Effects of One and Two Applications of Nematicides on Nematode Populations and Soybean Yields[1]

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Abstract: Yields of 'McNair 800' soybeans, *Glycine max* (L.) Merr., were significantly increased with ethylene dibromide + chloropicrin, DBCP, phenamiphos, and aldicarb applied at-planting and with phenamiphos, aldicarb, and DBCP applied postplant to soil infested with *Meloidogyne incognita* (Kofoid and White) Chitwood. Yields of 'GaSoy 17' were significantly increased with ethylene dibromide + chloropicrin, DBCP, phenamiphos, and aldicarb applied, preplant and with DBCP, carbofuran, phenamiphos, aldicarb, and DBCP applied postplant to soil infested with *Hoplolaimus columbus* Sher. In several instances, preplant or at-planting treatments plus postplant treatments with the same or different chemicals were more effective than either treatment alone. Generally, the fumigants were more effective than the nonfumigants when they were applied at-planting to *M. incognita*-infested soil and preplant to *H. columbus*-infested soil. Phenamiphos, aldicarb, and DBCP were about equally effective when they were applied postplant in *M. incognita*-infested soil, but DBCP was more effective than carbofuran. Carbofuran, phenamiphos, aldicarb, and DBCP were about equally effective when applied postplant to *H. columbus*-infested soil. *Key Words: Meloidogyne incognita,* root-knot nematode, *Hoplolaimus columbus,* Columbia lance nematode, *Glycine max,* soybean, chemical control.

Nematicides are used for nematode control on soybeans, *Glycine max* (L.) Merr., where resistant varieties are not available and crop rotations are not adequate or practical. For several years, DBCP (1,2-dibromo-3-chloropropane) has been the most commonly used material, but it is no longer available for use because of environmental considerations. DD (1,3 dichloropropene, 1,2-dichloropropane), 1,3-D (1,3-dichloropropene), and ethylene dibromide (1,2-dibromoethane) have long been recognized as excellent nematicides. Their use, however, has been greatly restricted because they have been considered highly phytotoxic and unsafe to use on row crops at planting (3). More recently, several nonfumigant carbamate and organophosphorous compounds have become available. Generally, the nonfumigants have been less effective than the fumigants (2,5,8). Although nematicides often provide a beneficial yield response in heavily infested soil, yields are often lower than one would expect if nematodes were completely controlled (9,10). Most nematicides have been applied to soybeans before or at the time of planting. Very little work has been done to explore different methods and time of application. We report results of evaluations of time of application relative to planting time and of split applications with the same or different nematicides.

MATERIALS AND METHODS

Experiments were conducted on a Tifton sandy loam infested with *Meloidogyne incognita* (Kofoid and White) Chitwood at Tifton, Georgia, in 1977 and 1978, and on a Marlboro sand infested with *Hoplolaimus columbus* Sher at Midville, Georgia, in 1977. Soybean cultivars 'McNair 800' and 'GaSoy 17' were grown at Tifton and Midville, respectively.

Hairy vetch, (*Vicia villosa* Roth), a winter legume susceptible to root-knot nematodes, was grown at Tifton before each experiment to increase the numbers of nematodes in the soil. The soil was plowed to a depth of 25 cm with a moldboard plow. After plowing, beds 13-15 cm high were formed and the herbicide trifluralin (*a,a,a*-trifluoro-2,6-dinitro-*N,N*-dipropyl-*p*-toluidine) was applied at 0.56 kg (a.i.)/ha and incorporated to a depth of 8 cm with a power-driven rototiller. At Midville the soil was disked twice to a depth of 10 cm, treated with the herbicide vernolate (*S*-propyl dipropylthiocarbamate) at 2.24 kg (a.i.)/ha, and rototilled 7.5 cm deep. Beds 13-15 cm high were formed with a subsoiler and lister-

Received for publication 26 March 1980.

[1]Cooperative investigations of Agricultural Research, Science and Education Administration, U. S. Department of Agriculture, and the University of Georgia College of Agriculture Experiment Stations, Coastal Plain Station, Tifton, GA 31793. This paper reports the results of research only. Mention of a pesticide herein neither constitutes a recommendation for use by the U. S. Department of Agriculture nor does it imply registration under FIFRA.

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bedder and were smoothed with a combination rototiller-leveling device. The subsoiler chisel ran 40 cm deep under the row. Lime and fertilizer were applied according to need indicated by soil tests. Plots were cultivated and insecticides were applied as needed. Irrigation was applied only in severe drought periods.

