Journal of Nematology 26(2):175–181. 1994.

Effects of Tropical Rotation Crops on *Meloidogyne arenaria* Population Densities and Vegetable Yields in Microplots[1]

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Abstract: The effects of 12 summer crop rotation treatments on population densities of *Meloidogyne arenaria* race 1 and on yields of subsequent spring vegetable crops were determined in microplots. The crop sequence was: (i) rotation crops during summer 1991; (ii) cover crop of rye (*Secale cereale*) during winter 1991–92; (iii) squash (*Cucurbita pepo*) during spring 1992; (iv) rotation crops during summer 1992; (v) rye during winter 1992–93; (vi) eggplant (*Solanum melongena*) during spring 1993. The 12 rotation treatments were castor (*Ricinus communis*), cotton (*Gossypium hirsutum*), velvetbean (*Mucuna deeringiana*), crotalaria (*Crotalaria spectabilis*), fallow, hairy indigo (*Indigofera hirsuta*), American jointvetch (*Aeschynomene americana*), sorghum–sudangrass (*Sorghum bicolor* × *S. sudanense*), soybean (*Glycine max*), horsebean (*Canavalia ensiformis*), sesame (*Sesamum indicum*), and peanut (*Arachis hypogaea*). Compared to peanut, the first eight rotation treatments resulted in lower ($P \leq 0.05$) numbers of *M. arenaria* juveniles on most sampling dates. Soybean, horsebean, and sesame rotations were less effective in suppressing nematodes. Yield of squash was greater ($P \leq 0.05$) following castor, cotton, velvetbean, and crotalaria than following peanut. Compared to the peanut rotation, yield of eggplant was enhanced ($P \leq 0.10$) following castor, crotalaria, hairy indigo, American jointvetch, and sorghum-sudangrass. Several of these rotation crops may provide a means for depressing *M. arenaria* population densities on a short-term basis to enhance yields in a subsequent susceptible vegetable crop.

Key words: Aeschynomene americanum, Arachis hypogaea, Canavalia ensiformis, cropping systems, *Crotalaria spectabilis, Cucurbita pepo,* fallow, *Glycine max, Gossypium hirsutum, Indigofera hirsuta, Meloidogyne arenaria, Mucuna deeringiana,* nematode, nematode management, *Ricinus communis, Sesamum indicum, Solanum melongena, Sorghum bicolor,* sustainable agriculture.

In the southeastern United States, crop rotation remains an important method for limiting damage caused by root-knot nematodes (*Meloidogyne* spp.) to field and vegetable crops (4). Cotton (*Gossypium hirsutum* L.) and sorghum (*Sorghum bicolor* (L.) Moench) or sorghum–sudangrass (*S. bicolor* × *S. sudanense* (Piper) Stapf) hybrids are useful against certain species and races of root-knot nematodes (8,17), but the long growing season of the Southeast allows the use of uncommon or tropical crops in rotations as well (12,16). A number of tropical rotation crops have been used in the region to suppress root-knot nematodes, beginning with velvetbean (*Mucuna deeringiana* (Bort.) Merr.) in the 1920's (22). More recently, velvetbean has been effective in suppressing a variety of root-knot nematode species and races in greenhouse, microplot, and field tests (14). Compared to other summer rotation crops, velvetbean resulted in the lowest population densities of *Meloidogyne incognita* (Kofoid & White) Chitwood at seven sites in north Florida (9). Tropical legumes such as American jointvetch (*Aeschynomene americana* L.) and hairy indigo (*Indigofera hirsuta* L.) suppressed population densities of *M. arenaria* (Neal) Chitwood, *M. incognita,* and *M. javanica* (Treub) Chitwood in other studies (10,11,18). Crotalaria (*Crotalaria spectabilis* Roth.) apparently reacted as a trap crop for root-knot nematodes (2,21), and has been effective in lowering population densities of several *Meloidogyne* spp. in greenhouse and field tests (2,13). Sesame (*Sesamum indicum* L.) has been used for management of *M. arenaria* (12,16) and

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Received for publication 15 October 1993.

[1] Florida Agricultural Experiment Station Journal Series No. R-03433. This research was supported by a grant from the Extension Service, USDA, Integrated Pest Management Program, and by a grant from the USDA, CSRS, Southern Regional Sustainable Agriculture Research and Education Program.

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The authors thank John Anderson, Tom Schmid, Jeff Dickson, Jeff Simmons, and Reggie Wilcox for technical assistance, and Kristy Woods for manuscript preparation.

