Journal of Nematology 19(1):38–43. 1987.

Root-knot Nematode Management and Yield of Soybean as Affected by Winter Cover Crops, Tillage Systems, and Nematicides[1]

N. A. Minton and M. B. Parker[2]

Abstract: Management of *Meloidogyne incognita* on soybean as affected by winter small grain crops or fallow, two tillage systems, and nematicides was studied. Numbers of *M. incognita* did not differ in plots planted to wheat and rye. Yields of soybean planted after these crops also did not differ. Numbers of *M. incognita* were greater in fallow than in rye plots, but soybean yield was not affected by the two treatments. Soybean yields were greater in subsoil-plant than in moldboard plowed plots. Ethylene dibromide reduced nematode population densities more consistently than aldicarb and phenamiphos. Also, ethylene dibromide increased yields the most and phenamiphos the least. There was a positive correlation ($P = 0.001$) of seed size (weight of 100 seeds) with yield ($r = 0.79$), indicating that factors affecting yield also affected seed size.

Key words: aldicarb, conservation tillage, ethylene dibromide, *Glycine max, Meloidogyne incognita,* moldboard plow, phenamiphos, root-knot nematode, rye, *Secale cereale,* soybean, subsoil-plant, tillage, *Triticum aestivum,* wheat.

Conservation tillage and double cropping are being adopted rapidly in the United States. Conservation tillage may be described as any tillage sequence that reduces loss of soil or water relative to conventional tillage (2). This may be accomplished with reduced tillage and less disturbance of crop residue on the soil surface. Multiple cropping is growing two or more successive crops the same year on the same land area. In the United States in 1984, 8.7 million hectares of soybean (*Glycine max* (L.) Merr.) were grown by conservation tillage and 2.1 million hectares were double cropped (3). In Georgia, 0.4 and 0.2 million hectares were grown by conservation tillage and double cropped, respectively (3).

Only limited information is available on the impact of conservation tillage and double cropping of small grain–soybean on nematode populations and their control. Nematode control studies on soybean have been conducted primarily with conventional tillage and monocropping. In the few soybean tillage experiments in which nematode population densities have been studied, variations have occurred among tillage systems, cropping sequences, and nematode species. In Tennessee, the average number of soybean cyst nematodes (*Heterodera glycines* Ichinohe) in no-till soybean plots was significantly less than in plots that were disked, chiseled, subsoiled under the row, or subsoiled between the rows (12). Cyst population densities following moldboard plowing did not differ from those for any tillage treatment, except fewer cysts were present in the treatment subsoiled between rows than in the moldboard plowed plots (12). In Indiana, greater population densities of *Pratylenchus scribneri* Steiner occurred in conventional tilled soybeans than in zero tilled, and there was a more dramatic expression of nematode patchiness (non-uniform distribution) in the conventional tilled than in zero tilled (1). The researchers attributed the greater population densities to larger and more robust roots under conventional tillage. Treatment with carbofuran reduced the patchiness (or increased the dispersion) of *Hoplolaimus galeatus* (Cobb) Filipjev and

Received for publication 17 February 1986.

[1] Cooperative investigations of USDA ARS and the University of Georgia College of Agriculture Experiment Station, Tifton, GA 31793.

Mention of a pesticide neither constitutes a recommendation nor implies registration under FIFRA.

[2] Research Nematologist, USDA ARS, and Associate Professor of Agronomy, the University of Georgia College of Agriculture, Coastal Plain Experiment Station, Tifton, GA 31793.

The authors gratefully acknowledge the financial support of the Georgia Agricultural Commodity Commission for Soybean.

Schuurmans-Stekhoven (1). Tillage treatments in Georgia affected vertical distribution of nematodes (8). Population densities of *Hoplolaimus columbus* Sher were greater in the 20–33-cm and 33–46-cm soil layers in conventionally tilled soybean plots that received in-row subsoiling than in conventionally tilled plots that had not been subsoiled, but total numbers of nematodes in the two tillage treatments did not differ (8). In a similar study (6), subsoiling suppressed the root-knot index of soybean when compared with conventional tillage, but population densities of *Meloidogyne incognita* (Kofoid and White) Chitwood were not affected in three zones of the soil profile. In two experiments, 1,2-dibromo-3-chloropropane reduced numbers of nematodes and increased soybean yields (6).

