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Velvetbean and Bahiagrass as Rotation Crops for Management of *Meloidogyne* spp. and *Heterodera glycines* in Soybean

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Abstract: Soybean (*Glycine max*) yield often is limited by the phytoparasitic nematodes *Meloidogyne* spp. and *Heterodera glycines* in the southeastern United States. We studied the effects of rotation with bahiagrass (*Paspalum notatum*), velvetbean (*Mucuna pruiens*), or continuous soybean, aldicarb, and soybean cultivar on yield and population densities in two fields infested with a mixture of *Meloidogyne* spp. and *H. glycines*. Velvetbean and bahiagrass reduced population levels of both nematode species to near zero prior to planting soybean. At harvest, both nematode populations were equal in soybean following bahiagrass and continuous soybean but were lower following velvetbean. Both bahiagrass and velvetbean as previous crops were equal in producing significantly ($P < 0.003$) higher yield than continuous soybean. Velvetbean increased subsequent soybean yield by 98% and bahiagrass increased subsequent soybean yield by 85% as previous crops compared to continuous soybean. The major differences between the two rotation crops were yield response of the nematode-susceptible cultivars and at-harvest nematode populations. Velvetbean tended to mask genetic differences among cultivars more so than bahiagrass. Velvetbean also produced a more long-term effect on nematode populations, with numbers of both *Meloidogyne* spp. and *H. glycines* lower in soybean following velvetbean than following bahiagrass or continuous soybean.

Key words: aldicarb, bahiagrass, biodiversity, crop rotation, *Glycine max, Heterodera glycines,* host-plant resistance, *Meloidogyne, Mucuna pruiens,* nematode, *Paspalum notatum,* root-knot nematode, soybean, soybean cyst nematode, velvetbean.

Soybean (*Glycine max* L.) yield in the southeastern United States often is limited by the phytopathogenic nematodes *Meloidogyne* spp. and *Heterodera glycines* Ichinohe (Kinloch, 1980; Schmitt, 1985). Many times these nematodes occur in the same fields and can reduce yield to such an extent that economic production in a soybean monoculture system is not possible (Weaver et al., 1988a). Use of crop rotations and resistant cultivars are currently the only effective and economical management tools in fields where mixed populations of these nematodes occur (Rodríguez-Kábana et al., 1989; Rodríguez-Kábana et al., 1990; Weaver et al., 1988b; Weaver et al., 1993).

Rotation with graminaceous crops such as grain sorghum (*Sorghum bicolor*) (Rodríguez-Kábana et al., 1990), sorghum-sudangrass hybrid (*S. bicolor* × *S. sudanense*) (Weaver et al., 1995), maize (*Zea mays*) (Weaver et al., 1988b), and bahiagrass (*Paspalum notatum*) (Rodríguez-Kábana et al., 1989) increases soybean yield in nematode-infested fields. Among dicotyledons, only velvetbean (*Mucuna pruiens*) has been found to be effective as a rotation crop (Weaver et al., 1993). Nematode-susceptible cultivars usually have the greatest percentage yield response to rotation, but the highest-yielding treatments usually involve nematode-resistant cultivars following the rotation crop (Rodríguez-Kábana et al., 1989; Rodríguez-Kábana et al., 1990; Weaver et al., 1988b, 1993). Bahiagrass is a popular pasture grass in the southeastern United States that has few pest problems and is well-adapted to the sandy soils of the area (Ball et al., 1991). Velvetbean is a forage and green manure crop not currently grown commercially in the United States but with a long history of production in the Southeast and whose potential as a rotation crop is being recognized (Buckles, 1995).