M. incognita (19). Rotation with castor (*Ricinus communis* L.) for management of *M. arenaria* has improved yields of subsequent crops of peanut (*Arachis hypogaea* L.) (15,16) and soybean (*Glycine max* (L.) Merr.) (11). Some nematode suppression is also attributed to horsebean (*Canavalia ensiformis* (L.) DC.), which exhibited few galls from *M. arenaria* race 2 and *M. javanica*, but severe galling from *M. incognita* race 1 (13).

Tests with one or several of these crops have been conducted in Alabama, and reductions in population densities of *M. arenaria* have often resulted from their use (12–18). Our objective was to compare all of the above-mentioned crops in a single experiment, in order to determine their relative abilities to suppress population densities of *M. arenaria* race 1 and to enhance yields of subsequent vegetable crops.

MATERIALS AND METHODS

All experiments were conducted in 76-cm-d microplots encircled with 60-cm-wide fiberglass sheets inserted 50 cm deep into the soil (5), located at the University of Florida Green Acres Agronomy Research Farm in Alachua County. Microplots were arranged in rows 1.5 m apart in an Arredondo fine sand (93% sand, 4% silt, 3% clay; 1% organic matter; pH = 5.8). In October 1990, these microplots contained very high population densities of second-stage juveniles (J2) of *M. arenaria* race 1 ($>$1,000 J2/100 cm^3 soil), as a result of two previous seasons with peanut (7). A winter cover crop of rye (*Secale cereale* L. cv. Wrens Abruzzi) was maintained each winter from November through February in all microplots during the course of the experiments.

In spring 1991, the following 12 crop rotation treatments were established in the microplots: American jointvetch, 'Hale' castor, crotalaria, 'Flamingo' hairy indigo, horsebean, velvetbean, 'Oro Benne' sesame, 'SX-17' sorghum–sudangrass, 'Deltapine 90' cotton, 'Kirby' soybean, 'Florunner' peanut, and fallow. Each treatment was replicated six times in a randomized complete block design. Blocks were established based on *M. arenaria* densities existing in the microplots in October 1990. However, analyses of variance (ANOVA) revealed no significant block effects ($P \leqslant 0.10$) from 1991 to 1993.

Each microplot was fertilized with 25 g of 7-7-7 (N-P-K) and planted on 8 May 1991. Castor, cotton, horsebean, peanut, sorghum–sudangrass, and velvetbean were planted at the rate of 5–6 seeds and later thinned to three plants per plot. For crotalaria, 12–15 seeds were planted and thinned to three plants per plot. Seeds of American jointvetch, hairy indigo, sesame, and soybean were planted 5 cm apart in row spaced 12 cm apart. About 40 seeds per microplot were planted using this pattern, except for hairy indigo, for which 80–100 seeds per plot were used. Seeds of crotalaria and hairy indigo were scarified by abrasion before planting. Crops were removed on 29 October 1991, when three root systems per plot were rated for galling on a 0 to 5 scale, such that 0 = 0 galls; 1 = 1–2 galls; 2 = 3–10 galls; 3 = 11–30 galls; 4 = 31–100 galls; and 5 = > 100 galls per root system (20).

Following a winter cover crop of rye, microplots were replanted on 16 March 1992 with three seeds of squash (*Cucurbita pepo* L. cv. Lemondrop L.), and later thinned to two plants per plot. Fruit were harvested, counted, and weighed 10 times between 7 May and 1 June. Root systems were removed 1 June and rated for galling and egg masses on a 0 to 5 scale.

The experiment was repeated in 1992–93, beginning with the replanting of the tropical rotation crops on 10 June 1992. The 12 treatments and seeding rates were identical to those used the previous summer, except that the sesame cultivar used was 'Sesaco 16' instead of Oro Benne. Each microplot received the same crop (or fallow) it had during 1991, providing a 2-year rotation for each treatment. Plots were harvested and roots rated on 27 October 1992.

Following the winter rye crop, microplots were planted with seedlings (ca. 12 cm tall) of eggplant (*Solanum melongena* L. cv. Classic) on 6 April 1993. Plant heights were measured on 13 May and 9 June, and fruit were harvested, counted, and weighed weekly between 21 June and 30 July (six times). Root systems were removed and rated for galling on 30 July 1993.

The squash crop, second planting of rotation crops, and the eggplants were fertilized at planting with 20 g of 15-5-10 (N-P-K) per microplot, and sidedressed with half that amount approximately 1 month later. Fungicide, insecticide, and overhead irrigation were applied to plots as needed, except that a drip irrigation system was used for the eggplant crop in 1993. Weeds were removed manually from all plots throughout the experiments.

