EFFECTS OF SMALL GRAIN CROPS, ALDICARB, AND *MELOIDOGYNE INCOGNITA* RESISTANT SOYBEAN ON NEMATODE POPULATIONS AND SOYBEAN PRODUCTION†

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ABSTRACT

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Rotations of soybean (*Glycine max*) with winter grown wheat (*Triticum aestivum*), oat (*Avena sativa*), and rye (*Secale cereale*) were compared in relation to soybean yield and population densities of *Meloidogyne incognita, Paratrichodorus minor, Pratylenchus brachyurus,* and *Helicotylenchus* spp. Soil population densities of all the nematode species in plots that had been planted to small grains in the winter did not differ from those in fallow plots in the spring. However, fall populations of *Helicotylenchus* spp. were more numerous in soybean plots following wheat and rye than in soybean plots following oat and fallow. Small grain rotations did not affect population densities of *M. incognita* juveniles, root-knot indices, plant heights or soybean yield. *Meloidogyne incognita* juveniles were more numerous, root-knot indices and plant heights were greater, and yields were lower in plots planted to the moderately *M. incognita* resistant soybean cultivar, Coker 488, than in plots planted to the more highly resistant cultivar, Coker 6738. Yield of Coker 6738 was greater than Coker 488 following rye but yields of the two cultivars following wheat, oat, or fallow did not differ. Soil population densities of all nematode species present in the fall were reduced by at-plant application of aldicarb. Aldicarb also reduced root-knot indices and increased soybean plant height and yield. The population density of *M. incognita* was negatively correlated with yield.

Key words: aldicarb, *Avena sativa,* fallow, *Glycine max, Helicotylenchus* spp., *Meloidogyne incognita,* nematode, oat, *Paratrichodorus minor,* population densities, *Pratylenchus brachyurus,* rye, *Secale cereale,* soybean, *Triticum aestivum,* wheat.

RESUMEN

Minton, N. A. y K. Bondari. 1994. Efectos de cultivos de granos pequeños, aldicarb y de cultivares de soya resistentes a *Meloidogyne incognita* sobre las poblaciones de nematodos y producción de soya. Nematrópica 24:7–15.

Rotaciones de soya (*Glycine max*) con trigo (*Triticum aestivum*) espigado en invierno, avena (*Avena sativa*) y centeno (*Secale cereale*) fueron comparadas en relación a la producción de soya y densidades poblacionales de *Meloidogyne incognita, Paratrichodorus minor, Pratylenchus brachyurus* y *Helicotylenchus* spp. Las densidades poblacionales en el suelo de todas las especies de nematodos de las parcelas que

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habían sido sembradas con cultivos de granos pequeños en el invierno, no fueron diferentes de aquellas sembradas en parcelas barbechadas en la primavera. Sin embargo, las poblaciones en el otoño de *Helicotylenchus* spp. fueron más numerosas en las parcelas de soya seguidas de trigo y centeno que aquellas seguidas de avena y barbecho. Los cultivos de granos pequeños, no afectaron las densidades poblacionales de los juveniles de *M. incognita*, el índice de agallamiento, altura de plantas y producción de soya. Los juveniles de *M. incognita* fueron numerosos, los índices de agallamiento y altura de plantas más altos pero los rendimientos más bajos en las parcelas sembradas con el cultivar de soya moderadamente resistente a *M. incognita* (Coker 488) que los cultivados con el cultivar más resistente (Coker 6738). La produccion del Coker 6738 fue mayor que la del Coker 488 seguida de centeno pero fué igual en ambos cultivares seguidos de trigo, avena o barbecho. Las densidades poblacionales de todas las especies de nematodos presentes en el otoño fueron ruducidas con aplicaciones de aldicarb al momento de la siembra. El Aldicarb también redujo los índices de agallamiento e incrementó la altura y producción. La densidad poblacional de *M. incognita* resultó correlacionada negativamente con los rendimientos.

