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Comparison of Crop Rotation and Fallow for Management of *Heterodera glycines* and *Meloidogyne* spp. in Soybean

D. B. WEAVER, R. RODRÍGUEZ-KÁBANA, AND E. L. CARDEN[1]

Abstract: The effects of cropping systems (fallow, rotation with sorghum-sudangrass hybrid [*Sorghum bicolor* × *S. sudanense*], and continuous soybean [*Glycine max*]), nematicide (aldicarb) treatment, and soybean cultivar on yield and nematode population densities were studied in a field infested with a mixture of *Meloidogyne* spp. and *Heterodera glycines*. Soybean following sorghum-sudangrass yielded 111 kg/ha more than soybean following fallow and 600 kg/ha more than continuous soybean. Aldicarb treatment increased yield by 428 kg/ha, regardless of previous crop. Cultivars interacted significantly with nematicide treatment and previous crop with respect to yield. Sorghum-sudangrass reduced numbers of *Meloidogyne* spp. compared with fallow and continuous soybean, but cropping system did not affect *H. glycines* numbers. The cultivar × previous crop and cultivar × nematicide interactions were significant for numbers of *Meloidogyne* spp. and *H. glycines*. We concluded that sorghum-sudangrass hybrid and fallow are effective in reducing yield losses caused by mixed populations of *Meloidogyne* and *H. glycines*. Highest yields were obtained using crop rotation and cultivars with the highest levels of resistance to both nematodes.

Key words: aldicarb, biodiversity, crop rotation, *Glycine max*, *Heterodera glycines*, host-plant resistance, *Meloidogyne*, nematode, root-knot nematode, sorghum-sudangrass, *Sorghum bicolor*, *Sorghum sudanense*, soybean cyst nematode, soybean.

Meloidogyne spp. and *Heterodera glycines* are frequently major pests of soybean (*Glycine max*) in the southeastern United States (7,13). Often these nematode pathogens occur in the same fields and yields can be reduced to such an extent that profitable production in a monoculture system is not possible (17). Crop rotation and genetic resistance are currently the only management tools available that are effective and economical in fields where mixed populations of *Meloidogyne* spp. and *H. glycines* occur (10,11).

Rotation with grass crops such as grain sorghum (*Sorghum bicolor*) (10), bahiagrass (*Paspalum notatum*) (11), and maize (*Zea mays*) (18) has been highly effective in increasing yield of soybean, especially for nematode-susceptible cultivars, following the rotation crop. Although susceptible cultivars often show a large relative yield increase in response to rotation, the highest-yielding treatments usually involve cultivars with genetic resistance following the rotation crop (10,11,18). Other (dicotyledonous) rotation crops have been tried with varying success, including American jointvetch (*Aeschynomene americana*) (12), hairy indigo (*Indigofera hirsuta*) (12), upland cotton (*Gossypium hirsutum*), sesame (*Sesamum indicum*) (Rodríguez-Kábana and Weaver, unpubl.), and velvetbean (*Mucuna deeringiana*) (19). Velvetbean was the only nongrass crop that was as effective as bahiagrass or grain sorghum as a rotation crop. Development of rotation systems with nonhost crops for nematode control depends not only on yield response but on economic, ecological, and other constraints in individual situations (14). Crops that may have excellent nematode management potential in a rotation system may not be feasible due to other constraints.

Sorghum-sudangrass hybrid (*Sorghum bicolor* × *S. sudanense*) is an annual grass used in the southern United States as a forage and cover crop. The value of sorghum-sudangrass hybrids as a rotation crop for managing *Meloidogyne* spp. and *H. glycines* in fields where these species occur together is unknown. The objective of this experiment was to compare sorghum-sudangrass hybrids with fallow and monoculture soybean for their effects on yield and nematode population densities on seven soybean cultivars in a field infested

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[1] Professor, Department of Agronomy and Soils, Auburn University, Auburn University, AL 36849; Professor, Department of Plant Pathology, Auburn University, Auburn University, AL 36849; and Superintendent, Gulf Coast Substation, Auburn University, Fairhope, AL 36532.

