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Tropical Rotation Crops Influence Nematode Densities and Vegetable Yields[1]

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Abstract: The effects of eight summer rotation crops on nematode densities and yields of subsequent spring vegetable crops were determined in field studies conducted in north Florida from 1991 to 1993. The crop sequence was as follows: (i) rotation crops during summer 1991; (ii) cover crop of rye (*Secale cereale*) during winter 1991–92; (iii) 'Lemondrop L' squash (*Cucurbita pepo*) during spring 1992; (iv) rotation crops during summer 1992; (v) rye during winter 1992–93; (vi) 'Classic' eggplant (*Solanum melongena*) during spring 1993. The eight summer crop rotation treatments were as follows: 'Hale' castor (*Ricinus communis*), velvetbean (*Mucuna deeringiana*), sesame (*Sesamum indicum*), American jointvetch (*Aeschynomene americana*), weed fallow, 'SX-17' sorghum–sudangrass (*Sorghum bicolor* × *S. sudanense*), 'Kirby' soybean (*Glycine max*), and 'Clemson Spineless' okra (*Hibiscus esculentus*) as a control. Rotations with castor, velvetbean, American jointvetch, and sorghum-sudangrass were most effective in maintaining the lowest population densities of *Meloidogyne* spp. (a mixture of *M. incognita* race 1 and *M. arenaria* race 1), but *Paratrichodorus minor* built up in the sorghum–sudangrass rotation. Yield of squash was lower ($P \leq 0.05$) following sorghum-sudangrass than after any of the other treatments except fallow. Yield of eggplant was greater ($P \leq 0.05$) following castor, sesame, or American jointvetch than following okra or fallow. Several of the rotation crops evaluated here may be useful for managing nematodes in the field and for improving yields of subsequent vegetable crops.

Key words: Aeschynomene americana, castor, crop rotation, cropping systems, *Cucurbita pepo,* eggplant, fallow, *Glycine max, Hibiscus esculentus,* jointvetch, *Meloidogyne arenaria, Meloidogyne incognita, Mucuna deeringiana,* nematode management, nematode, okra, *Paratrichodorus minor, Ricinus communis,* sesame, *Sesamum indicum, Solanum melongena, Sorghum bicolor,* sorghum–sudangrass, soybean, squash, sustainable agriculture, vegetables, velvetbean, weed hosts.

Crop rotation is an important means of limiting nematode damage to susceptible crops grown in the southeastern United States (3). Root-knot nematodes (*Meloidogyne* spp.) have been frequent targets of management by crop rotation, and traditional crops such as cotton (*Gossypium hirsutum*), soybean (*Glycine max*), and sorghum (*Sorghum bicolor*) or sorghum-sudangrass (*S. bicolor* × *S. sudanense*) hybrids have been useful in rotation sequences for suppressing certain species and races of root-knot nematodes (3,5,12). Recently, several different tropical crops have been introduced into rotation sequences in the Southeastern United States for suppression of root-knot nematodes (8,11). Crops such as velvetbean (*Mucuna deeringiana*), castor (*Ricinus communis*), American jointvetch (*Aeschynomene americana*), and sesame (*Sesamum indicum*) have shown potential for this purpose in greenhouse and limited field tests (6–11,13).

Tests with one or several of these crops have been conducted against certain root-knot nematode species and races in Alabama, and reduction in densities have often resulted from their use (8–11,13). Our objective was to compare several of these rotation crops in a single field experiment for their effects on nematode densities and yields of subsequent vegetable crops. A site was selected that had a mixture of *Meloidogyne* spp. and other damaging nematode species.

Materials and Methods

Field experiments were conducted at the Suwannee Valley Agricultural Research

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and Education Center near Live Oak in Suwannee County, Florida. The site had been planted to rye (*Secale cereale*) during the winter of 1990–91. Soil at this location consisted of 87% sand, 5% silt, and 8% clay, with 3% organic matter and a pH of 5.8.

In 1991, an experiment was initiated with the following rotation treatments: 'Hale' castor, velvetbean, 'Oro Benne' sesame, 'Clemson Spineless' okra (*Hibiscus esculentus*), American jointvetch, fallow, 'SX-17' sorghum–sudangrass, and 'Kirby' soybean. Rotation crops were planted 14 June 1991 in six rows (0.76 m apart and 9.2 m long) per plot in a randomized complete block design with six replications. A 6-m clean fallow border was maintained around each plot in the direction of cultivation to reduce possible plot-to-plot contamination. Seeds of castor and velvetbean were planted ca. 30 cm apart in the rows within plots, but seeds of other crops were planted only 3–5 cm apart. Crops were harvested on 24 October 1991 by removing all aboveground vegetation from a 1-m^2 section measured across two rows near the center of each plot. Fresh biomass from each plot was determined in the field, and a subsample ($\leq$500 g fresh weight) removed and dried at 60 C to constant weight, for conversion of biomass data to dry weight. Root systems of five plants per plot were removed and 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 (15). Finally, all plots were mowed and rototilled before planting a winter cover crop of 'Vita Graze' rye on 11 November 1991.