Palabras clave: aldicarb, *Avena sativa*, barbecho, *Glycine max*, *Helicotylenchus* spp., *Meloidogyne incognita*, nematodos, *Paratrichodorus minor*, densidades poblacionales, *Pratylenchus brachyurus*, centeno, *Secale cereale*, soya, *Triticum aestivum*, trigo.

INTRODUCTION

Meloidogyne incognita (Kofoid & White) Chitwood is endemic in the southeastern United States and may devastate soybean crops (9,12,16). Yield losses have also been reported in Argentina (13) and Brazil (1). In Florida, yield losses of susceptible soybean cultivars were linearly related to the postharvest abundance of second-stage juveniles (J2) of *M. incognita* in soil following the previous year's crop (11).

Use of resistant cultivars is a common control measure for *M. incognita* in soybean. Although yields of resistant cultivars planted in soil heavily infested with *M. incognita* may greatly exceed those of susceptible cultivars, resistant cultivars also may not produce normal yields (16,18). Rotating soybean with crops that have low susceptibility to *M. incognita* can increase soybean yields substantially (10,11). In the southeastern United States, soybean is often planted after winter wheat (*Triticum aestivum* L.), oat (*Avena sativa* L.), or rye (*Secale cereale* L.). Sasser (26) reported varying levels of susceptibility of wheat, oat, and rye to *M. incognita* in 1954 and subsequently many commercial cultivars of wheat have been reported as hosts of *M. incognita* (4,8,20,23,26). No source of resistance to *M. incognita* was detected in 29 accessions of commercial and wild *Triticum* spp. (22); however, resistance was found in *Aegilops squarrosa* which now has been renamed *Triticum tauschii*. Resistance is conferred by a single dominant gene. In California, *M. incognita* was shown to be capable of infecting winter wheat and completing one life cycle during the growing season (21). However, other studies indicated that several wheat cultivars commonly grown in the southern United States were resistant to *M. incognita* (2,3). Resistance and susceptibility to *M. incognita* have been reported in oat (7,19,20,23). There are conflicting reports of susceptibility of rye to *M. incognita* (4,7,8,14,17,19,20,23,26).

No field research has compared the effects of winter wheat, oat, and rye, when grown concurrently in rotation with soybean cultivars, on *M. incognita* population densities and soybean production in the southeastern United States. The objective of this study was to compare final population densities of *M. incognita* J2 in the soil following wheat, oat, rye, and fallow and to relate those densities to the subsequent performance of two nematicide treated and untreated soybean cultivars with different levels of resistance to *M. incognita.*

MATERIALS AND METHODS

An experiment was conducted for 3 years near Tifton, Georgia. One year (1989) the experiment was located in a field with Tifton loamy sand (fine-loamy siliceous, thermic, Plinthic Kandiudults) and in the two other years (1991 and 1992) the experiment was in a field with Dothan loamy sand (fine-loamy, siliceous, thermic Plinthic Kandiudults). Both sites were infested with *M. incognita* race 4, *Pratylenhus brachyurus* (Godfrey) Goodey, *Paratrichodorus minor* (Colbran) Siddiqi, and *Helicotylenchus* spp. Soybean was grown in the field with Tifton soil in 1988 and okra (*Hibiscus esculentus* L.) was grown in the field with Dothan soil in 1990.

The experimental design was a split-split plot with winter small grains ('Florida 302' wheat, 'Florida 501' oat, 'Wrens' abruzzi rye) and weedy fallow as whole

Table 1. Sources of variation, degrees of freedom (df), and signicance ($P > F$) of effects for the number of nematodes/150 cm^3 soil in the fall, root-knot index, plant height, and yield of soybean plants.