with a mixture of *Meloidogyne* spp. and *H. glycines.*

Materials and Methods

The experiment was conducted in 1993 and 1994 near Elberta, Alabama, on a sandy loam soil (fine loamy, siliceous, thermic, Typic Paleudults; pH 6.2; and <1.0% organic matter) naturally infested with a mixture of *Meloidogyne* spp. (*M. incognita* and *M. arenaria*) and *H. glycines* of unknown race. Potassium chloride was applied in 1993 (34 kg/ha) and 1994 (45 kg/ha) to raise soil fertility to recommended levels (4). In 1993, a preemergence application of metolachlor (2.2 kg a.i./ha) was made for weed control. Later, fomesafene (0.42 kg a.i./ha) and bentazon (1.1 kg a.i./ha) were applied broadcast with crop oil concentrate (vegetable) at 1.0% v/v to control late-emerging weeds. Sethoxydim was applied at 0.33 kg a.i./ha with crop oil concentrate (vegetable) at 1.0% v/v for late-season grass control. Preemergence herbicide treatment was the same in 1994. Fomesafene and bentazon were again used in 1994, and quizalofop was applied later at 0.07 kg a.i./ha with crop oil concentrate (vegetable) at 1.0% v/v for late-season grass control. In 1993, insects were controlled with an initial broadcast application of methyl parathion (0.5 kg a.i./ha) followed by two later applications of permethrin (0.2 kg a.i./ha). In 1994 two applications of a mixture of permethrin (0.2 kg a.i./ha) and methyl parathion (0.25 kg a.i./ha) were made for insect control. No significant stem diseases were observed, and the only foliar diseases were those such as anthracnose (caused by *Colletotrichum truncatum*) that normally occur during the late part of the growing season in a humid, subtropical environment. Frogeye leaf spot (caused by *Cercospora sojina*), a disease which occurs frequently in this area, was present at low levels. The area was tilled with a moldboard plow followed by a disk harrow before planting in 1993 and 1994. Oat (*Avena sativa*) was planted as a cover crop in the fall of 1992. No cover crop was planted in 1993.

The field had been planted in a soybean cultivar evaluation test in 1992, and continuous soybean blocks had been in soybean for at least six consecutive years. Individual plots were sampled as described previously (11) on 13 October 1992 (about 2 weeks before soybean harvest) to coincide with the period of maximum population density for *Meloidogyne* spp. (9) and showed nematode population densities ranging from 0 to 1,040 second-stage juveniles (J2)/100 cm^3 soil for *Meloidogyne* spp. and 0 to 271 J2/100 cm^3 for *H. glycines.* Low *H. glycines* numbers were usually associated with cultivars that had resistance to *H. glycines* races 3 and 14. Plot areas that would later correspond to replications in 1994 had mean population densities that ranged from 14 to 307 J2/100 cm^3 soil for *Meloidogyne* spp. and 6 to 102 J2/100 cm^3 soil for *H. glycines.* Mean nematode population densities for the entire test area in 1992 were 137 J2/100 cm^3 soil for *Meloidogyne* spp. and 36 J2/100 cm^3 soil for *H. glycines.* Numbers of J2 of both *Meloidogyne* spp. and *H. glycines* at planting time were <10/100 cm^3 of soil in each year of the study.