Nematicide treatments were applied in a split-plot experimental design replicated four times. At-planting and postplant treatments were used at Tifton, and preplant and postplant treatments were used at Midville. Five preplant or at-planting treatments comprised the whole plots and four postplant treatments comprised the subplots. Chemicals applied preplant or at-planting were ethylene dibromide plus chloropicrin 72-27L (1,2-dibromoethane plus trichloronitromethane), DBCP 12.2EC (1,2-dibromo-3-chloropropane), phenamiphos 15G (ethyl 4-(methylthio)-*m*-tolyl isopropylphosphoramidate), aldicarb 15G (2-methyl-2-(methylthio)propionaldehyde *O*-(methylcarbamoyl)oxime), and carbofuran 10G (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate). Carbofuran, phenamiphos, aldicarb, and DBCP were applied postplant. Rates [kg (a.i.)/ha] applied for each application were ethylene dibromide + chloropicrin, 13.2 + 5.0 (with the exception of 19.9 + 7.4 at Tifton in 1977); phenamiphos, aldicarb, and carbofuran 2.2 (with the exception of 2.8 for aldicarb at Tifton at-planting); and DBCP, 10.0. Ethylene dibromide + chloropicrin and DBCP were injected 20 cm deep, using two chisels per row, and spaced 13 cm to either side of the row. Carbofuran, phenamiphos, and aldicarb were applied in a 30-cm band over the row. Plots treated preplant and at-planting were rototilled 10-15 cm deep and plots treated postplant were lightly cultivated after the chemicals were applied. Subplots consisted of four 6.1-m rows spaced 0.9 m and 0.96 m apart at Tifton and Midville, respectively.

At Tifton, at-planting and postplant treatments were applied on 19 May and 15 June 1977 and 15 May and 6 June 1978, respectively. Plots were seeded on 19 May 1977 and 15 May 1978. At Midville, preplant and postplant treatments were applied on 3 May and 16 June 1977, respectively, and plots were seeded on 26 May 1977.

Nematode numbers in the soil were determined from soil samples collected from the two center rows of each subplot. Nematodes were extracted by the centrifuge-sugar-flotation method (4). At the Tifton location, 10 plants were collected from the two outside rows of each subplot and the root-knot index was estimated. Ratings were made 20 September 1977 and 1 September 1978. Root-knot indices were based on a 1–5 scale: 1 = no galling, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100% of root systems galled. Soybean yields were obtained from the two center rows of each subplot. Data were subjected to analysis of variance and Duncan's multiple-range test (12).

RESULTS

Tifton location: Soybean yields were significantly increased by all chemicals except carbofuran in plots that received only at-planting or postplant treatments (Table 1). Yields of all at-planting treatments, with the exception of DBCP, were increased significantly by one or more postplant treatments. Only DBCP applied postplant significantly increased yields in plots treated at-planting with ethylene dibromide + chloropicrin, phenamiphos, and aldicarb. Yield increases from DBCP applied postplant were greater for some at-planting treatments than for others. DBCP increased yields 18, 37, 38, 53, and 77% when it was applied postplant to ethylene dibromide + chloropicrin, phenamiphos, aldicarb, and carbofuran at-planting treated plots and the untreated control, respectively. Yields were similar for plots that received only at-planting or postplant treatments of phenamiphos, aldicarb, or DBCP. Carbofuran applied at-planting or postplant had no significant effect on yield. Consequently, postplant applications of phenamiphos, aldicarb, and DBCP significantly increased yields of plots treated at-plant with carbofuran.

Examination of soil samples on 31 August 1977 showed that all nematicide treatments applied at-planting significantly reduced *M. incognita* larval populations (Table 2). All postplant treatments significantly reduced larval populations in plots that received no at-planting treatment; how-

Table 1. Soybean yields in kg/ha as affected by various combinations of at-planting and postplanting nematicide treatments, Tifton, Georgia (2-yr average).*

At-planting treatments	Postplant treatments				
	Control	Carbofuran	Phenamiphos	Aldicarb	DBCP
Ethylene dibromide + chloropicrin	2,419 a	2,365 a	2,271 a	2,607 a	2,843 a
DBCP	2,130 ab	2,144 ab	2,379 a	2,345 ab	2,372 a-c
Phenamiphos	1,794 b	1,861 a-c	2,177 a	2,117 a-c	2,453 ab
Aldicarb	1,626 bc	1,667 bc	2,003 a	1,922 bc	2,244 b-d
Carbofuran	1,176 cd	1,008 d	1,465 b	1,667 c	1,794 d
Control	1,076 d	1,431 cd	1,599 b	1,774 c	1,901 cd

*Data underscored by the same line in rows or followed by the same letter in columns are not significantly different at the 5% level according to Duncan's multiple-range test.