Source of variation	df[x]	*Meloidogyne incognita*[y]	*Pratylenchus brachyurus*[y]	*Helicotylenchus* spp.[y]	Root-knot index[z]	Height (cm)	Yield (kg/ha)
Year	2	**	**	**	**	**	*
Crop rotation (CR)	7	**	NS	**	**	*	*
Small grain (Grain)	3	NS	NS	**	NS	NS	NS
Soybean Cultivar (Soy)	1	**	NS	NS	**	**	**
Grain × Soy	3	NS	NS	NS	NS	NS	NS
Year × CR	14	NS	NS	NS	**	NS	**
Year × Grain	6	NS	NS	*	NS	NS	NS
Year × Soy	2	NS	NS	NS	**	*	**
Year × Grain × Soy	6	NS	NS	NS	NS	NS	NS
Nematicide (Nem)	1	**	**	*	**	**	**
Year × Nem	2	**	**	**	**	**	**
CR × Nem	7	NS	NS	*	**	NS	*
Grain × Nem	3	NS	NS	*	*	NS	NS
Soy × Nem	1	NS	NS	NS	**	NS	**
Grain × Soy × Nem	3	NS	NS	NS	NS	NS	NS
Year × CR × Nem	14	NS	NS	NS	NS	NS	NS

Asterisks indicate significant effects at the 0.05 (*) and 0.01 (**) probability levels; NS indicates $P > 0.05$.

[x]Year effect tested over replication (year) = error (a) with 15 df. Crop rotation (4 small grain and 2 soybean cultivar combination) and year × crop rotation effects were tested over replication × crop rotation (year) = error (b) with 105 df. All other effects were tested over residual error with 120 df.

[y]Nematode counts were transformed to $\sqrt{(n + 0.1)}$ prior to the analysis of variance.

[z]Scale of 1–5: 1 = no galls, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, 5 = 76–100% of roots galled.

plots, soybean cultivars ('Coker 488' and 'Coker 6738') as subplots, and nematicide treatments (aldicarb applied at planting versus an untreated control) as sub-subplots. The wheat, oat, and rye cultivars used are genetically adapted to the southeastern U.S.A. Florida 302 wheat and Florida 501 oat were considered to have moderate and low levels of susceptibility, respectively, to *M. incognita* based on growth room tests (19). In field microplots, *M. incognita* reproduction on Wrens abruzzi rye was low (19). The soybean cultivars used have moderate (Coker 488) and high (Coker 6738) levels of resistance to *M. incognita* (15). Sub-subplots were 6.1 m long and 3.7 m wide with four rows spaced 0.9 m apart. Treatments were replicated six times.

Small grains were planted 20 December 1988, 19 November 1990, and 9 December 1991 after the soil had been disked twice. Fallow plots were not disked; residues from the previous crop were left on the soil surface and winter weeds were allowed to grow. The dominant weed in fallow plots was evening primrose (*Oenothera laciniata* Hill); weeds did not grow in small grain plots. In the spring, small grains and weeds were mowed with a rotary mower and the clippings were left on the plots. The soil was disked twice and moldboard plowed 25 cm deep. Soybean was planted 22 May 1989, 30 May 1991 and 13 May 1992. Aldicarb was applied at 3.4 kg a.i./ha in a 30-cm-wide band ahead of the planter and incorporated 3–5 cm deep. Cultural practices, including control of insects and weeds, were those recommended by the Georgia Cooperative Extension Service (5). Fields were irrigated as needed.

Soil samples for nematode assays were collected in May or June and in October or November each year. Ten 2.5-cm-diam cores of soil were collected 0–20 cm deep in each sub-plot. Nematodes were extracted from 150 cm^3 of soil using a centrifugal-sugar flotation method (6) and counted. Ten plants were dug from the two outside rows of each sub-subplot and rated for root galling in September or October each year using a scale of 1–5 (1 = no galling, 2 = 1–25%, 3 = 26–50%, 4 = 51–75, and 5 = 76–100% of roots galled). Soybean yield and plant height data were obtained from the two inside rows of each sub-subplot.