Soil samples consisting of five cores (2.5-cm-d × 20-cm-deep) were collected from each microplot to determine nematode densities in soil before planting (Pi) and at final harvest (Pf) of each crop. Sampling dates were 13 March 1991 (Pi for rotation crops), 29 October 1991 (Pf for rotation crops), 27 February 1992 (Pi for squash), 26 May 1992 (Pf for squash and Pi for rotation crops), 26 October 1992 (Pf for rotation crops), 3 February 1993 (Pi for eggplant), and 30 July 1993 (Pf for eggplant). On each sampling date, the five soil cores from each plot were mixed, and nematodes were extracted from a 100-cm^3 subsample by sieving and centrifugation (3).

The effects of the tropical crop rotation treatments on nematode densities and on yields of subsequent vegetable crops were evaluated using ANOVA, followed by mean separation with Duncan's multiple-range test. Single degree of freedom orthogonal contrasts (1) were determined for the peanut control vs. all the other treatments. Both untransformed and transformed $[\log_{10}(\chi + 1)]$ nematode data were analyzed, but since results were similar in both cases, only untransformed data and analyses are presented.

RESULTS AND DISCUSSION

Initial population densities of *M. arenaria* race 1 juveniles (J2) in the microplots were high (Table 1). Following the summer rotation treatments (29 October 1991), numbers of *M. arenaria* declined in all microplots except those planted to peanut (Table 1). On 29 October 1991 and the subsequent four sampling dates, seven of the rotation treatments (cotton, velvetbean, crotalaria, fallow, hairy indigo, American jointvetch, and sorghum–sudangrass) consistently resulted in much lower ($P \leq 0.05$) numbers of *M. arenaria* than did the peanut rotation. Castor was generally as effective as these seven treatments, but occasionally it harbored intermediate levels of J2 (200–600/100 cm^3). These results are consistent with other studies that have successfully used castor (12,15,16), 'Deltapine 90' cotton (17), velvetbean (9,14), crotalaria (2,13), hairy indigo (10,18), American jointvetch (18), or 'SX-17' sorghum–sudangrass (8) for the management of *M. arenaria* or other *Meloidogyne* spp. When compared in the same test in the current study, these crops resulted in similar levels of efficacy, which were comparable to fallow. The soybean, horsebean, and sesame rotations were less effective and resulted in intermediate levels of *M. arenaria* J2 in soil (Table 1). Response of horsebean to root-knot nematodes depends on nematode species and race (13), but it does not appear to be particularly effective in lowering densities of *M. arenaria* race 1. In Alabama, 'Baco' sesame has been effective in the management of *M. arenaria* populations in the field (12,16), and several sesame cultivars, including Baco and Oro Benne were free of galling from *M. incognita* and exhibited only slight galling in response to *M. arenaria* (12). Nevertheless, neither Oro Benne (used in 1991) nor Sesaco 16 (used in 1992) sesame appeared to be particularly effective as rotation crops under Florida conditions, but it is clear that the response of sesame cultivars to a range of *Meloidogyne* spp. deserves further investi-

TABLE 1. Population densities of *Meloidogyne arenaria* juveniles (1991–93) in soil of microplots receiving crop rotation treatments.

	Nematodes/100 cm^3 soil						
	Rotation crops		Squash	Rotation crops		Eggplant	
Rotation treatment	Pi 13 Mar. 1991	Pf 29 Oct. 1991	Pi 27 Feb. 1992	Pi† 26 May 1992	Pf 26 Oct. 1992	Pi 3 Feb. 1993	Pf 30 July 1993
Castor	1,024 a	572 bc	101 c	234 bc	28 c	77 b	490 a
Cotton	944 a	67 c	46 c	110 c	12 c	15 b	300 a
Velvetbean	924 a	116 c	105 c	149 c	117 c	72 b	703 a
Crotalaria	1,276 a	91 c	86 c	150 c	18 c	155 b	737 a
Fallow	994 a	97 c	13 c	75 c	25 c	30 b	367 a
Hairy indigo	954 a	84 c	43 c	122 c	20 c	53 b	940 a
American jointvetch	1,124 a	83 c	113 c	92 c	10 c	33 b	258 a
Sorghum–sudangrass	1,170 a	150 c	176 c	177 c	15 c	35 b	912 a
Soybean	1,187 a	698 b	588 ab	552 a	247 c	237 b	799 a
Horsebean	1,212 a	556 bc	284 bc	168 c	646 b	305 ab	1,508 a
Sesame	1,036 a	355 bc	240 bc	315 abc	67 c	275 b	1,040 a
Peanut	1,102 a	1,200 a	819 a	478 ab	1,210 a	795 a	690 a
Contrast:							
Peanut vs. other treatments	NS	***	***	***	***	***	NS