In 1993, the field was divided into two blocks, each 112.5 m × 90 m, with one-third of each block planted to sorghum-sudangrass hybrid Pioneer 855F, one-third planted to soybean cultivar Kirby, and one-third left fallow. Weeds were not controlled in the fallow treatment. Enough experimental area remained to plant an additional one-third block (112.5 m × 30 m) of Kirby to provide three blocks of continuous soybean and two blocks of the other cropping system treatments. In 1994, seven soybean cultivars (Braxton, Brim, Bryan, Carver, Leflore, Stonewall, and Thomas), selected to have a range of host resistance to *Meloidogyne* spp. and *H. glycines* (Table 1), were planted (14 June) within these split blocks in a 2 × 7 factorial treatment structure with and without aldicarb. Treatments were placed in eight randomized complete blocks (replications) within each split block, thus the 14 treatments were replicated a total of 16 times for the rotation treatments and 24 times for the continuous soybean treatment. Individual plots were two rows, 7.5 m long with 0.81 m between rows. Cultivars used were the same as in a previous study (19) except Kirby was replaced by Carver, a recent release by the Alabama Agricultural Experiment Station (16). Carver was selected for resistance to *M. incognita, M. arenaria,* and races 3 and 14 of *H. glycines.* A 15G formulation of aldicarb was applied at 17.8 g a.i./100 m of row (2.2 kg a.i./ha) in a 25-cm band over the row with an electric-driven Gandy applicator (Gandy Company, Owatonna, MN) and incorporated 2–3 cm deep just before planting. A composite soil sample was collected from each split block on 2 November 1993 to determine the immediate effect of soybean, fallow, and sorghum-sudangrass hybrid on nematode population densities. Soil samples were collected from individual plots for nematode assay on 15 November 1994. Samples consisted of a composite of 15–20 soil cores (2.5-cm-d) taken from the root zone 20–25 cm deep. Nematodes were extracted from a 100-cm^3 subsample by a modified Baermann method (8). Seed were harvested from each plot with a small plot combine.

All data were subjected to analysis of variance. The previous crop × block interaction was used as an error term (error a, Table 2) to test the effect of previous crop, and the replications within blocks × all other effects mean squares (pooled) were used to test the other main effects and interactions. Some treatments (Carver and Leflore) had zero mean and zero variance for numbers of *H. glycines.* Because of differences in treatment variances, these treatments were omitted from the analysis of variance and the estimation of experimental error. Means were separated by Fisher's least significant difference ($P \leqslant 0.05$).

Results and Discussion

Second-stage juveniles of *Meloidogyne* spp. and *H. glycines* were not detectable in fall 1993 in split blocks left fallow or planted to the sorghum-sudangrass hybrid. Following Kirby soybean, the average number of *Meloidogyne* spp. was 77 J2/100 cm^3 soil and the average number of *H. glycines* was 41 J2/100 cm^3 soil following Kirby. Thus the fallow and sorghum-sudangrass hybrid were effective in lowering population densities of both nematode species.

Cropping sequence affected soybean yield (Table 2). Yield averaged across cultivars and nematicide treatment was 25% higher following the sorghum-sudangrass hybrid, and 20% higher following fallow than following soybean (Table 3). The cultivar × previous crop interaction (Table 2) suggested that yield response to rotation was dependent upon cultivar or genetic resistance. Carver, the cultivar with the broadest spectrum of nematode resistance and highest average yield, showed little yield response to cropping system. Carver following sorghum-sudangrass yielded only 5% more than Carver following con-

TABLE 1. Host response of soybean cultivars to *Meloidogyne* spp. and *Heterodera glycines* races 3 and 14.

Cultivar	Maturity group	*M. incognita*	*M. arenaria*	*H. glycines* Race 3	*H. glycines* Race 14	Reference
Braxton	VII	R[a]	R	S	S	(6)
Brim	VI	S	S	S	S	(3)
Bryan	VI	R	R	R	S	(2)
Carver	VII	R	R	R	R	(16)
Leflore	VI	R	S	R	R	(5)
Stonewall	VII	S	S	R	S	(15)
Thomas	VII	R	S	R	S	(1)

[a] R = resistant; S = susceptible.

TABLE 2. Analysis of variance in soybean yield and numbers of second-stage juveniles of *Meloidogyne* spp. and *Heterodera glycines* in 1994 following fallow or a previous crop of a sorghum-sudangrass hybrid or soybean and treated with aldicarb at 17.8 g a.i./100 m row in a 25-cm band.

		Mean squares ($\times 10^{-3}$)		
Source	df[a]	*Meloidogyne* spp.	*H. glycines*	Soybean yield
Previous crop (P)	2	68.5*	25.6	17,744.1*
Error a	2	3.5	11.8	614.5
Nematicide (N)	1	47.5**	1.3	34,699.3**
P × N	2	5.8*	0.1	138.8
Cultivar (C)	6 (4)[b]	342.3**	12.9**	41,730.6**
P × C	12 (8)	42.0**	4.0**	4827.0**
N × C	6 (4)	39.3**	1.6**	892.2**
P × N × C	12 (8)	20.5**	0.9**	57.7
Error b	688 (477)	0.7	0.3	138.2