Data were analyzed using the PROC GLM of SAS (24,25). The statistical model included effects due to year, replicate, crop rotation system (small grain-soybean cultivar), nematicide application (treated versus untreated control), and all possible interactions. Rotation effects were compared for the eight combinations of four small grains (including fallow, referred to as small grain here for convenience) and two soybean cultivars. These were partitioned further to compare effects of small grain, soybean cultivar, and the interaction of the two. The replicate within year mean square (error a) was used to test the significance of the year effect. The mean square for replicate × rotation within year (error b) was used to test the significance of rotation and year × rotation effects. All other effects included in the model were tested with the residual mean square (error c). If significant, the pairwise comparison option of PROC GLM (PDIFF) was used to group least squares means. Square root transformation was applied to nematode counts prior to analysis, but the detransformed means are reported here. Differences referred to in the text were significant at $P \leq 0.05$ unless otherwise stated.

RESULTS

Numbers of *M. incognita* J2 present in the soil in the spring following the grain crops was greater in 1992 (213/150 cm^3

Table 2. Mean number of nematodes in soil from soybean plots in the fall, root-knot index, soybean plant height, and soybean yield in 3 years (96 observations per year).[x]

Year	Nematodes/150 cm³ soil			Root-knot index[z]	Height (cm)	Yield (kg/ha)
	Meloidogyne incognita[y]	*Pratylenchus brachyurus*[y]	*Helicotylenchus* spp.[y]			
1989	241 c	11 b	3 b	1.7 b	98 b	2 150 ab
1991	1 482 b	192 a	180 a	1.2 c	108 a	2 310 a
1992	2 469 a	14 b	120 a	3.0 a	85 c	1 667 b

[x]Means followed by the same letter within a column do not differ at $P < 0.05$.
[y] Nematode counts were transformed to $\sqrt{n + 0.1}$ prior to the analysis of variance. Detransformed data are presented.
[z] Scale of 1–5: 1 = no galls, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, 5 = 76–100% of roots galled.

soil) than in 1989 (14/150 cm³ soil) and1991 (6/150 cm³ soil). *Paratrichodorus minor* was detected at relatively low levels (< 20/150 cm³ soil) in the spring each year. *Pratylenchus brachyurus* was not detected in the spring of 1989 and 1991 but was detected (< 10/150 cm³ soil) in the spring of 1992. *Helicotylenchus* spp. was present in the spring at relatively low levels in 1991 (< 5/150 cm³ soil) and 1992 (< 60/150 cm³ soil) and none were detected in 1989. Compared to the fallow, the grain crops did not affect the spring population levels of any nematode species in any year.

Significant differences occurred among years in plant height, soybean yield, and root-knot indices, and numbers of *M. incognita* J2, *P. brachyurus*, and *Helicotylenchus* spp. recovered from the soil in the fall (Table 1). The largest populations of *M.*

Table 3. Effects of small grain-soybean cultivar rotations on the 3-year mean number of nematodes in soil from soybean plots in the fall, root-knot index, soybean plant height, and yield of two soybean cultivars (36 observations per rotation).[x]

Rotation	Nematodes/150 cm³ soil			Root-knot index[z]	Height (cm)	Yield (kg/ha)
	Meloidogyne incognita[y]	*Pratylenchus brachyurus*[y]	*Helicotylenchus* spp.[y]			
Wheat-Coker 488	1 453 a	10 a	84 abc	2.4 a	98 ab	2 017 ab
Wheat-Coker 6738	899 b	21 a	128 a	1.4 b	96 bc	2 109 ab
Oat-Coker 488	1 660 a	60 a	48 bc	2.4 a	100 a	2 014 ab
Oat-Coker 6738	641 b	109 a	41 c	1.5 b	95 bc	2 151 a
Rye-Coker 488	1 728 a	22 a	93 a	2.6 a	99 ab	1 873 b
Rye-Coker 6738	805 b	164 a	164 a	1.4 b	97 abc	2 203 a
Fallow-Coker 488	1 900 a	21 a	44 bc	2.5 a	98 abc	1 879 b
Fallow-Coker 6738	832 b	60 a	49 bc	1.5 b	95 c	2 104 ab

[x]Means followed by the same letter within a column do not differ at $P \leq 0.05$.
[y] Nematode counts were transformed to $\sqrt{n + 0.1}$ prior to the analysis of variance. Detransformed data are presented.
[z] Scale of 1–5: 1 = no galls, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, 5 = 76–100% of roots galled.