In terms of both yield improvement and nematode population reduction, bahiagrass (Rodríguez-Kábana et al., 1989) and velvetbean (Weaver et al., 1993) have been found in separate experiments to be the most effective rotation crops. Both crops are nonhosts for *H. glycines* and *Meloidogyne* spp. The

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effect of velvetbean on nematode populations has been long recognized (Watson, 1922) and has recently been documented experimentally (Kloepper et al., 1991; Rodríguez-Kábana et al., 1992a; Rodríguez-Kábana et al., 1992b; Vincente and Acosta, 1987). In an experiment involving rotation effects on soybean, velvetbean was found to reduce *Meloidogyne* spp. juvenile (J2) populations to 1% of the level found in adjacent soybean crop, and *H. glycines* J2 were undetectable following velvetbean (Weaver et al., 1993). Yield of soybean was increased an average of 105% following velvetbean. In another experiment, bahiagrass reduced numbers of *Meloidogyne* spp. and *H. glycines* to undetectable levels by the end of the second growing season (Rodríguez-Kábana et al., 1989), with corresponding yield improvement even greater than that for velvetbean. Although yields in these two experiments were comparable, the two previous crops differed slightly in their effect on at-harvest nematode populations in the subsequent soybean crop. Neither crop had an effect on *Meloidogyne* spp. populations, but bahiagrass produced an increase in numbers of *H. glycines*. However, the effect of the rotation crops on nematode populations was short-lived, with nematode numbers returning to high levels after one season of soybean.

Because these experiments were conducted in different years, the results cannot be compared directly. The objectives of this research were to compare the effects of velvetbean and bahiagrass as rotation crops with soybean monoculture for influences on nematode population levels and soybean yield.

Materials and Methods

The experiments were conducted during 1994, 1995, and 1996 at two sites (referred to hereafter as the Kaiser field and the Gottler field) near Elberta, Alabama. The Kaiser field is a Pactolus loamy fine sand soil (thermic, coated Aquic Quartzipsamments; pH 5.9, <1.0% organic matter). The Gottler field is a Norfolk fine sandy loam soil (fine-loamy, kaolinitic, thermic, Typic Kandiudults; pH 5.8, <1.0% organic matter). Both fields were naturally infested with a mixture of *Meloidogyne* spp. (*M. incognita* and *M. arenaria*) and *H. glycines* of unknown race.

In 1993, the entire plot area was planted to soybean in both fields. In summer 1994, each field was divided into two blocks, each 112.5 × 90 m. One-third of each block was planted to velvetbean (cultivar unknown, obtained from Rufus Adams, Adams-Briscoe Seed Co., Jackson, GA), one-third planted with Argentine bahiagrass, and one-third planted with Kirby soybean. Velvetbean was replanted in summer 1995, the bahiagrass was allowed to continue growing, and Thomas soybean was planted in the continuous soybean blocks. Both Kirby and Thomas are resistant to *Meloidogyne incognita* and *H. glycines* (race 3) and are representative of nematode-resistant cultivars grown in the area. Each split block was sampled for nematodes at soybean maturity in October 1993, 1994, and 1995. Several composite samples were taken for each split block and averaged.

In spring 1996, both fields were tilled with a moldboard plow followed by disking to completely bury the crop debris. Fertilizer was applied (45 kg/ha P and K) broadcast to raise soil fertility to recommended levels (Cope et al., 1981). At the Gottler field, 2,240 kg/ha dolomitic limestone also was applied. Immediately following planting of the soybean in 1996 in both fields, a preemergence application of metolachlor (2.2 kg a.i./ha) and paraquat (0.7 kg a.i./ha) was applied along with crop oil concentrate (petroleum based) at 1.0% v/v to manage weeds. Approximately 2 weeks after planting, bentazon (0.56 kg a.i./ha), fomesafen (0.21 kg a.i./ha), and chlorimuron (0.009 kg a.i./ha) were applied postemerge with ionic surfactant (1.0% v/v) to manage late-emerging weeds.

The experimental design was a randomized complete block, with split blocks replicated two times. Blocks were divided into previous crops. In 1996, seven soybean cultivars (Benning, Braxton, Brim, Bryan, Carver, Stonewall, and Thomas) selected to have a range of host resistance to *Meloidogyne* spp. and *H. glycines* (Table 1) were planted within these split blocks in a 2 × 7 factorial design with and without aldicarb treatment. Treatments were placed in eight randomized complete blocks (replicates) within each split block. Thus, the 14 treatments were replicated 16 times within each location and previous crop. Individual plots were two rows, 7.5 m long with 0.81 m between rows. Cultivars were the same as in a previous study (Weaver et al., 1993) (no change) except Leflore was replaced by Benning, a recent release by the Georgia Agricultural Experiment Station (Boerma et al., 1997). 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, Owatonna, MN) and incorporated 2 to 3 cm deep just before planting. A composite soil sample was collected from each plot for nematode assay on 10 October 1996. Samples consisted of a composite of 15 to 20 soil cores (2.5-cm-diam.) taken from the root zone 20 to 25 cm deep. Nematodes were extracted from a 100-cm^3 subsample by a modified Baermann method (Rodríguez-Kábana and Pope, 1981). Seeds were harvested from each plot with a small plot combine.