* and ** indicate $P = 0.05$ and 0.01, respectively.
[a] Blocks have two degrees of freedom, and replicates within block and previous crop have 49 degrees of freedom.
[b] Degrees of freedom in parentheses are for the analysis of variance for *H. glycines*.

tinuous soybean, and 2% more than continuous soybean when following fallow. Yield of Braxton increased by 196% following sorghum-sudangrass and 160% following fallow compared with continuous soybean. Other cultivars that yielded well in the continuous soybean system (Bryan, Leflore, Stonewall and Thomas) are all resistant to *H. glycines* race 3. *Meloidogyne* spp. resistance did not affect yield as much as resistance to *H. glycines* because Braxton, resistant to *Meloidogyne* spp., yielded less than Brim, which has no known nematode resistance.

Aldicarb treatment increased yield by 17% averaged over previous crop and cultivars. Yield response to aldicarb was not influenced by previous crop but was dependent on cultivar (Table 2). These responses were consistent with those of a previous study involving velvetbean as a rotation crop (19). All cultivars yielded higher following aldicarb treatment, but the size of the response differed, causing the significant nematicide treatment × cultivar interaction. Stonewall generally showed a large yield response to aldicarb, averaging 771 kg/ha more in aldicarb-treated than in untreated plots, whereas Braxton averaged only 202 kg/ha more in treated plots. The small response of Braxton could be attributed to generally lower

TABLE 3. Effect of cropping system, aldicarb[a], and soybean cultivar on soybean yield (kg per hectare) during 1994.

	Continuous soybean		Soybean following sorghum-sudangrass		Soybean following fallow	
Cultivar	+aldicarb	−aldicarb	+aldicarb	−aldicarb	+aldicarb	−aldicarb
Braxton	973	809	2708	2558	2470	2168
Brim	1606	1201	2601	2327	2869	2238
Bryan	3326	2905	3656	3354	3674	3244
Carver	3844	3354	4083	3507	3876	3469
Leflore	3261	2815	3208	2872	3177	2668
Stonewall	2842	2098	3229	2461	3046	2244
Thomas	2651	2342	3064	2805	2991	2771
Mean	2644	2218	3221	2841	3158	2682

Data are averages of 16 replications, except continuous soybean, which are averages of 24 replications. LSD ($\alpha = 0.05$) value for comparing means within a column for the sorghum-sudangrass rotation and fallow is 257, LSD for continuous soybean is 211 kg/ha.
[a] Aldicarb applied at 17.8 g a.i./100 m row in a 25-cm band.

yield, but the larger response of Stonewall is not so easily explained. The previous crop × nematicide × cultivar interaction was not significant (Table 2), indicating that response of cultivars to nematicide treatment was consistent across cropping systems.

Previous crop or fallow did not affect *H. glycines* numbers in the subsequent soybean crop compared with continuous soybean (Table 2). Average population densities of *H. glycines* ranged from 11 J2/100 cm^3 soil following continuous soybean without aldicarb to 26 J2/100 cm^3 soil following sorghum-sudangrass with aldicarb (Table 4). Previous studies showed variable effects of previous crops on numbers of *H. glycines*. Maize has been found to reduce *H. glycines* in the subsequent soybean crop (18) and sorghum has been found to increase numbers of *H. glycines* in the subsequent soybean crop (10). Like sorghum-sudangrass, both maize and sorghum are nonhosts of *H. glycines*. These studies were conducted in different years. Thus environmental factors other than previous crop appear to play a large role in determining the size of *H. glycines* populations in a subsequent soybean crop. Population densities of *H. glycines* differed on soybean cultivars; for example, Carver and Leflore (both resistant to *H. glycines* race 3 and 14) supported fewer *H. glycines* J2 than any other cultivar following sorghum-sudangrass, and fewer than other cultivars except Brim following soybean and Brim and Stonewall following fallow. Although it has no known resistance to *H. glycines*, Brim was observed to support low numbers of *H. glycines* in a previous study (19). The relatively late nematode sampling date and earlier maturity of Brim was probably a factor, along with plant death caused by rapid early population development (9) and root feeding by *Meloidogyne* spp. on the susceptible Brim. Previous crop effects on *H. glycines* numbers were cultivar-dependent (Table 2). For cultivars susceptible to *H. glycines* (Brim and Braxton), J2 densities were higher following sorghum-sudangrass than following fallow or soybean. Aldicarb did not affect numbers of *H. glycines*.