ever, no postplant treatment reduced larval populations significantly in plots that did receive at-planting treatments. Larval populations in the soil were low in all plots on 18 July 1978 and there were no significant differences among treatments (data not shown). On 31 October 1978, however, populations in the soil were high and differed significantly among treatments (Table 3). Populations were significantly reduced by at-planting treatments of ethylene dibromide + chloropicrin and DBCP. Postplant treatments of phenamiphos and aldicarb significantly reduced larval populations in plots that received no at-planting treatment. Phenamiphos applied postplant significantly reduced larval populations in plots treated at-planting with carbofuran, phenamiphos, and aldicarb. Aldicarb applied postplant significantly reduced larval population levels in plots treated at-planting with phenamiphos.

Root-knot indices were significantly reduced by at-planting treatments of ethylene dibromide + chloropicrin, DBCP, and phenamiphos (Table 4). All postplant treatments except carbofuran significantly decreased root-knot indices in plots that received no at-planting treatment. The postplant phenamiphos treatment significantly reduced root-knot indices in all plots treated at planting except those receiving ethylene dibromide + chloropicrin. Also, aldicarb applied postplant significantly reduced root-knot indices in all plots treated at planting except those receiving ethylene dibromide + chloropicrin and carbofuran.

Yields were negatively correlated ($P = 0.01$) with *M. incognita* larval counts in 1977 ($r = -0.40$) and 1978 ($r = -0.49$) and

Table 2. Effect of various combinations of at-planting and postplanting nematicide treatments on numbers of *Meloidogyne incognita* larvae recovered from 150 cm^3 soil on 31 August 1977, Tifton, Georgia.*

At-planting treatments	Postplant treatments				
	Control	Carbofuran	Phenamiphos	Aldicarb	DBCP
Ethylene dibromide + chloropicrin	2 c	14 b	6 a	42 a	10 a
DBCP	40 bc	26 b	4 a	14 a	30 a
Phenamiphos	56 bc	6 b	8 a	14 a	6 a
Aldicarb	112 bc	36 b	28 a	80 a	4 a
Carbofuran	240 b	228 ab	54 a	52 a	54 a
Control	1502 a	310 a	102 a	192 a	60 a

*Data underscored by the same line in rows or followed by the same letter in columns are not significantly different at the 5% level according to Duncan's multiple-range test.

Table 3. Effect of various combinations of at-planting and postplanting nematicide treatments on numbers of *Meloidogyne incognita* larvae recovered from 150 cm³ soil on 31 October 1978, Tifton, Georgia.*

At-planting treatments	Postplant treatments				
	Control	Carbofuran	Phenamiphos	Aldicarb	DBCP
Ethylene dibromide + chloropicrin	212 b	112 d	22 a	24 a	70 b
DBCP	194 b	412 cd	124 a	446 a	876 ab
Phenamiphos	1,714 a	1,370 bc	158 a	124 a	1,326 a
Aldicarb	1,542 a	2,698 a	404 a	836 a	1,744 a
Carbofuran	1,724 a	1,100 bc	380 a	784 a	1,466 a
Control	1,728 a	2,208 ab	568 a	480 a	792 ab

*Data underscored by the same line in rows or followed by the same letter in columns are not significantly different at the 5% level according to Duncan's multiple-range test.

with the 2-year root-knot indices ($r = -0.56$).

Midville location: Soybean yields were significantly increased by all chemicals except carbofuran in plots receiving only preplant treatments and also in all plots that received only postplant treatments (Table 5). In plots that received only the preplant treatments, yields from plots treated with ethylene dibromide + chloropicrin and DBCP were significantly greater than those treated with carbofuran, phenamiphos, and aldicarb. In plots that received only the preplant treatments, ethylene dibromide + chloropicrin, DBCP, phenamiphos, and aldicarb increased yields 100, 104, 32, and 35%, respectively, over the untreated control; whereas in plots that received only postplant treatments, carbofuran, phenamiphos, aldicarb, and DBCP increased yields 69, 64, 77, and 69%, respectively, over the untreated control. Yields in plots treated preplant with carbofuran were significantly increased by all postplant treatments, and yields of plots treated preplant with aldicarb were significantly increased by postplant treatments of DBCP.