The rye cover crop was mowed, and the residues were rototilled in late February. 'Lemondrop L' squash (*Cucurbita pepo*) was planted in all plots on 16 March 1992. Seeds were planted 30 cm apart in 3 rows (1.5 m apart × 9.2 m long) per plot. Squash received 560 kg/ha of a 13-4-13 (N-P-K) fertilizer at planting, 500 kg/ha of the same fertilizer on 12 April, and an additional 280 kg/ha on 21 May (1). Insects and diseases were managed as needed using practices recommended for squash in Florida (4,14). Fruit from the center row of each plot was harvested, counted, and weighed nine times between 7 May and 29 May. Root systems were removed and rated for galling on 3 June.

Following rototilling of the squash crop residues, the rotation crop treatments were planted on 11–12 June 1992. Treatments were identical to those used in 1991 except that sesame variety T32A (Sesaco Corporation, San Antonio, TX) was used in 1992. Cultural practices and plot design were the same as in 1991; each plot received the same rotation crop treatment in both years. Plots were harvested for biomass and roots rated for galling on 9 November 1992. A winter cover crop of rye was maintained as before on all plots from mid-November 1992 to late February 1993.

On 8 April 1993, seedlings (ca. 12 cm tall) of 'Classic' eggplant (*Solanum melongena*) were planted in each plot. Cultural practices, plot design, and planting patterns were identical to those used for squash in the previous year, except that the spacing between plants in the row was 45 cm rather than 30 cm. Fruit from the center row (9.2 m) of each plot was harvested, counted, and weighed nine times between 17 June and 19 July. Roots were removed and rated for galling on 20 July.

All rotation crops and vegetable crops received overhead irrigation as needed. Weed control was by mechanical cultivation for 1–2 months after planting and by hand thereafter. The weed fallow treatment was planted initially (14 June 1991) with partridge pea (*Cassia fasiculata*), but when this crop failed to germinate, plots were cultivated for about 2 months during the 1991 season, after which a sparse weed cover was permitted to grow until November. During the 1992 season (June–November), no weed control was attempted in the weed fallow treatment. The most common weeds occurring in these plots were hairy indigo (*Indigofera hirsuta*), alyceclover (*Alysicarpus vaginalis*), nutsedge

(*Cyperus* spp.), sicklepod (*Cassia obtusifolia*), and beggarweed (*Desmodium* sp.).

Soil samples consisting of six cores (2.5 cm d × 20 cm deep) were collected from the center row (squash, eggplant) or center two rows (rotation crops) of each plot to determine nematode densities in soil at or shortly before planting (Pi) and at final harvest (Pf) of each crop. Sampling dates were as follows: 13 June 1991 (Pi for rotation crops), 24 October 1991 (Pf for rotation crops and Pi for rye), 11 February 1992 (Pf for rye), 12 March 1992 (Pi for squash), 3 June 1992 (Pf for squash and Pi for rotation crops), 2 November 1992 (Pf for rotation crops and Pi for rye), 12 February 1993 (Pf for rye), 8 April 1993 (Pi for eggplant), and 20 July 1993 (Pf for eggplant). On each sampling date, the six soil cores from each plot were mixed, and nematodes were extracted from a 100-cm^3 subsample (2).

The effects of the tropical crop rotation treatments on nematode densities and on yields of subsequent vegetable crops were evaluated using analysis of variance, followed by mean separation with Duncan's multiple-range test ($P \leq 0.05$). Nematode data were log$_{10}$-transformed before analyses, but untransformed arithmetic means are presented in the tables.

RESULTS

A mixture of *Meloidogyne arenaria* race 1 and *M. incognita* race 1 occurred in this site. Densities of *Meloidogyne* spp. juveniles in soil increased quickly following okra and soybean in the first rotation (Table 1). On most sampling dates, *Meloidogyne* spp. numbers were lower ($P \leq 0.05$) following castor, velvetbean, American jointvetch, and sorghum–sudangrass than were numbers following okra. Numbers of root-knot nematodes in the weed-fallow treatment were relatively low during 1991, but increased to higher numbers in 1992 and 1993 when weed growth was heavier. On the last sampling date (20 July 1993), *Meloidogyne* spp. numbers were relatively high ($\geq$164/10 cm^3 soil) for all treatments, following 3½ months of a susceptible eggplant crop.