Numbers of J2 of *Meloidogyne* spp. were lower in the continuous soybean plots than in soybean following sorghum-sudangrass or fallow but this was not consistent for all cultivars (Table 5). Numbers of J2 of *Meloidogyne* spp. in Carver plots were largely unaffected by previous crop, whereas plots planted to other cultivars had lower numbers of J2 following soybean, which contributed to a significant previous crop × cultivar interaction (Table 2). High numbers of *Meloidogyne* spp. in plots planted to the resistant Carver are consistent with previous research (9), which showed that large populations of

TABLE 4. Effect of cropping system, aldicarb[a], and soybean cultivar on numbers of second-stage juveniles of *Heterodera glycines* per 100 cm^3 soil during 1994.

Cultivar	Continuous soybean		Soybean following sorghum-sudangrass		Soybean following fallow	
	+aldicarb	−aldicarb	+aldicarb	−aldicarb	+aldicarb	−aldicarb
Braxton	21	12	81	58	32	24
Brim	9	4	15	20	9	7
Bryan	27	16	41	27	23	21
Carver	1	0	0	0	0	0
Leflore	0	0	0	0	0	0
Stonewall	17	16	11	24	5	7
Thomas	16	30	37	37	22	6
Mean	13	11	26	22	13	13

Data are averages of 16 replications, except continuous soybean, which are averages of 24 replications. LSD (α = 0.05) value for comparing means within a column for the sorghum-sudangrass rotation and fallow is 13, LSD for continuous soybean is 11 J2/100 cm^3 soil.

[a] Aldicarb applied at 17.8 g a.i./100 m row in a 25-cm band.

TABLE 5. Effect of cropping system, aldicarb[a], and soybean cultivar on numbers of second-stage juveniles of *Meloidogyne incognita* per 100 cm^3 soil during 1994.

Cultivar	Continuous soybean		Soybean following sorghum-sudangrass		Soybean following fallow	
	+ aldicarb	− aldicarb	+ aldicarb	− aldicarb	+ aldicarb	− aldicarb
Braxton	2	4	26	41	18	31
Brim	6	8	42	39	20	47
Bryan	5	6	15	21	2	8
Carver	52	73	42	108	71	118
Leflore	32	47	36	55	41	76
Stonewall	18	31	83	56	67	75
Thomas	13	29	26	53	41	64
Mean	18	28	39	53	37	60

Data are averages of 16 replications, except continuous soybean, which are averages of 24 replications. LSD (α = 0.05) value for comparing means within a column for the sorghum-sudangrass rotation and fallow is 18, LSD for continuous soybean is 15 J2/100 cm^3 soil.

[a] Aldicarb applied at 17.8 g a.i./100 m row in a 25-cm band.

Meloidogyne spp. tend to develop on resistant genotypes and have already begun to decline due to plant death on susceptible genotypes when sampled late in the growing season. On average, aldicarb treatment reduced numbers of J2 of *Meloidogyne* spp. (Table 5); however, cultivars responded differently. For some cultivars, particularly those with low *Meloidogyne* spp. numbers, there was no significant effect of aldicarb. Cultivars with large population densities of *Meloidogyne* spp., such as Carver, showed a much larger effect due to aldicarb treatment. The previous crop × cultivar interaction for numbers of J2 of *Meloidogyne* spp. was probably related to reduced plant vigor of lower-yielding cultivars in the continuous soybean plots.

General results of this study were similar to those of other studies in this field area involving rotation crops for nematode management, except that this study included a fallow treatment. The magnitude of the yield response to rotation was much lower than in previous studies involving bahiagrass (11), grain sorghum (10), and velvetbean (19). One reason could be the relatively high yield of the continuous soybean plots. Rainfall was plentiful in this area in 1994, contributing to the high yields. Also consistent with previous studies was the significant previous crop × cultivar interaction for yield, which occurred because the nematode-susceptible cultivars had a higher yield response to rotation than the nematode-resistant cultivars. We concluded that sorghum-sudangrass hybrid and fallow are effective in reducing yield losses caused by mixed populations of *Meloidogyne* and *H. glycines*. Highest yields were obtained using crop rotation and cultivars with the highest levels of resistance to both nematodes.