All data were subjected to analysis of variance. Previous crop, cultivar, and nematicide treatment were fixed factors, and locations were random. Both locations were combined into a single analysis. Effect of previous crop was tested using the location × previous crop interaction mean square, and the location × previous crop interaction was tested using the block × previous crop interaction mean square. Cultivar and nematicide treatment effects were tested using the cultivar × nematicide treatment mean square. Interactions between main effects were tested using an error term derived from the pooling of replication × main effect and replication × main effect interactions.

Results and Discussion

Nematode populations in continuous soybean declined over the three-year period in the Kaiser field, with more normal year-to-year variation in nematode numbers in the Gottler field (Table 2). Velvetbean reduced nematode populations of *Meloidogyne* spp. and *H. glycines* to undetectable levels by fall 1995 at both locations. For bahiagrass, only one *Meloidogyne* spp. J2/100cm^3 soil was found at the Gottler field. Thus, both rotation crops were equally effective in reducing nematode populations over the two-year period.

In the subsequent soybean crop, aldicarb treatment increased yield by 12% averaged across previous crops and cultivars (Table 3). There was no interaction between aldicarb treatment and location, and aldicarb treatment and cultivar for yield. However, there was a small previous crop × aldicarb treatment interaction for yield ($P < 0.01$), caused mainly by larger yield increases in the continuous soybean (407 kg/ha) than in the bahiagrass (197 kg/ha) and velvetbean

TABLE 1. Host responses of soybean cultivars to *Meloidogyne incognita, M. arenaria,* and *Heterodera glycines* races 3 and 14.

Cultivar	Maturity group	*Meloidogyne* *incognita*	*Meloidogyne* *arenaria*	*H. glycines* Race 3	*H. glycines* Race 14	Reference
Benning	VII	R[a]	R	R	S	Boerma et al., 1997
Braxton	VII	R	R	S	S	Hinson et al., 1981
Brim	VI	S	S	S	S	Burton et al., 1983
Bryan	VI	R	R	R	S	Boerma et al., 1991
Carver	VII	R	R	R	R	Weaver et al., 1995
Stonewall	VII	S	S	R	S	Weaver et al., 1989
Thomas	VII	R	S	R	S	Boerma et al., 1989

[a] R = resistant, S = susceptible.

TABLE 2. Populations of *Meloidogyne* spp. and *Heterodera glycines,* October sampling, in velvetbean, bahiagrass, and soybean blocks at two experimental sites for a 3-year period.

		Second-stage juveniles per 100 cm^3 soil in previous crop block					
		Meloidogyne spp.			*Heterodera glycines*		
Site	Year	Velvetbean	Bahiagrass	Soybean	Velvetbean	Bahiagrass	Soybean
Gottler	1993[a]	132 a[b]	90 a	41 a	4 a	12 a	10 a
	1994	0 a	5 a	30 b	0 a	0 a	25 b
	1995	0 a	1 a	78 b	0 a	0 a	16 b
Kaiser	1993	306 a	292 a	247 a	67 a	129 a	106 a
	1994	1 a	2 a	64 b	0 a	0 a	29 b
	1995	0 a	0 a	77 b	0 a	0 a	5 b

[a] The entire experimental areas were planted to soybean during summer 1993.
[b] Means followed by the same letter within year, site, and nematode species are not significantly different ($P \leq 0.05$) according to F test.

(202 kg/ha) previous crop treatments. There was no effect of aldicarb on nematode populations.

