Coastal Bermudagrass Rotation and Fallow for Management of Nematodes and Soilborne Fungi on Vegetable Crops[1]

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Abstract: The efficacy of clean fallow, bermudagrass (*Cynodon dactylon*) as a rotational crop, and fenamiphos for control of root-knot nematode (*Meloidogyne incognita* race 1) and soilborne fungi in okra (*Hibiscus esculentus*), snapbean (*Phaseolus vulgaris*), and pepper (*Capsicum annuum*) production was evaluated in field tests from 1993 to 1995. Numbers of *M. incognita* in the soil and root-gall indices were greater on okra than on snapbean or pepper. Application of fenamiphos at 6.7 kg a.i./ha did not suppress numbers of nematodes on any sampling date when compared with untreated plots. The lack of efficacy could be the result of microbial degradation of the nematicide. Application of fenamiphos suppressed root-gall development on okra following fallow and 1-year sod in 1993, but not thereafter. A few galls were observed on roots of snapbean following 2- and 3-year fallow but none following 1-, 2-, and 3-year bermudagrass sod. Population densities of *Pythium aphanidermatum, P. myriotylum,* and *Rhizoctonia solani* in soil after planting vegetables were suppressed by 2- or 3-year sod compared with fallow but were not affected by fenamiphos. Yields of snapbean, pepper, and okra did not differ between fallow and 1-year sod. In the final year of the study, yields of all crops were greater following 3-year sod than following fallow. Application of fenamiphos prior to planting each crop following fallow or sod did not affect yields.

Key words: Bermudagrass, *Capsicum annuum, Cynodon dactylon, Cyperus esculentus,* fenamiphos, *Hibiscus esculentus,* management, *Meloidogyne incognita,* nematicide, nematode, nutsedge, okra, pepper, *Phaseolus vulgaris,* resistance, root-knot nematode, snapbean, sod-based rotation.

Vegetables are grown in Georgia as cash crops for fresh market and processing. In Georgia, vegetable production has increased to about 75,000 hectares (Bertrand, 1996). Nematodes and soilborne diseases cause 5% to 20% yield loss annually in vegetable crops in Georgia (Bertrand, 1996; Johnson et al., 1977, 1992a, 1996; Sumner et al., 1978). Continuous cropping of vegetables is considered a poor production practice because of the increase of soilborne pests and the expected loss in marketable yields (Johnson, 1982; Johnson et al., 1983). Vegetable crops are being integrated with agronomic crop production to more efficiently utilize land, equipment, and other resources. These crop production fields are optimal for the development of many plant-parasitic nematodes and soilborne fungal pests. The integration of crop rotation, resistant cultivars, nonhost crops, and nematicides is often the most economical means of managing nematodes and soilborne fungal pests on vegetable crops.

Okra (*Hibiscus esculentus* L.) is a specialty crop grown for fresh market and processing. Currently, there are no commercially available cultivars of okra that are resistant to root-knot nematodes (Thies, 1996) and *Fusarium oxysporium* Schlecht. f. sp. *vasinfectum* (Atk.) Snyd. & Hans. that induces *Fusarium* wilt complex (Johnson et al., 1977). Resistance in beans has been reported only for *Meloidogyne incognita* (Kofoid & White) Chitwood. A nongalling snapbean (*Phaseolus vulgaris* L. cv. NemaSnap) was developed with a high level of resistance to *M. incognita* (Wyatt et al., 1983). A yellow-fruited hot cayenne pepper (*Capsicum annuum* L. cv. Charleston Hot), released in 1992, is resistant to the four known races of *M. incognita* as well as *M. javanica* (Treub) Chitwood, *M. arenaria* (Neal) Chitwood, and *M. hapla* Chitwood (Dukes and Fery, 1997).

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The use of forage crops in rotation with vegetable crops to manage nematodes and soilborne pathogens is often attractive to vegetable and cattle producers. Among root-knot nematode-resistant forage crops that may be used in rotation with susceptible vegetable crops is improved bermudagrass (*Cynodon dactylon* (L.) Pers. cv. Coastal). Coastal bermudagrass has been grown in the southeastern United States as a forage crop for more than 50 years (Burton, 1943). In addition, it has been used in crop rotations to reduce yield losses caused by root-knot nematodes and soilborne fungi and to improve quality of agronomic and vegetable crops (Burton and Johnson, 1987; Johnson et al., 1995).