Among the rotation crops, only okra showed high levels of root galling (Table 2). Squash following okra or soybean had more ($P \leq 0.05$) galling than squash following castor, velvetbean, sesame, Ameri-

TABLE 1. Effect of tropical rotation crops on densities of *Meloidogyne* spp. juveniles at Live Oak, Florida, 1991–93.

	Nematodes/100 cm^3 soil								
	Rotation crops		Rye	Squash	Rotation crops		Rye	Eggplant	
Rotation treatment	Pi 13 June 1991	Pf 24 Oct. 1991†	Pf 11 Feb. 1992	Pi 12 Mar. 1992	Pi 3 June 1992‡	Pf 2 Nov. 1992†	Pi 12 Feb. 1993	Pi 8 Apr. 1993	Pf 20 July 1993
Castor	8 a	1 b	5 c	2 c	0 c	3 c	4 b	3 c	889 b
Velvetbean	8 a	15 b	5 c	9 c	3 bc	47 c	15 b	8 c	524 b
Sesame	4 a	7 b	1 c	4 c	0 c	52 c	27 b	16 bc	1,581 ab
Okra	32 a	908 a	1,416 a	1,086 a	468 a	1,119 a	411 a	148 a	3,025 a
American jointvetch	6 a	3 b	5 c	6 c	1 c	5 c	21 b	1 c	750 b
Weed	7 a	12 b	4 c	39 c	87 b	54 c	91 b	14 bc	1,906 a
Sorghum–sudangrass	20 a	184 b	1 c	3 c	0 c	13 c	2 b	1 c	164 b
Soybean	8 a	423 a	131 b	61 b	58 b	219 b	14 b	37 b	686 b

Data are untransformed arithmetic 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 performed on log-transformed data.

† Also serves as initial population (Pi) for rye.

‡ Also serves as final population (Pf) for squash.

TABLE 2. Root gall indices on tropical rotation crops and subsequent squash and eggplant crops in a field infested with *Meloidogyne incognita* and *M. arenaria* at Live Oak, Florida, 1991–93.

	Root gall index†			
Treatment	Rotation crop (24 Oct. 1991)	Squash (3 June 1992)	Rotation crop (2 Nov. 1992)	Eggplant (20 July 1993)
Castor	0 b	0.4 c	0 b	3.2 a
Velvetbean	0 b	0.5 c	0 b	3.3 a
Sesame	0 b	0.2 c	0 b	3.3 a
Okra	4.4 a	4.2 a	5.0 a	4.7 a
American jointvetch	0 b	0.5 c	0 b	2.3 a
Weed fallow	—‡	0.9 bc	—	3.2 a
Sorghum–sudangrass	0 b	0.4 c	0 b	2.5 a
Soybean	0.4 b	2.1 b	0 b	3.2 a

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.

† Root gall index: 0 = 0 galls; 1 = 1–2 galls; 2 = 3–10 galls; 3 = 11–30 galls; 4 = 31–100 galls; 5 = >100 galls per root system (15). Root galls rated on final harvest date of each crop.

‡ No gall rating for fallow plots.

can jointvetch, or sorghum–sudangrass. In the second rotation, all okra plants were stunted and died before harvest, and the remaining root systems had high (>100) numbers of galls. After 3½ months in the field, eggplants showed intermediate levels of galling, regardless of treatment.

Paratrichodorus minor reached its highest levels in plots receiving sorghum–sudangrass, and populations peaked just before the planting of squash in 1992 (Table 3). Differences among other treatments were somewhat inconsistent and varied with sampling date. Densities of *P. minor* declined on squash (March–June 1992) but not on eggplant (April–July 1993).

Criconemella spp. (a mixture of *C. sphaerocephala* and *C. ornata*) reached levels greater than 80/100 cm^3 soil only in the sorghum–sudangrass rotations (data not shown). Densities of *Criconemella* spp. in-

TABLE 3. Effect of tropical rotation crops on densities of *Paratrichodorus minor* at Live Oak, Florida, 1991–93.