Unlike the previous experiments (Rodríguez-Kábana et al., 1992b; Weaver et al., 1993), where neither bahiagrass nor velvetbean had an effect on subsequent populations of *Meloidogyne* spp. in soybean, rotation crops in this experiment differed in their effect on *Meloidogyne* spp. numbers. Numbers of *Meloidogyne* spp. in the subsequent soybean crop were not significantly different ($P < 0.05$) for the bahiagrass rotation (119 J2/100cm^3 soil, averaged across cultivars and nematicide treatment) and continuous soybean (99 J2/100cm^3 soil) but were lower in soybean following velvetbean (60 J2/100 cm^3 soil). There was no location × previous crop interaction for numbers of *Meloidogyne* spp., but there was a strong interaction between previous crop and cultivar for *Meloidogyne* spp. numbers. This was primarily due to large differences among cultivars for *Meloidogyne* spp. numbers in continuous soy-

TABLE 3. Effect of cropping system, aldicarb, and soybean cultivar on yield and juvenile numbers of *Meloidogyne* spp. and *Heterodera glycines,* averaged over Gottler and Kaiser experimental locations.

		Continuous soybean			Soybean following bahiagrass			Soybean following velvetbean		
			Juveniles/100 cm^3 soil			Juveniles/100 cm^3 soil			Juveniles/100 cm^3 soil	
Cultivar	Aldicarb application[a]	Yield (kg/ha)	*Meloidogyne* spp.	*H. glycines*	Yield (kg/ha)	*Meloidogyne* spp.	*H. glycines*	Yield (kg/ha)	*Meloidogyne* spp.	*H. glycines*
Benning	–	1,713	182	18	3,243	226	42	3,393	57	3
Benning	+	2,132	163	33	3,499	174	20	3,624	63	0
Braxton	–	665	66	34	2,232	61	29	2,752	71	6
Braxton	+	929	65	44	2,645	85	52	2,953	63	7
Brim	–	845	24	20	2,413	48	15	2,994	32	0
Brim	+	1,380	24	18	2,701	46	6	3,323	54	2
Bryan	–	1,774	139	18	2,870	69	23	2,790	40	1
Bryan	+	2,021	87	35	3,093	53	21	2,934	26	1
Carver	–	2,021	112	1	3,362	113	0	3,078	63	0
Carber	+	2,520	107	4	3,678	156	3	3,335	72	1
Stonewall	–	1,134	70	10	2,507	168	12	2,832	78	0
Stonewall	+	1,625	103	36	2,838	123	12	2,909	65	2
Thomas	–	1,265	138	9	2,803	188	22	2,960	75	1
Thomas	+	1,657	100	22	2,916	156	24	3,131	85	1
$\bar{x}$	–	1,345	104	16	2,776	125	20	2,971	59	2
$\bar{x}$	+	1,752	93	27	2,973	113	20	3,173	61	2

Data are averages of 32 replications. LSD (0.05) values for comparing any two means within a cropping system are 225, 25, and 8 for yield, *Meloidogyne* spp., and *H. glycines,* respectively.
[a] Aldicarb applied at 17.8 g a.i./100 m row in a 25-cm band.

bean and soybean following bahiagrass. With the exception of a low value for Bryan soybean treated with aldicarb, there were no cultivar differences following velvetbean (Table 3).

There was no difference between continuous soybean (22 J2/100 cm^3 soil, averaged across cultivars and nematicide treatment) and bahiagrass (20 J2/100 cm^3 soil) for numbers of *H. glycines,* but soybean following velvetbean had significantly lower ($P < 0.05$) *H. glycines* numbers (2 J2/100 cm^3 soil). Thus, velvetbean not only lowered nematode populations of all species prior to planting soybean but, unlike bahiagrass, the effect continued until the end of the soybean growing season. Numbers of *H. glycines* were lower than in previous experiments (Rodríguez-Kábana et al., 1992b; Weaver et al., 1993), and so it is difficult to make comparisons with the current study. There was no location × previous crop interaction for numbers of *H. glycines.* Interactions between previous crop and cultivar were similar to those for *Meloidogyne* spp., with large genotypic effects in continuous soybean and soybean following bahiagrass but no effect of genotype following velvetbean. The previous crop × aldicarb treatment interaction followed the same trend: increases in numbers of *H. glycines* caused by aldicarb treatment in continuous soybean and soybean following bahiagrass, but no effect following velvetbean (Table 3).