Coastal bermudagrass is resistant to *M. incognita* race 1, *M. javanica, M. arenaria,* and *M. hapla* (Bertrand et al., 1985; Good, 1972; Riggs et al., 1962; Johnson et al., 1995). Information on the efficacy of coastal bermudagrass for the management of other nematodes and soilborne fungal pathogens is limited (Good, 1972; Rodríguez-Kábana et al., 1994; Johnson et al., 1995).

The objective of this 3-year study was to determine the effects of coastal bermudagrass sod-based rotations, fallow, and a nematicide on population densities of plant-parasitic nematodes and soilborne fungal pathogens and on yield of three vegetable crops.

Materials and Methods

The experiment was established on Tifton loamy sand (fine, loamy, siliceous, Thermic Plinthic Paleudults: 85% sand, 10% silt, 5% clay; 0.5% organic matter; pH 5.8 to 6.0) infested with *M. incognita* race 1, *Criconemella ornata* (Raski) Loof & De Grisse, *Pratylenchus brachyurus* (Godfrey) Filipjev & Schuurmans Stekhoven, *Helicotylenchus dihystera* (Cobb) Sher, *Paratrichodorus minor* (Colbran) Siddiqi, and soilborne pathogenic fungi.

The experimental design was a split-split plot, randomized complete block with four replications. Sprigs and rhizomes of coastal bermudagrass were planted on 12 test plots (three test plots within each replicate) on 14 May 1992, and four additional test plots (one within each replicate) were clean fallowed. Whole-plots were 5.4 m wide × 15.2 m long and separated by 6.1-m-wide alleys that were disk-harrowed and kept weed-free before planting vegetable crops. The clean fallow treatment within each replication was 16.2 m wide × 15.2 m long, allowing different fallow whole-plot comparisons with a given sod-based rotation each year. Whole-plot treatments were vegetable crops following i) clean fallow, ii) 1-year sod, iii) 2-year sod, and iv) 3-year sod. The clean fallow plots were disk-harrowed and kept weed-free before planting vegetable crops. Subplots (5.4 m wide × 7.6 m long) were treated with fenamiphos 3 SC broadcast at 6.7 kg a.i./ha and incorporated 6 to 8 cm deep with a tractor-powered rototiller, or untreated. The rototiller was equipped with shields to prevent soil movement and potential contamination between plots. Okra cv. Clemson Spineless (seeds 15 cm apart), snapbean cv. Nema-Snap (seeds 15 cm apart), and pepper cv. Charleston Hot (transplants 30 cm apart) were planted in two rows spaced 91 cm apart in different beds on 6 May 1993, 26 May 1994, and 16 May 1995. Okra and snapbean were direct-seeded 1.5 to 2.0 cm deep, and pepper seedlings were grown in a greenhouse and transplanted into the field plots.

Trifluralin was applied (0.56 kg a.i./ha) preplant to pepper, and metolachlor was applied (2.24 kg a.i./ha) preplant to snapbean and okra for weed control. Both herbicides were sprayed on the soil surface and incorporated 5 to 7 cm deep with a tractor-mounted rototiller. Insects and foliar fungal diseases were controlled as needed in all vegetable plots with pesticides recommended for the area.

The bermudagrass was cut, left on the plots to dry, and burned on all plots in March each year to reduce crop residue and enhance soil and seedbed preparation. Fallow and 1-year sod plots were disc-harrowed and plowed 15 to 25 cm deep with a moldboard plow on 5 May 1993. Fallow and 2-year sod plots were prepared similarly on 26 May 1994, and fallow and 3-year sod plots were prepared similarly on 9 May 1995. All plots received 896 kg/ha 5-10-15 fertilizer (nitrogen 5% [nitrate nitrogen 1.0%, ammoniacal nitrogen 4.0%], phosphoric acid 10%, soluble potash 15%, calcium 9%, sulfur 7%) broadcast after tillage each year. The fertilizer was incorporated 5 to 10 cm deep with a tractor-mounted rototiller immediately before planting the vegetable crops each year.

Twenty soil cores, 2.5 cm diam. × 25 cm deep, were collected monthly from two rows of each vegetable crop from planting until harvest each year. Soil cores from each plot were mixed, and nematodes were extracted from a 150-cm^3 subsample by centrifugal flotation (Jenkins, 1964). Soil samples collected after planting also were assayed for *Pythium* spp. with P_5ARP medium (Jeffers and Martin, 1986), and *Rhizoctonia solani* Kühn anastomosis group AG-4 was assayed with tannic acid-benomyl medium (Sumner and Bell, 1982), with a multiple-pellet soil sampler (Henis et al., 1978). Postemergence damping-off and stand counts within a marked 2-m segment of row in snapbean and 7.6 m of row in okra and pepper were determined at various intervals each year.

