides rutgersi* Hooper & Myers was enhanced by aldicarb (6). The nematicide concentration in the soil would decrease with time. At some point, concentrations that have been shown to induce any combination of increased hatching, male attraction, fecundity, or other biological phenomena could occur and account for some of the late season resurgence. The effect of concentration with aldicarb may be

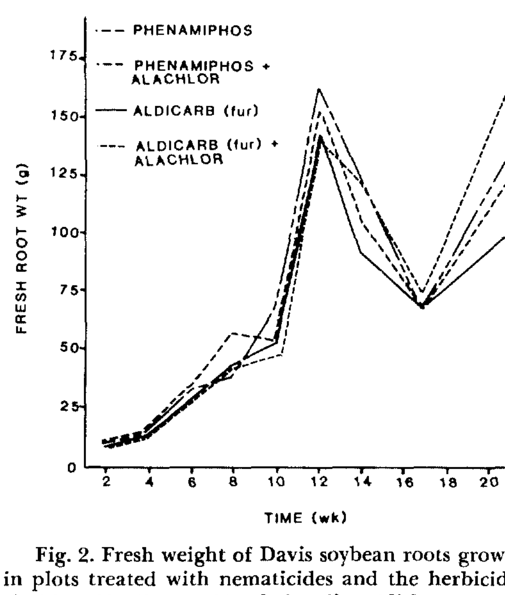

Fig. 2. Fresh weight of Davis soybean roots grown in plots treated with nematicides and the herbicide alachlor, Chadbourn, North Carolina, 1979.

illustrated by comparing the differences in the two experiments. In 1978, the aldicarb band was incorporated three times as deep as in 1979 resulting in a 1/3 concentration per unit volume of soil. The in-furrow treatment would probably give a low concentration in most of the root zone except near the area of seed placement. The higher concentration in the shallow incorporated band did not give the resurgence. This phenomenon must be investigated because in-furrow is becoming a popular practice which could result in higher nematode populations that would require longer rotations, more nematicides, or resistant cultivars plus a nematicide. Different cultivars, locations, and initial populations may have affected results in the 2 years of this study.

Increased yields may have resulted from some indirect effects. At 2 weeks after treatment in the 1979 experiment (similar trend in the 1978 experiment), the roots from nematicide treated plots weighed less than those from the check, alachlor, and linuron treatments. The nematicides alone and in combination with herbicides may stunt roots initially, thus providing fewer infection sites for nematodes. This may be additive to the other effects on the nematode alone.

The reason for the altered population dynamics of *H. glycines* as well as *H. dihystera* and some microbivorous nematodes (9) resulting from pesticide combinations compared to the nematicide alone have not been determined. They are probably complex, ranging from the alteration of the behavior of one chemical by the other chemical, altered physiology of the plant, and biological changes within the soil environment.

It is essential and of practical importance to understand the biology and population dynamics in the soybean ecosystem in relation to plant growth and yield. Once these relationships are understood, important nematode management questions can better be answered.

LITERATURE CITED

1. Barker, K. R. (Chairman). 1978. Determining nematode responses to control agents. Pages 114-125 *in* E. Zehr, ed. Methods for evaluating plant fungicides, nematicides, and bactericides, St. Paul, Minnesota: American Phytopathological Society.

2. Dropkin, V. H., C. H. Baldwin, T. Gaither, and W. Mace. 1976. Growth of Heterodera glycines in soybeans in the field. Plant Dis. Rept. 60:977-980.

3. Hough, A., and I. J. Thomason. 1975. Effects of aldicarb on the behavior of Heterodera schachtii and Meloidogyne javanica. J. Nematol. 7:221-229.

4. Johnson, A. W., C. C. Dowler, and E. W. Hauser. 1975. Crop rotation and herbicide effects on population densities of plant-parasitic nematodes. J. Nematol. 7:158-168.

5. Kraus, R., G. R. Noel, and D. I. Edwards. 1982. Effect of preemergence herbicides and aldicarb on Heterodera glycines population dynamics and yield of soybean. J. Nematol. 14:452 (Abstr.).

6. Myers, R. F. 1973. Assay of nematicidal and nemastatic chemicals using axenic cultures of Aphelenchoides rutgersi. Nematologica 18:447-457.

7. Nusbaum, C. J., and K. R. Barker. 1971. Population dynamics. Pp. 303-323 *in* B. M. Zuckerman, W. F. Mai, and R. F. Rohde, eds. Plant parasitic nematodes. New York: Academic Press.

8. Riggs, R. D., and L. R. Oliver. 1982. Effect of trifluralin (Treflan) on soybean cyst nematode. J. Nematol. 14:466 (Abstr.).

9. Schmitt, D. P., and F. T. Corbin. 1981. Interaction of fensulfothion and phorate with preemergence herbicides on soybean-parasitic nematodes. J. Nematol. 13:37-41.

10. Steele, A. E. 1977. Effects of selected carbamate and organophosphate nematicides on hatching and emergence of Heterodera schachtii. J. Nematol. 9:149-152.

11. Steudel, W. 1972. Versuche zum Einfluss von Aldicarb auf den Schlupfuorgang bei zysten von Heterodera schachtii nach langerer Einwirkung. Nematologica 18:270-274.