H. columbus populations were significantly reduced in all plots receiving only preplant treatments except those treated with phenamiphos and carbofuran (Table 6). All postplant treatments except DBCP significantly reduced populations in plots that did not receive preplant treatments. Aldicarb and DBCP applied postplant significantly reduced populations in plots

Table 4. Effect of various combinations of at-planting and postplant nematicide treatments on 2-yr average root-knot index of soybean roots, Tifton, Georgia.*

At-planting treatments	Postplant treatments				
	Control	Carbofuran	Phenamiphos	Aldicarb	DBCP
Ethylene dibromide + chloropicrin	1.4 e	1.5 c	1.1 c	1.1 e	1.2 d
DBCP	2.2 d	2.0 c	1.1 c	1.3 de	2.0 c
Phenamiphos	2.7 cd	3.5 b	1.8 bc	1.9 cd	2.3 c
Aldicarb	3.2 bc	3.3 b	2.0 b	2.2 bc	2.7 bc
Carbofuran	4.0 a	3.8 ab	3.0 a	3.5 a	3.8 a
Control	3.9 ab	4.4 a	2.9 a	2.8 ab	3.2 ab

*Data underscored by the same line in rows or followed by the same letter in columns are not significantly different at the 5% level according to Duncan's multiple-range test.

Based on a 1–5 scale: 1 = no galling, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100% of root systems galled.

Table 5. Soybean yields in kg/ha as affected by various combinations of preplant and postplant nematicide treatments, Midville, Georgia.*

Preplant treatments	Postplant treatments				
	Control	Carbofuran	Phenamiphos	Aldicarb	DBCP
Ethylene dibromide + chloropicrin	2,364 a	2,318 ab	2,271 a	2,453 a	2,238 ab
DBCP	2,413 a	2,493 a	2,177 ab	2,312 ab	2,339 a
Phenamiphos	1,559 b	1,841 c	1,915 ab	2,023 b	1,902 b
Aldicarb	1,593 b	2,036 bc	1,821 b	1,982 b	2,110 ab
Carbofuran	1,317 bc	1,976 bc	1,976 ab	2,056 b	1,942 b
Control	1,183 c	2,003 bc	1,935 ab	2,097 b	1,996 ab

*Data underscored by the same line in rows or followed by the same letter in columns are not significantly different at the 5% level according to Duncan's multiple-range test.

treated preplant with carbofuran. Yields were negatively correlated ($P = 0.01$) with *H. columbus* counts ($r = -0.52$).

CONCLUSIONS

These results show that soybeans planted in nematode-infested soil respond to preplant, at-planting, and postplant applications of fumigant and nonfumigant nematicides. The apparent absence of phytotoxicity of ethylene dibromide + chloropicrin applied at-planting and DBCP applied postplant was of special significance. It has been generally accepted that most crop plants will not tolerate ethylene dibromide + chloropicrin applied at time of planting and DBCP applied postplant. Generally, when fumigant and nonfumigant nematicides were applied at-planting to *M. incognita*-infested soil and preplant to *H. columbus*-infested soil, the fumigants were more effective. Phenamiphos, aldicarb, and DBCP were about equally effective when they were applied postplant in *M. incognita*-infested soil, but DBCP was more effective than carbofuran. All chemicals were about equally effective when applied postplant in *H. columbus* infested soil. These results demonstrate that ethylene dibromide + chloropicrin applied at-planting was as effective as DBCP. Our data corroborate those of Rodriquez-Kabana et al. (11), who found that applications of ethylene dibromide and ethylene dibromide + chloropicrin at-planting increased soybean yields significantly without causing phytotoxicity. Other researchers (1,6,7) also reported recently that ethylene dibromide applied alone at-planting was effective. It is usually less expensive to apply nematicides at-planting than preplant because the at-planting

Table 6. Effect of combinations of preplant and postplant nematicide treatments on numbers of *Hoplolaimus columbus* recovered from 150 cm³ soil on 26 July 1977, Midville, Georgia.*

Preplant treatments	Postplant treatments				
	Control	Carbofuran	Phenamiphos	Aldicarb	DBCP
Ethylene dibromide + chloropicrin	150 c	146 a	120 a	112 b	112 b
DBCP	100 c	136 a	158 a	150 ab	98 b
Phenamiphos	332 a-c	270 a	312 a	388 a	210 ab
Aldicarb	212 bc	216 a	292 a	300 ab	266 ab
Carbofuran	424 ab	228 a	304 a	172 ab	138 ab
Control	466 a	188 a	158 a	174 ab	368 a

*Data underscored by the same line in rows or followed by the same letter in columns are not significantly different at the 5% level according to Duncan's multiple-range test.

applications can be made during the planting operation, whereas preplant applications must be made in a separate operation. Our data also indicate that postplant applications of nematicides to soybeans may be advisable when nematode populations are extremely high and at-planting treatments are not adequate, or when the need for a nematicide is indicated but where no preplant or at-planting application has been made.

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