LITERATURE CITED

1. Boerma, H. R., R. S. Hussey, D. V. Phillips, and E. D. Wood. 1989. Registration of 'Thomas' soybean. Crop Science 29:489–490.

2. Boerma, H. R., R. S. Hussey, D. V. Phillips, E. D. Wood, and S. L. Finnerty. 1991. Registration of 'Bryan' soybean. Crop Science 31:487.

3. Burton, J. W., T. E. Carter, Jr., and E. B. Huie. 1993. Registration of 'Brim' soybean. Crop Science 34:301.

4. Cope, J. T., Jr., C. E. Evans, and H. C. Williams. 1981. Soil test fertilizer recommendations for Alabama soils. Circular 252, Agricultural Experiment Station, Auburn University, Auburn University, AL.

5. Hartwig, E. E., L. D. Young, and C. J. Edwards, Jr. 1985. Registration of 'Leflore' soybean. Crop Science 25:1128–1129.

6. Hinson, K., R. A. Kinloch, H. A. Peacock, W. H. Chapman, and W. T. Scudder. 1981. Braxton soybean. Florida Agricultural Experiment Station Circular S-276. Gainesville.

7. Kinloch, R. A. 1980. The control of nematodes injurious to soybean. Nematrópica 10:141–153.

8. Rodríguez-Kábana, R., and M. H. Pope. 1981. A simple method for extraction of nematodes from soil. Nematrópica 11:175–176.

9. Rodríguez-Kábana, R., and D. B. Weaver. 1984. Soybean cultivars and development of populations of *Meloidogyne incognita* in soil. Nematrópica 14:45–56.

10. Rodríguez-Kábana, R., D. B. Weaver, D. G. Robertson, P. S. King, and E. L. Carden. 1990. Sorghum in rotation with soybean for the management of cyst and root-knot nematodes. Nematrópica 20: 111–119.

11. Rodríguez-Kábana, R., D. B. Weaver, R. Garcia, D. G. Robertson, and E. L. Carden. 1989. Bahiagrass for the management of root-knot and cyst nematodes in soybean. Nematrópica 19:185–193.

12. Rodríguez-Kábana, R., D. B. Weaver, D. G. Robertson, R. W. Young, and E. L. Carden. 1990. Rotations of soybean with two tropical legumes for the management of nematode problems. Nematrópica 20:101–110.

13. Schmitt, D. P. 1985. Plant-parasitic nematodes associated with soybeans. Pp. 541–546 *in* R. M. Shibles, ed. World Soybean Research Conference III Proceedings. Boulder, CO: Westview Press.

14. Trivedi, P. C., and K. R. Barker. 1986. Management of nematodes by cultural practices. Nematrópica 16:213–236.

15. Weaver, D. B., R. Rodríguez-Kábana, and H. R. Boerma. 1989. Registration of 'Stonewall' soybean. Crop Science 29:1329.

16. Weaver, D. B., and R. Rodríguez-Kábana. 1995. Registration of 'Carver' soybean. Crop Science 35:1226.

17. Weaver, D. B., R. Rodríguez-Kábana, and E. L. Carden. 1988. Multiple-species nematode resistance in soybean: Effect of genotype and fumigation on yield and nematode numbers. Crop Science 28:293–298.

18. Weaver, D. B., R. Rodríguez-Kábana, D. G. Robertson, R. L. Akridge, and E. L. Carden. 1988. Effect of crop rotation on soybean in a field infested with *Meloidogyne arenaria* and *Heterodera glycines*. Supplement to the Journal of Nematology 20:106–109.

19. Weaver, D. B., R. Rodríguez-Kábana, and E. L. Carden. 1993. Velvetbean in rotation with soybean for management of *Heterodera glycines* and *Meloidogyne incognita*. Supplement to the Journal of Nematology 25:809–813.