In a double-cropped corn (*Zea mays* L.) and soybean system (corn planted in March and soybean in July) (9), numbers of *Meloidogyne arenaria* (Neal) Chitwood and *Paratrichodorus minor* (Colbran) Siddiqi in the soil remained low for 3 years. Population densities under soybean were not significantly different among tillage treatments (moldboard plow, subsoil-plant and no-tillage) (9). Also, the population densities did not change in these plots under corn planted in the no-tillage system. Ethylene dibromide and phenamiphos reduced nematode population densities, but did not significantly increase yields (9). In another 2-year, double-cropped corn–soybean system, ethylene dibromide, phenamiphos, and aldicarb reduced numbers of *M. incognita* and *Belonolaimus longicaudatus* Rau in subsoil-plant corn and increased corn yields (7). These nematicides also increased yields of soybean planted in moldboard plowed plots following corn (7). Researchers in Tennessee concluded that the major factor influencing nematode communities in conventional and no-tillage systems in a soybean–wheat (*Triticum aestivum* Lam) rotation appeared to be presence or absence of wheat rather than the tillage systems (4). Total numbers of plant-parasitic nematodes in May were greater in plots planted to wheat than in no-wheat plots; however, in July and October when the plots were planted to soybean, nematode population densities were the same.

The objective of this study was to determine the combined effects of winter small grain or fallow, tillage treatments, and nematicides on nematode population densities and soybean yields.

Materials and Methods

The experimental area which had a Dothan loamy sand had been planted to soybean for approximately 10 years before this study. A split-split plot experimental design was used with winter small grain or fallow as whole plots, tillage as subplots, and nematicide treatments as sub-subplots. Sub-subplots were 6.1 m long and 7.2 m wide with eight rows each spaced 0.9 m apart. Treatments were replicated four times. The whole plot treatments were 'Wrens Abruzzi' rye (*Secale cereale* L.) and 'Omega' wheat or fallow (plots planted to wheat in 1980–81 and left fallow during the winters of 1981–82 and 1982–83). Wheat was omitted from the experiment during 1981–82 and 1982–83 because the nematode population densities and soybean yields in 1981 were the same in rye and wheat plots. Subplot treatments (methods of soil preparation for planting soybean) were moldboard plowing to a depth of 25 cm and subsoiling under the row in previously undisturbed soil to a depth of 35 cm (subsoil-plant) (11). Nematicide treatments in the sub-subplots applied only to soybean were ethylene dibromide (27 kg a.i./ha), phenamiphos (2.2 kg a.i./ha), aldicarb (2.2 kg a.i./ha), and control.

The plots were disked and planted to wheat or rye on 17 December 1980. On 6 November 1981 and 12 November 1982, rye plots were disked and planted and plots planted to wheat in 1980 were left fallow. Fallowed plots were not disked, but the soybean stalks were cut with a rotary mower; weeds were allowed to grow during the winters of 1981–82 and 1982–83. The small grain was harvested 29 May 1981, 6

June 1982, and 6 June 1983; the straw was left on the plots. 'Ga Soy 17' soybean, which is susceptible to *M. incognita,* was planted 4 June 1981, 8 June 1982, and 9 June 1983. Plots prepared for planting soybean with a moldboard plow were disked before the soil was turned 25 cm deep. Subsoil-plant plots were not disked. Ethylene dibromide was applied 20 cm deep with two chisels spaced 25 cm apart in the moldboard plow prepared plots before planting and 30 cm deep in the subsoiler chisel slit in the subsoil-plant plots at planting. Phenamiphos and aldicarb were applied at planting in an 18-cm-wide band behind the planter seed tube and ahead of the press wheel in both tillage treatments.

Fertilizer was applied as recommended on the basis of soil tests for soybean, rye, and wheat production in Georgia. Weeds present at the time soybean was planted were cutleaf evening primrose (*Oenothera laciniata* Hill), Texas panicum (*Panicum texanum* Buckl.), large crabgrass (*Digitaria sanguinalis* (L.) Scop.), and yellow nutsedge (*Cyperus esculentus* L.). Weeds were controlled in soybean in the moldboard plowed plots by applying trifluralin (0.56 kg/ha) before planting and cultivating as needed. Weeds in subsoil-plant plots were controlled with a postplant application of paraquat (0.56 kg/ha), oryzalin (0.84 kg/ha), and metribuzin (0.37 kg/ha in 1982 and 0.18 kg/ha in 1983). Methomyl and methyl parathion were applied as needed to control insects. All plots were irrigated when soybeans were planted and as needed thereafter.