Data are means of six replications. Means in columns followed by the same letter are not different ($P \leq 0.05$), according to Duncan's multiple-range test. *** indicates single degree of freedom orthogonal contrast significant at $P \leq 0.001$; NS = contrast not significant at $P \leq 0.05$.

† Also serves as Pf for squash crop.

gation. At the end of the 4-month eggplant crop (30 July 1993), J2 population densities had reached similar levels in all microplots, regardless of rotation crop treatment (Table 1).

Many of the rotation crops were free of root-knot nematode galling in both seasons (Table 2). Horsebean and sesame exhibited low levels of galling in both seasons, hairy indigo had intermediate levels

TABLE 2. Root gall ratings at harvest of crops from microplots receiving crop rotation treatments.

	Root-gall rating†			
Rotation treatment	Rotation crops 29 Oct. 1991	Squash 1 June 1992	Rotation crops 27 Oct. 1992	Eggplant 30 July 1993
Castor	0 d	3.8 abcd	0 d	4.6 a
Cotton	0 d	3.7 abcd	0.3 cd	4.0 a
Velvetbean	0 d	4.5 abc	0 d	4.1 a
Crotalaria	0 d	3.9 abcd	0 d	4.4 a
Fallow	—	4.0 abcd	—	4.5 a
Hairy indigo	2.4 b	3.9 abcd	3.2 a	4.8 a
American jointvetch	0 d	3.6 bcd	0 d	3.8 a
Sorghum–sudangrass	0 d	3.2 d	0 d	4.4 a
Soybean	0 d	4.8 ab	0.8 bcd	4.6 a
Horsebean	0.7 c	3.4 cd	1.1 bc	4.5 a
Sesame	0.5 cd	4.8 a	1.5 b	4.9 a
Peanut	5.0 a	4.8 a	3.8 a	4.8 a
Contrast:				
Peanut vs. other treatments	***	*	***	NS

Data are means of six replications. Means in columns followed by the same letter are not different ($P \leq 0.05$), according to Duncan's multiple-range test. *, *** indicate single degree of freedom orthogonal contrasts significant at $P \leq 0.05$ and $P \leq 0.001$, respectively; NS = contrast not significant at $P \leq 0.05$.

† Root galling rated on a 0 to 5 scale, such that 0 = 0 galls; 1 = 1–2 galls; 2 = 3–10 galls; 3 = 11–30 galls; 4 = 31–100 galls; and 5 = >100 galls per root system (20).

of galling, and peanut had the highest gall ratings. Values of egg mass ratings on 27 October 1992 (data not shown) were approximately half those of the gall ratings reported (Table 2) for the rotation crops, except for peanut, on which the mean egg mass index (3.67) and gall index (3.78) were nearly identical. Moderate to high levels of galling were observed at the end of the season on squash and eggplant, regardless of the rotation treatment.

Rotation treatments affected weight but not numbers of harvested yellow squash (Table 3). For seven of the rotation treatments, the weight of harvested squash was >50% higher than that from the rotation with peanut. Lowest squash yields followed peanut, sesame, and horsebean. Eggplant growth and number of fruit harvested were not affected ($P \leqslant 0.10$) by rotation treatment (Table 4). Differences in eggplant fruit weight with treatment were evident at $P = 0.08$. Nevertheless, two-thirds of the rotation treatments resulted in ≥50% increases over the weight of eggplant harvested following the peanut treatment. Vegetable yield following castor was approximately double that following peanut in both years (Tables 3,4). Both 'Classic' eggplant and 'Lemondrop L' squash are excellent hosts of *M. arenaria*, and yield differences among treatments were observed in both crops. However, differences among treatments were more easily detected in the squash crop ($P \leqslant 0.05$) than in the eggplant crop ($P \leqslant 0.10$). On the other hand, Pf of *M. arenaria* reached higher levels following eggplant than squash (Table 1). These discrepancies between results of the eggplant and squash experiments may be due to some important differences in cultural practices in the two crops such as seasonal differences or irrigation practices. In addition, the squash crop was grown for 2½ months (16 March–1 June), whereas the eggplant was maintained for almost 4 months (6 April–30 July), allowing more time for buildup of *M. arenaria* population density.