There was no difference in soybean yield response to bahiagrass or velvetbean as previous crops. Velvetbean increased subsequent soybean yield by 98% and bahiagrass by 85% as previous crops compared to continuous soybean (Table 3). There was no location × previous crop interaction for yield. Yield response to rotation was highly dependent upon cultivar and followed the trends for the interactions of previous crop and cultivar for the nematode species. In continuous soybean, yield among cultivars was variable and closely reflected the relative resistance of cultivars to nematodes. For example, the best-yielding cultivars in continuous soybean were Carver, Bryan, and Benning, which were the only cultivars resistant to both species of *Meloidogyne* and at least one race of *H. glycines.* Bahiagrass tended to mask some of these differences, improving the yield of Carver by 1,249 kg/ha and the yield of the nematode-susceptible Brim by 1,444 kg/ha. Velvetbean tended to mask these genetic differences even more. Yield of Carver was improved by 936 kg/ha following velvetbean (a slight yield decrease compared to bahiagrass), but yield of Brim was increased by 2,046 kg/ha, representing a 184% increase. As with the nematode species, velvetbean as a rotation crop tended to minimize any yield difference due to soybean genotype. There was a small interaction between previous crop and nematicide treatment for yield. Aldicarb treatment increased yield more in the continuous soybean than with either of the rotation crops (Table 3).

Both velvetbean and bahiagrass were equally effective in reducing nematode populations prior to planting of the soybean crop. Both produced equal yield responses in the subsequent soybean crop. The major difference between the two rotation crops was in yield response of the nematode-susceptible cultivars and in at-harvest nematode populations. Velvetbean tended to mask genetic differences among cultivars more so than bahiagrass. Velvetbean also produced a more long-term effect on nematode populations, with numbers of both *Meloidogyne* spp. and *H. glycines* lower in soybean following velvetbean than following bahiagrass or continuous soybean. We believe velvetbean has the potential to be superior to grass crops as a nematode management tool for soybean in areas of severe nematode infestation.

Literature Cited

Ball, D. M., C. S. Hoveland, and G. D. Lacefield. 1991. Southern forages. Atlanta: Potash and Phosphate Institute.

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

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.

Boerma, H. R., R. S. Hussey, D. V. Phillips, E. D.

Wood, and S. L. Finnerty. 1997. Registration of 'Benning' soybean. Crop Science 37:1982.

Buckles, D. 1995. Velvetbean: A "new" plant with a history. Economic Botany 49:13–25.

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

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.

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

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

Kloepper, J. W., R. Rodríguez-Kábana, J. A. McInroy, and D. J. Collins. 1991. Analysis of populations and physiological characterization of microorganisms in rhizospheres of plants with antagonistic properties to phytopathogenic nematodes. Plant and Soil 136:95–102.

Rodríguez-Kábana, R., J. W. Kloepper, D. G. Robersston, and L. W. Wells. 1992a. Velvetbean for the management of root-knot and southern blight in peanut. Nematropica 22:75–79.

Rodríguez-Kábana, R., J. Pinochet, D. G. Robertson, and L. W. Wells. 1992b. Crop rotation studies with velvetbean (*Mucuna deeringiana*) for the management of *Meloidogyne* spp. Supplement to the Journal of Nematology 24:662–668.

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

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

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. Nematropica 20:111–119.

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. Nematropica 20:101–110.

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.

Vincente, N. E., and N. Acosta. 1987. Effects of *Mucuna deeringiana* on *Meloidogyne incognita.* Nematropica 17:99–102.

Watson, J. R. 1922. Bunch velvetbeans to control root-knot. Agricultural Experiment Station Bulletin 163. University of Florida, Gainesville, FL.

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

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

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.

Weaver, D. B., R. Rodríguez-Kábana, and E. L. Carden. 1995. Comparison of crop rotation and fallow for management of *Heterodera glycines* and *Meloidogyne* spp. in soybean. Supplement to the Journal of Nematology 27:585–591.

Weaver, D. B., R. Rodríguez-Kábana, D. G. Robertson, R. L. Akridge, and E. L. Carden. 1988b. Effect of crop rotation on soybean in a field infested with *Meloidogyne arenaria* and *Heterodera glycines.* Annals of Applied Nematology (Journal of Nematology 20, Supplement) 2:106–109.