Soil samples for nematode assays, plant height, and yield were taken from the fourth and fifth rows of each plot. Ten 2.5-cm-d cores of soil were collected from the 0–20-cm depth 19 December 1980, 15 April and 24 September 1982, and 23 March and 23 September 1983. Nematodes were extracted from 150 cm^3 of soil by the centrifugal-sugar flotation method (5). Roots of 10 plants were dug from the third and sixth rows of each plot to evaluate root galling. Root gall ratings were based on a scale of 1–5, with 1 = no galling, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100% of roots galled. Soybeans were harvested 21 October 1981, 10 October 1982, and 2 November 1983. In 1983, the weight of 100 seeds was determined. Data were analyzed statistically by methods according to Steel and Torrie (10); only significant ($P = 0.05$) data are discussed.

RESULTS

Nematodes recovered from the soil were *M. incognita, P. minor, Pratylenchus brachyurus* (Godfrey, 1929) Goodey, 1951, and *Helicotylenchus* spp. Because of the high level of correlation of *M. incognita* juveniles and root-knot indices with yield and the lack of significant correlations for the other nematode species, data for only *M. incognita* are included. On 19 December 1980 when the experiment was begun, an average of 1,075 *M. incognita* juveniles per 150 cm^3 soil were present. Numbers of juveniles in the soil declined during the winter and spring; average numbers present on 9 April 1981 and 3 June 1981 were 175 and 88 per 150 cm^3 soil, respectively. Differences in numbers of *M. incognita* in rye vs. wheat were not significant, and rye and wheat in the winter did not affect population densities of *M. incognita* in the soil on 12 October 1981 nor the root-knot indices of soybean plants (data not shown). However, population densities of *M. incognita* in the soil on 12 October 1981 were greater in moldboard plowed plots (796/150 cm^3 soil) than in subsoil-plant plots (284/150 cm^3 soil). Also, ethylene dibromide and aldicarb treatments had lower population densities than phenamiphos and control treatments. Average numbers present in nematicide-treated plots were ethylene dibromide, 232; aldicarb, 295; phenamiphos, 767; and control, 865. All nematicides reduced root-knot indices (data not shown).

Soybean yield differences in 1981 caused by wheat and rye and tillage treatments were not significant (data not shown). However, average yield differences for nematicide treatments across small grain and tillage treatments were significant. Yields

TABLE 1. Average number of *Meloidogyne incognita* juveniles per 150 cm^3 soil taken in March and April from tillage and nematicide treatments following winter rye or fallow, 2-year average, 1982–83.

Winter crop and tillage treatment	Ethylene dibromide 27 kg ai/ha	Aldicarb 2.2 kg ai/ha	Phenamiphos 2.2 kg ai/ha	Control	Av
Rye					
Moldboard plow	67 a x	97 a x	101 a x	300 a x	141 a
Subsoil-plant	68 a x	42 a x	104 a x	99 a x	78 a
Average	68 x	70 x	103 x	200 x	110*
Fallow					
Moldboard plow	49 a x	850 a y	815 a y	1,154 a y	717 a
Subsoil-plant	42 a x	135 b x	184 b x	536 b x	224 a
Average	46 x	493 y	500 y	845 z	471
Average (tillage and winter crop treatments combined)	57 x	282 y	302 y	523 z	
Average (nematicide and winter crop treatments combined)					
Moldboard plow					429*
Subsoil-plant					151

Values followed by the same letter within columns (a, b) (within rye or fallow) or on the same line (x–z) are not significantly (P = 0.05) different according to Duncan's multiple-range test.
* Differences between averages for rye vs. fallow and moldboard plow vs. subsoil-plant were significant (P = 0.05).

for ethylene dibromide, aldicarb, phenamiphos, and control treatments were 2,728 kg/ha, 2,365 kg/ha, 1,922 kg/ha, and 1,828 kg/ha, respectively. Yields for ethylene dibromide and aldicarb treatments were significantly greater than for the phenamiphos and control treatments, and yield for the ethylene dibromide treatment was significantly greater than for the aldicarb treatment.

Nematode counts (Tables 1, 2) and soybean yields (Table 3) for 1982 and 1983 are presented as 2-year averages. Interactions occurred for winter crop vs. nematicides and winter crop vs. tillage treatments for *M. incognita* juveniles in the soil in March and April. *Meloidogyne incognita* juveniles were more numerous in fallow than in rye plots in the spring preceding soybean planting (Table 1). Tillage and nematicide treatments applied to soybean had residual effects on nematode population densities in the rye and fallow plots. The average number of juveniles was greater in the moldboard plowed plots than in subsoil-plant plots. Numbers in fallow plots were also greater than in rye plots. Nematicides applied to soybean had no effect on nematode population densities in rye plots. In fallow plots, however, all nematicides reduced the average number of nematodes, with ethylene dibromide being the most effective treatment.