	Nematodes/100 cm^3 soil								
	Rotation crops		Rye	Squash	Rotation crops		Rye	Eggplant	
Rotation treatment	Pi 13 June 1991	Pf 24 Oct. 1991†	Pf 11 Feb. 1992	Pi 12 Mar. 1992	Pi 3 June 1992‡	Pf 2 Nov. 1992†	Pi 12 Feb. 1993	Pi 8 Apr. 1993	Pf 20 July 1993
Castor	29 a	16 a	58 d	86 c	32 a	52 bc	44 a	73 b	87 c
Velvetbean	32 a	154 a	155 b	140 bc	50 a	79 abc	43 a	82 b	151 abc
Sesame	31 a	81 a	189 b	153 b	48 a	145 ab	74 a	106 ab	86 c
Okra	28 a	57 a	62 d	64 c	21 a	21 d	30 a	58 b	117 bc
American jointvetch	29 a	33 a	79 cd	102 bc	25 a	26 cd	51 a	73 b	206 a
Weed fallow	46 a	17 a	72 cd	75 c	52 a	42 cd	46 a	82 b	201 ab
Sorghum–sudangrass	20 a	189 a	551 a	627 a	169 a	238 a	92 a	158 a	111 bc
Soybean	33 a	47 a	124 bc	110 bc	26 a	67 bc	41 a	104 ab	120 abc

Data are untransformed arithmetic 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 performed on log-transformed data.

† Also serves as initial population (Pi) for rye.

‡ Also serves as final population (Pf) for squash.

creased to 415/100 cm^3 on sorghum–sudangrass during the summer of 1992 (mean Pf/Pi > 100). *Criconemella* spp. declined rapidly under squash (March–June 1992) and eggplant (April–July 1993). *Paratylenchus* spp. were present initially in most plots at the beginning of the experiment, but declined by mid-1992 (data not shown). By April 1993, *Pratylenchus brachyurus* colonized plots in the sorghum–sudangrass, soybean, and velvetbean rotations. On 20 July 1993, mean levels of *P. brachyurus* in eggplant plots following sorghum–sudangrass, soybean, and velvetbean (10–12/100 cm^3 soil) were greater ($P \leq 0.05$) than those following any other rotation crop (0–1/100 cm^3 soil).

Biomass of the rotation crops depended on plant species, with sorghum–sudangrass producing the greatest aboveground biomass. Yield of squash following sorghum–sudangrass was lower ($P \leq 0.05$) than that following any other treatment except weed fallow (Table 4). Weights of harvested eggplant were greatest following castor, sesame, and American jointvetch, and least following okra and weed fallow. Eggplant yields following the sorghum–sudangrass treatment were intermediate.

DISCUSSION

Several of the rotation treatments resulted in *Meloidogyne* spp. densities far below those observed in the okra rotation, and in some instances, significantly ($P \leq 0.05$) below those in the soybean and weed fallow rotations. These results are consistent with previous work demonstrating suppression of certain root-knot nematode species or races by castor (8,10,11), velvetbean (6,9), sesame (8,11), American jointvetch (13), and sorghum–sudangrass (5). The current research demonstrates the efficacy of these rotation crops against a mixture of two *Meloidogyne* spp., both of which increase on squash, eggplant, and other vegetables. Unfortunately, there is a concern that some rotations, while effective against *Meloidogyne* spp., may increase populations of other nematodes. Both *Paratrichodorus minor* and *Criconemella* spp. increased more rapidly in sorghum–sudangrass than in other rotation treatments. Although numbers of *P. brachyurus* in this experiment were low and inconsequential, this nematode occurred more often following velvetbean, soybean, and sorghum–sudangrass.

Vegetable yields were affected by the rotation treatments. Lowest squash yields followed weed fallow and sorghum–sudangrass; the latter treatment resulted in unusually high levels of *P. minor* prior to the squash crop. Yield of squash following okra was similar to that following five other rotation crops, even though root-knot nematodes reached much higher lev-

TABLE 4. Total yield after nine harvests of yellow squash (1992) and eggplant (1993) following tropical rotation crops at Live Oak, Florida.

Rotation treatment	Yellow squash		Eggplant	
	Number of fruit per 9.2-m row	Weight of fruit (kg per 9.2-m row)	Number of fruit per 9.2-m row	Weight of fruit (kg per 9.2-m row)
Castor	175 ab	28.9 a	172 a	77.3 a
Velvetbean	167 ab	25.3 ab	132 bc	60.7 bc
Sesame	180 a	27.5 a	150 ab	70.2 ab
Okra	164 ab	26.8 a	104 cd	48.1 cd
American jointvetch	173 ab	27.8 a	139 b	64.9 ab
Weed fallow	146 bc	19.7 bc	98 d	45.2 d
Sorghum–sudangrass	128 c	17.1 c	133 bc	60.8 bc
Soybean	165 ab	24.5 ab	132 bc	59.1 bcd

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.

els following okra than after the other crops. In the eggplant crop, lowest yields followed okra and weed fallow, both of which resulted in high densities of *Meloidogyne* spp. If root-knot nematode density is an important determinant of vegetable yield, then results with the squash and eggplant crops appear somewhat contradictory. However, both crops were maintained very well, and were irrigated to overcome any symptoms of wilting. Squash plants in particular were healthy and productive, even those with high root gall indices. Squash was also a crop of comparatively short duration (ca. 2½ months), and possibly a longer time was needed to observe more adverse effects on the crop (e.g., 3½ months for eggplant). Resurgence of *Meloidogyne* spp. densities by the end of the eggplant crop (3½ months of a susceptible host) suggests that the rotation treatments used here are effective through only a single subsequent vegetable crop, and should be repeated before a second susceptible vegetable crop is grown.