Snapbeans were harvested by hand on 24 June 1993, 15 July 1994, and 17 July 1995; peppers were harvested on 19 August 1993, 12 September 1994, and 17 July 1995. Pods of okra were harvested by hand three times each week from 20 June to 25 August 1993, 15 August to 2 September 1994, and 18 July to 1 September 1995. Marketable fruits of all crops were weighed.

After the final harvest of each crop, 20 plants were dug from each plot and rated for root galling by *M. incognita* on a 1-to-5 scale: 1 = 0%, 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, and 5 = 76% to 100% of roots galled (Barker et al., 1986).

Due to its recent establishment, bermudagrass from 1-year sod was cut for hay only once on 3 May 1993. Bermudagrass from 2-year and 3-year sod was cut for hay on 10 June and 6 August 1993 and on 23 May 1994. The hay was cut and left on the plots, dried to approximately 16% moisture, and weighed. After all crops were harvested each year, the number of yellow nutsedge (*Cyperus esculentus* L.) plants per m^2 in each plot was recorded. All data were analyzed with ANOVA followed by mean separation with LSD (SAS Institute, Cary, NC). Only significant ($P = 0.05$) differences are discussed unless stated otherwise.

Results

Meloidogyne incognita race 1 was the most prevalent plant-parasitic nematode encountered. Numbers of *M. incognita* second-stage juveniles (J2) ranged from 0 to 119/150 cm^3 soil in all plots sampled in May, June, and July each year and did not differ among crops or between rotations or nematicide treatments. Population densities of J2 increased to their highest numbers in plots of all crops in August each year (Table 1). Numbers of *M. incognita* J2 were highest in plots of okra and low to moderate in plots of snapbean and pepper. Generally, numbers of J2 were lower in snapbean and pepper following 2-year and 3-year sod rotations than in fallow. The application of fenamiphos did not suppress numbers of nematode species on any sampling date when compared with untreated plots.

Root-gall indices on okra were consistently greater than those on snapbean and pepper in all plots (Table 1). Application of fenamiphos suppressed root-gall development on okra following fallow and 1-year sod in 1993, but not thereafter when compared with the untreated control. Root-gall indices of okra were not different between fallow and 1-year or 2-year sod, but were lower following 3-year sod than fallow. A few galls were observed on roots of snapbean following 2- and 3-year fallow but none following 1-year, 2-year, or 3-year sod. No galls were observed on roots of pepper following fallow or sod rotations. Root-gall indices of snapbean and pepper were not affected by fenamiphos or fallow vs. sod rotation treatments.

Numbers of *C. ornata, P. brachyurus, P. minor,* and *H. dihystera* ranged from 0 to 315/150 cm^3 soil and were not affected by fenamiphos or fallow vs. sod rotation treatments.

Pathogenic fungi isolated from soil

TABLE 1. Numbers of *Meloidogyne incognita* second-stage juveniles (J2) and root-gall indices of vegetable crops grown in fenamiphos-treated and untreated plots following fallow and coastal bermudagrass sod rotations.

Year/crop	Fenamiphos[a]	J2 per 150 cm^3 soil, August[b]		Root-gall indices[c]	
1993		Fallow	1-year sod	Fallow	1-year sod
Okra	+	114 a	31 a	1.90 b	1.70 b
	–	119 a	43 a	2.24 a	2.08 a
Snapbean	+	0 b	0 a	1.00 c	1.00 c
	–	0 b	4 a	1.00 c	1.00 c
Pepper	+	0 b	8 a	1.00 c	1.00 c
	–	0 b	1 a	1.00 c	1.00 c
1994		Fallow	2-year sod	Fallow	2-year sod
Okra	+	501 aY	1,050 aX	2.31 a	2.50 a
	–	728 a	732 a	2.29 a	2.53 a
Snapbean	+	253 bX	10 bY	1.25 b	1.00 b
	–	45 c	86 b	1.35 b	1.00 b
Pepper	+	201 bX	43 bY	1.00 b	1.00 b
	–	52 c	5 b	1.00 b	1.00 b
1995		Fallow	3-year sod	Fallow	3-year sod
Okra	+	1,008 a	1,210 a	3.30 aX	2.60 aY
	–	1,430 a	1,314 a	3.81 aX	2.65 aY
Snapbean	+	568 bX	20 bY	1.28 b	1.00 b
	–	93 c	173 b	1.18 b	1.00 b
Pepper	+	453 bX	88 bY	1.00 b	1.00 b
	–	105 c	10 b	1.00 b	1.00 b