Numbers of *M. incognita* in the soil in September and soybean yields were not different for rye and fallow plots. Also, there were no interactions among treatments. Therefore, September nematode population densities and root-knot indices (Table 2) and yields and seed weights (Table 3) are presented as averages across rye and fallow treatments. In September, *M. incognita* population densities were greater in moldboard plowed plots than in subsoil-plant plots in untreated control plots. Average population densities across all nematicide treatments also were greater in moldboard plowed plots than in subsoil-plant plots. Compared with the control, all nematicide treatments in the moldboard plowed plots reduced population densities. Also, in the moldboard plowed plots, fewer nematodes were present in aldicarb treated plots than in phenamiphos treated plots. In the subsoil-plant plots, ethylene dibromide and aldicarb reduced nematode population densities compared with the control. Average population densities across

TABLE 2. Average number of *Meloidogyne incognita* juveniles per 150 cm^3 soil in September and root-knot indices of soybean as affected by tillage and nematicide treatments, 2-year average, 1982–83.

Tillage treatment	Ethylene dibromide 27 kg ai/ha	Aldicarb 2.2 kg ai/ha	Phenamiphos 2.2 kg ai/ha	Control	Av
		Juveniles			
Moldboard plow	476 a xy	358 a x	932 a y	1,442 a z	801 a
Subsoil-plant	219 a x	109 a x	646 a xy	810 b y	446 b
Average	348 x	233 x	789 y	1,126 y	
		Root-knot index*			
Moldboard plow	1.8 a x	1.7 a x	2.2 a x	3.5 a y	2.3 a
Subsoil-plant	1.4 a x	1.5 a x	1.9 a x	3.0 b y	1.9 b
Average	1.6 x	1.6 x	2.0 y	3.2 z	

Values followed by the same letter within columns (a, b) (within *M. incognita* juvenile counts or root-knot indices) or on the same line (x–z) are not significantly ($P = 0.05$) different according to Duncan's multiple-range test.
* Root-knot index based on 1–5, with 1 = no galling and 5 = 76–100% of roots galled.

tillage treatments also were less for ethylene dibromide and aldicarb treatments than for the phenamiphos treatment and control.

The root-knot index for the control and the average root-knot index across nematicide treatments were less in subsoil-plant than in moldboard plowed plots (Table 2). The average root-knot indices for all nematicide treatments were less than for the control, and the average root-knot indices for ethylene dibromide and aldicarb treatments were less than for the phenamiphos treatment.

Soybean yields for aldicarb, phenamiphos, and control treatments were greater in subsoil-plant plots than in moldboard plowed plots (Table 3). The average yield across nematicide treatments was also greater in subsoil-plant plots than in moldboard plowed plots. All nematicides increased yields in subsoil-plant plots, as did ethylene dibromide and aldicarb in moldboard plowed plots. In moldboard plowed plots, ethylene dibromide increased yields more than aldicarb and phenamiphos, and aldicarb increased yields more than phenamiphos. In subsoil-plant plots, ethylene dibromide and aldicarb increased yields more than phenamiphos. Average yield increases across tillage treatments were greatest for ethylene dibromide and least for phenamiphos. There was a negative correlation ($P = 0.0001$) of yield and number of *M. incognita* juveniles in the soil ($r = -0.61$) and yield and root-knot index ($r = -0.74$).

In 1983, the average soybean seed size, as indicated by the weight of 100 seeds, was greater in subsoil-plant plots than in moldboard plowed plots. Only ethylene dibromide increased seed size significantly in

TABLE 3. Soybean yield (kg/ha), 2-year average, 1982–83 and seed weight (g/100 seeds) for 1983 as affected by tillage and nematicide treatments.

Tillage treatment	Ethylene dibromide 27 kg ai/ha	Aldicarb 2.2 kg ai/ha	Phenamiphos 2.2 kg ai/ha	Control	Av
		Yield			
Moldboard plow	2,601 a y	2,070 b x	1,673 b w	1,425 b w	1,942 b
Subsoil-plant	2,688 a y	2,661 a y	2,271 a x	1,767 a w	2,345 a
Average	2,641 z	2,365 y	1,969 x	1,593 w	
		Seed weight			
Moldboard plow	15.2 a x	14.7 a wx	14.1 a wx	13.2 a w	14.3 b
Subsoil-plant	15.8 a w	15.7 a w	15.0 a w	14.3 a w	15.2 a
Average	15.5 y	15.2 y	14.5 x	13.7 w	

Values followed by the same letter within columns (a, b) (within yield and seed weight) or on the same line (w–z) are not significantly ($P = 0.05$) different according to Duncan's multiple-range test.

the moldboard plowed plots, and no nematicide increased seed size in the subsoil-plant plots. However, the average seed size across tillage treatments was greater for all nematicide treatments than for control. The average seed size in plots treated with ethylene dibromide and aldicarb was greater than in phenamiphos plots. There was a positive correlation ($P = 0.0001$) of seed size (weight/100 seeds) with yield ($r = 0.79$) indicating that factors affecting yield also affected seed size.