Table 4. Effects of small grain, soybean cultivars, and nematicide application on mean number of nematodes in soil from soybean plots in the fall, root-knot index, soybean plant height, and soybean yield.

		Nematodes/150 cm^3 soil					
Variable	n[x]	*Meloidogyne incognita*[y]	*Pratylenchus brachyurus*[y]	*Helicotylenchus* spp.[y]	Root-knot index[z]	Height (cm)	Yield (kg/ha)
Small grain							
Wheat	72	1 160 a[w]	15 a	105 a	1.9 a	97 a	2 063 a
Oat	72	1 091 a	83 a	44 b	1.9 a	98 a	2 082 a
Rye	72	1 223 a	76 a	124 a	2.0 a	98 a	2 038 a
Fallow	72	1 311 a	38 a	46 b	2.0 a	97 a	1 991 a
Soybean cultivar							
Coker 488	144	1 681 a	25 a	86 a	2.5 a	99 a	1 945 b
Coker 6738	144	791 b	79 a	66 a	1.4 b	96 b	2 142 a
Nematicide							
Aldicarb	144	907 b	3 b	46 b	1.7 b	100 a	2 273 a
Control	144	1 522 a	149 a	113 a	2.2 a	95 b	1 796 b

[w]Means within a column, within small grain, soybean cultivar, or nematicide followed by the same letter are not different ($P < 0.05$).
[x]n = number of observations.
[y]Nematode counts were transformed to $\sqrt{n + 0.1}$ prior to the analysis of variance. Detransformed data are presented.
[z]Scale of 1–5: 1 = no galls, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, 5 = 76–100% of roots galled.

incognita and the highest root-knot indices occurred in 1992 when yields were lowest (Table 2).

Differences among the eight combinations of small grain and soybean cultivar rotations were significant for all parameters studied (Table 1). Root-knot indices and population levels of *M. incognita* J2 were lower in all rotations with Coker 6738 than those with Coker 488 (Table 3).

Helicotylenchus spp. were more numerous in wheat-Coker 6738, rye-Coker 488, and rye-Coker 6738 rotations than in oat-Coker 488, oat-Coker 6738, fallow-Coker 488, and fallow-Coker 6738 rotations. Soybean plants were taller in the oat-Coker 488 rotation than in wheat-Coker 6738, oat-Coker 6738, and fallow-Coker 6738 rotations (Table 3). Yields were greater in oat-Coker 6738 and rye-Coker 6738 rotations than in rye-Coker 488 and fallow-Coker 488 rotations.

When winter rotations were examined separate from effects due to soybean cultivars, more *Helicotylenchus* spp. were present in soybean plots following wheat or rye than in plots following oat or winter fallow (Tables 1–4). Soybean cultivars however, affected several parameters. *Meloidogyne incognita* J2 were more numerous and root-knot indices were greater in Coker 488 than in Coker 6738. Also, Coker 488 plants were taller but yielded less than Coker 6738.

Population densities of all nematode species in the fall were suppressed by aldicarb (Table 4). Aldicarb also suppressed the root-knot index and increased plant height and soybean yield. Significant nematicide × soybean cultivar interactions for root-knot index and yield indicated differential cultivar responses to aldicarb (Table 1). Aldicarb decreased root-knot indices more on the moderately resistant Coker 488 than on the more highly resistant Coker 6738 (data not shown). Similarly, aldicarb increased the yield of Coker 488 628 kg/ha compared to controls, whereas the yield of Coker 6738 was increased by only 325 kg/ha.