Plots receiving the fallow treatment were relatively clean during 1991 but became very weedy in 1992. Clean fallow can be destructive to soil fertility (7), and it is possible that reduced soil fertility may be responsible for the reduced yields of squash following the fallow treatment. The same effect may also have occurred with eggplant, although the weed hosts clearly built up high densities of *Meloidogyne* spp. as well. Regardless of the mechanisms involved, fallow, particularly weed-fallow, does not appear to be a good rotation choice for this system. Among the options evaluated, rotation with castor, American jointvetch, or sesame consistently resulted in the highest yields of subsequent vegetable crops.

As in previous work (5), sorghum–sudangrass was effective in lowering *Meloidogyne* spp. densities, but cannot be recommended if *P. minor* is present and of concern. Often, rotation crops may increase the population densities of one or more nontarget plant-parasitic nematodes. Such increases may be acceptable if the nontarget nematode is not a problem in subsequent crops. Nevertheless, it is important that candidate rotation crops be evaluated against a range of nontarget organisms, to anticipate possible adverse or unexpected effects.

LITERATURE CITED

1. Hochmuth, G. J., and E. A. Hanlon. 1989. Commercial vegetable crop nutrient requirements. Circular 806, Florida Cooperative Extension Service, University of Florida, Gainesville.

2. Jenkins, W. R. 1964. A rapid centrifugal-flotation technique for separating nematodes from soil. Plant Disease Reporter 48:692.

3. Johnson, A. W. 1982. Managing nematode populations in crop production. Pp. 193–203 *in* R. D. Riggs, ed. Nematology in the Southern Region of the United States. Southern Cooperative Series Bulletin 276, Arkansas Agricultural Experiment Station, Fayetteville.

4. Johnson, F., P. Koehler, and D. Short. 1992. 1992–93 Florida insect control guide. Volume 2: Field crops and pastures, vegetables. Florida Cooperative Extension Service, University of Florida, Gainesville.

5. McSorley, R., and R. N. Gallaher. 1991. Nematode population changes and forage yields of six corn and sorghum cultivars. Supplement to the Journal of Nematology 23:673–677.

6. McSorley, R., and R. N. Gallaher. 1992. Comparison of nematode population densities on six summer crops at seven sites in north Florida. Supplement to the Journal of Nematology 24:699–706.

7. Rhoades, H. L., and R. B. Forbes. 1986. Effects of fallow, cover crops, organic mulches, and fenamiphos on nematode populations, soil nutrients, and subsequent crop growth. Nematropica 16:141–151.

8. Rodríguez-Kabána, R., P. S. King, D. G. Robertson, and C. F. Weaver. 1988. Potential of crops uncommon to Alabama for management of root-knot and soybean cyst nematodes. Supplement to the Journal of Nematology 2:116–120.

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

10. Rodríguez-Kábana, R., D. G. Robertson, C. F. Weaver, and L. Wells. 1991. Rotation of bahiagrass and castorbean with peanut for the management of *Meloidogyne arenaria*. Supplement to the Journal of Nematology 23:658–661.

11. Rodríguez-Kábana, R., D. G. Robertson, L. Wells, P. S. King, and C. F. Weaver. 1989. Crops uncommon to Alabama for the management of *Meloidogyne arenaria* in peanut. Supplement to the Journal of Nematology 21:712–716.

12. Rodríguez-Kábana, R., D. G. Robertson, L. Wells, C. F. Weaver, and P. S. King. 1991. Cotton as a

rotation crop for the management of *Meloidogyne arenaria* and *Sclerotium rolfsii* in peanut. Supplement to the Journal of Nematology 23:652–657.

13. 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.

14. Simone, G., and T. Kucharek. 1993. 1993 Florida plant disease control guide. Volume 2: Vegetable crops. Florida Cooperative Extension Service, University of Florida, Gainesville.

15. Taylor, A. L., and J. N. Sasser. 1978. Biology, identification and control of root-knot nematodes (*Meloidogyne* species). Raleigh: North Carolina State University Graphics.