Discussion

The results of this experiment showed that *M. incognita* can be managed satisfactorily for the production of soybean in rye stubble in minimum tilled soil. Even though damaging levels of nematodes were present following rye, a fumigant and two contact nematicides applied at planting reduced their effects on soybean.

Population density of *M. incognita* in rye plots was lower than in fallowed plots but not enough to significantly affect soybean yield. Reasons for fewer nematodes in rye plots than in fallowed plots were not determined, but weeds growing in the fallowed plots may be better hosts than rye for *M. incognita*.

The increased yield in 1982–83 in the subsoil-plant treatment compared with the moldboard plow treatment was similar to results reported for in-row subsoiling of disk harrowed (6) and moldboard plowed (8) soybean plots. As in the earlier experiments, subsoiling in the row may have permitted the soybean roots to penetrate and proliferate below a hardpan where soil moisture was more favorable, resulting in fewer roots in the sampled zone (0–20 cm depth). In contrast, the soil above the hardpan (if one were present) in the moldboard plowed plots may have contained more roots and consequently more nematodes in the sampled zone than were present in the subsoiled plots.

Generally, ethylene dibromide was the most effective nematicide in controlling *M. incognita* and phenamiphos the least effective. These results differ from those of a previous experiment (7) where the three nematicides were equally effective in controlling nematodes and increasing yields of corn planted in minimum tillage and soybean planted in a moldboard plowed seedbeds. The nematicides may have performed differently in the two experiments because of the different tillage treatments, nematode species present, or crops grown.

This experiment was conducted for only 3 years. These differences in cultural systems over a long period of time could result in greater differences in nematode population densities, soil compaction, and weed population densities.

Literature Cited

1. Alby, T., J. M. Ferris, and V. R. Ferris. 1983. Dispersion and distribution of *Pratylenchus scribneri* and *Hoplolaimus galeatus* in soybean fields. Journal of Nematology 15:418–426.

2. Anonymous. 1982. Resource conservation glossary, 3rd ed. Ankeny, Iowa: Soil Conservation Society of America.

3. Anonymous. 1985. The 1984 national survey of conservation tillage practices. Ft. Wayne, Indiana: Conservation Tillage Information Center.

4. Baird, S. M., and E. C. Bernard. 1984. Nematode population and community dynamics in soybean-wheat cropping and tillage regimes. Journal of Nematology 16:379–386.

5. Jenkins, W. R. 1964. A rapid centrifugal-flotation technique for separating nematodes from the soil. Plant Disease Reporter 48:692.

6. Minton, N. A., and M. B. Parker. 1975. Interaction of four soybean cultivars with subsoiling and a nematicide. Journal of Nematology 7:60–64.

7. Minton, N. A., M. B. Parker, and D. R. Sumner. 1985. Nematode control related to fusarium wilt in soybean and root-rot and zinc deficiency in corn. Journal of Nematology 17:314–321.

8. Parker, M. B., N. A. Minton, O. L. Brooks, and C. E. Perry. 1975. Soybean yields and lance nematode populations as affected by subsoiling, fertility, and nematicide treatments. Agronomy Journal 67: 663–666.

9. Parker, M. B., N. A. Minton, E. D. Threadgill, D. D. Dowler, and D. R. Sumner. 1985. Tillage, nitrogen, herbicide, and nematicide effects on double-cropped corn and soybean under irrigation in the coastal plain. Georgia Agriculture Experiment Station Research Bulletin 326, University of Georgia, Athens.

10. Steel, R. G. D., and J. D. Torrie. 1960. Principles and procedures of statistics. New York: McGraw-Hill Book Co.

11. Threadgill, E. D. 1982. Residual tillage effects as determined by cone index. Transactions of the ASAE 25:859–863, 867.

12. Tyler, D. D., J. R. Overton, and A. Y. Chambers. 1983. Tillage effects on soil properties, diseases, cyst nematodes, and soybean yields. Journal of Soil and Water Conservation 38:374–376.