During 1992, about two-thirds of the microplots were colonized by *Paratrichodorus minor* (Colbran) Siddiqi, and by the end of the experiment nearly all (97%) microplots were infested. This nematode was not detected at the beginning of the study or in a previous study (7) involving peanut. *Paratrichodorus minor* can occur at great soil depths (6), and should be capable of moving underneath a 50-cm-deep microplot. This nematode built up most rapidly in mi-

TABLE 3. Yield of yellow squash following crop rotation treatments in microplots (yields are totals of 10 harvests between 7 May and 1 June 1992).

Rotation treatment	Total number of fruit per plot	Total weight of fruit (g/plot)	Weight increase over peanut treatment (%)
Castor	13.2 a	1,522 a	118
Cotton	11.8 ab	1,319 ab	89
Velvetbean	12.0 ab	1,247 abc	79
Crotalaria	11.5 ab	1,147 abcd	64
Fallow	11.3 abc	1,121 abcde	61
Hairy indigo	11.2 abc	1,086 bcde	56
American jointvetch	9.3 bcd	1,075 bcde	54
Sorghum–sudangrass	10.3 abcd	1,012 bcde	45
Soybean	9.8 bcd	937 bcde	34
Horsebean	8.2 cd	811 cde	16
Sesame	8.0 d	714 de	2
Peanut	9.2 bcd	698 e	—
Contrast:			
Peanut vs. other treatments	NS	**	—

Data are means of six replications. Means in columns followed by the same letter are not different at $P \leqslant 0.05$ (weight of fruit) or $P \leqslant 0.10$ (number of fruit), according to Duncan's multiple-range test. ** indicates single degree of freedom orthogonal contrast significant at $P \leqslant 0.01$; NS = contrast not significant at $P \leqslant 0.05$.

TABLE 4. Heights and yield of eggplant following crop rotation treatments in microplots (yields are totals of six harvests between 21 June and 30 July 1993).

Rotation treatment	Plant height (cm) 13 May	Plant height (cm) 9 June	Total number of fruit per plot	Total weight of fruit (g/plot)	Weight increase over peanut treatment (%)
Castor	18 a	49 a	16.2 a	4,444 ab	97
Cotton	11 a	39 a	13.0 a	3,607 abc	60
Velvetbean	13 a	39 a	11.7 a	3,238 bc	44
Crotalaria	17 a	49 a	15.7 a	4,170 ab	85
Fallow	12 a	34 a	11.3 a	2,949 bc	31
Hairy indigo	16 a	48 a	15.8 a	4,042 ab	79
American jointvetch	15 a	47 a	17.3 a	4,876 a	116
Sorghum–sudangrass	17 a	36 a	15.8 a	4,180 ab	86
Soybean	16 a	50 a	13.7 a	3,611 abc	60
Horsebean	14 a	44 a	11.8 a	3,385 abc	50
Sesame	12 a	43 a	11.0 a	3,072 bc	36
Peanut	16 a	39 a	10.2 a	2,253 c	—
Contrast:					
Peanut vs. other treatments	NS	NS	NS	**	—

Data are means of six replications. Means in columns followed by the same letter are not different ($P \leq 0.10$), according to Duncan's multiple-range test. ** indicates single degree of freedom orthogonal contrast significant at $P \leq 0.01$; NS = contrast not significant at $P \leq 0.05$.

croplots planted to sorghum–sudangrass, but its effects on yield were not clear. Eggplant following sorghum–sudangrass yielded well (Table 4).

In conclusion, many of the rotation crops examined here could be useful in suppressing *M. arenaria* numbers and enhancing yield of a subsequent susceptible vegetable crop. However, it is likely that these favorable effects may last only through a single vegetable crop. By the end of the susceptible vegetable crop, *M. arenaria* densities increased again (Table 1), more so in a crop of longer duration (e.g., eggplant, 4 months) than in a shorter one (e.g., squash, 2½ months). In addition, some candidate crops may be impractical choices for rotation systems due to nontarget effects. For example, both crotalaria and castor are toxic to livestock (2,12). Nevertheless, rotation with selected tropical rotation crops may provide a means of successfully growing a vegetable crop in sites infested with root-knot nematodes. Additional research is needed to discover new crops and cultivars useful for this purpose, to elucidate modes of action, and to integrate rotation with other nematode management methods.

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