Crop rotation × nematicide interactions were significant for *Helicotylenchus* spp., root-knot index, and yield (Table 1). Soil population densities of *Helicotylenchus* spp. in soybean grown after wheat or rye were relatively high and the population reduction due to aldicarb ranged from 80–270/150 cm^3 soil. Conversely, soil population densities of *Helicotylenchus* spp. were relatively low in soybean grown after oat and fallow, and the reduction due to aldicarb was small ranging from 22 to 26/150 cm^3 soil. Root-knot index reductions due to aldicarb in rotations that included Coker 488 were relatively large. Aldicarb reduced the root-knot index of Coker 488 by 0.5 when planted after rye and by 1.1 when planted after oat. By comparison, root-knot index reductions due to nematicide for Coker 6738 following rye were 0, 0.3, and 0.3 following wheat, oat, and fallow, respectively. The greatest yield increases due to aldicarb in the small grain-soybean cultivar rotations were 708 kg/ha and 702 kg/ha for Coker 488 following oat and rye, respectively. The smallest yield increase due to aldicarb was 117 kg/ha for Coker 6738 following rye.

Yield was negatively correlated P = 0.0001) with the number of *M. incognita* J2 in the soil in the spring (r = - 0.44), number of *M. incognita* J2 in the soil in the fall (r = - 0.29), and the root-knot index (r = -0.60). Soybean yield was not correlated with the population density of other nematode species.

DISCUSSION

Spring population levels of *M. incognita* in small grain and fallow plots were similar, suggesting that nematode populations were not affected by winter grain crop rotations. Opperman *et al.* (19) found that spring populations of *M. incognita* in microplots in Florida were greater following rye than wheat; however, the ratio of the population in the spring to the population in the fall was less than one for both crops. Johnson and Motsinger (8) determined that Wrens Abruzzi rye and Coker 797 wheat were suitable hosts for *M. incognita* at optimum temperatures but that J2 population densities did not increase in field plots during two winters at Tifton, Georgia. Populations of *M. incognita* J2 in the soil in rye and wheat plots decreased during the winter similarly to those in clean fallow.

The low levels of *P. minor*, *P. brachyurus*, and *Helicotylenchus* spp. in the soil in the spring following small grains suggest that these nematodes did not reproduce appreciably during the winter or were present primarily in the roots. Under warmer greenhouse conditions, Pedersen and Rodríguez-Kábana (20) found that populations of *P. minor* and *Helicotylenchus dihystera* (Cobb) Sher increased on some cultivars of rye, oat, and wheat. Even though *P. brachyurus* and *Helicotylenchus* spp. in our experiment were present at soybean harvest in relatively large numbers and population levels were reduced by aldicarb, correlation analyses suggested that these species had little effect on soybean yield, supporting results we obtained earlier (17). In that study the spring population density of *M. incognita* J2 was greater in fallow than in rye plots, but soybean yield was not increased by the rye rotation. Also, population densities of *M. incognita* J2 did not differ in plots planted to wheat and rye, nor did yields of soybean differ. In a subsequent study (15), the population density of *M. incognita* J2 was not measurably affected by rye preceding minimum-till soybean but root-knot indices of soybean plants were lower and yield was 17% greater following rye than following fallow.

The major factors affecting soybean yields in this experiment were soybean cultivars and aldicarb. Although aldicarb increased yields of both cultivars, the yield increase achieved with aldicarb for Coker 6738 would probably not offset the cost of aldicarb application in most fields infested with *M. incognita.* Neither would it be cost-effective to plant wheat, oat, or rye as a rotational crop for the sole purpose of reducing nematode damage. Thus, our results confirm that the use of resistant cultivars to reduce nematode damage and increase soybean yield is the most environmentally and economically sound practice available for managing *M. incognita* in soybean.

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