Data are means of four replications.
[a] + = Fenamiphos 3 SC applied broadcast at 6.7 kg a.i./ha before planting and incorporated into the top 6- to 8-cm soil layer with a tractor-mounted rototiller; – = untreated.
[b] Means in columns for a given rotation followed by the same letter are not different ($P = 0.05$) according to the Waller-Duncan k-ratio *t*-test. Paired means in rows with letters X and Y differ ($P = 0.05$) according to a Least Significant Difference test.
[c] 1 = 0%, 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, 5 = 76% to 100% of roots galled.

samples collected in May and September each year were *Pythium* spp. and *Rhizoctonia solani* AG-4. The number of *Pythium* spp. colony-forming units (cfu) per gram of soil was higher in fallow plots than in 2-year sod (126 vs. 88 cfu) on 16 September 1994 and 3-year sod (142 vs. 70 cfu) on 12 May 1995. Numbers of *Pythium* spp. cfu were not affected by cropping systems on other sampling dates and were not affected by fenamiphos treatment on any sampling date. *Rhizoctonia solani* AG-4 was not detected in soil samples collected in 1993, but numbers of cfu per 100 g oven-dry soil were higher in fallow than in 2-year sod plots (26 vs. 0.6 cfu) on 16 May 1994 and 3-year sod plots (5.3 vs. 0 cfu) on 12 May 1995. Numbers of *R. solani* cfu were not affected by fenamiphos treatment.

The range of percent postemergence damping-off 29 days after planting in 1993 was greater in okra (4% to 18%) than snapbean (2% to 9%) and pepper (4% to 7%). In okra, percent postemergence damping-off was greater in untreated plots than fenamiphos-treated plots (18% vs. 4%). The primary cause of plant death and low okra yield was wilt induced by *F. oxysporum* f. sp. *vasinfectum* and *M. incognita*. Generally, percent postemergence damping-off across all crops in 1994 and 1995 was not affected by cropping system or fenamiphos treatment. One exception was in okra where 37% of early plant death, primarily from *Fusarium* wilt, occurred in fallow plots compared with 20% in 3-year sod 58 days after planting in 1995.

Good stands of snapbean were obtained each year in all plots. The primary pathogenic fungi isolated from lesions on roots and hypocotyls of snapbean were *Pythium aphanidermatum* Edson (Fitzp.), *P. myriotylum* Drechs, *Sclerotium rolfsii* Sacc., *R. solani* AG-4, and *Marasmius* spp. Acceptable initial stands of okra and pepper were obtained each year except 1994. During June 1994, the field plots received 21.8 cm rainfall during a hurricane compared to 5.6 cm in June 1993 and 9.4 cm in June 1995. Due to poor stands, okra was replanted on 15 June 1994.

Yields of snapbean, pepper, and okra in metric tons per hectare did not differ between fallow and 1-year sod (Table 2). During the second year of the study, yields of pepper and okra were greater following 2-year sod than fallow, but snapbean yield was not affected. In the final year, yields of all crops were greater following a 3-year sod rather than fallow. The application of fenamiphos prior to planting each crop following fallow or sod did not significantly affect yields. The total yields (mt/ha) of bermudagrass hay were 4.41, 50.32, and 50.11 for 1-year sod, 2-year sod, and 3-year sod, respectively.

Numbers of yellow nutsedge plants were similar in snapbean and okra, but increased in pepper following fallow each year (Table 2). Yellow nutsedge population densities declined in all crops following 2- and 3-year sod. The application of fenamiphos did not affect population densities of yellow nutsedge.

Discussion

Considerable variation in *M. incognita* population densities occurred among years. The cause of the greater numbers of *M. incognita* J2 extracted from soil in fenamiphos-treated snapbean and pepper plots compared to untreated plots following fallow in both 1994 and 1995 is not fully understood. Root-knot nematode population densities generally peaked near harvest of each crop, and, at that time, numbers in fenamiphos-treated plots of snapbean and pepper were greater than those in untreated plots. Similar results were reported from other studies (Johnson et al., 1996). The application of fenamiphos to soil affects microbial populations (Ou, 1991) and may affect population

TABLE 2. Yield of vegetable crops and density of yellow nutsedge plants as influenced by fenamiphos following fallow and coastal bermudagrass sod rotations.

Year/crop	Fenamiphos[a]	Yield (tons/ha)[b]		Number yellow nutsedge plants per m^2	
1993		Fallow	1-year sod	Fallow	1-year sod
Okra	+	18.39 a	11.32 a	11 a	13 b
	−	17.42 a	12.42 a	8 a	10 b
Snapbean	+	2.85 a	1.23 a	10 a	7 b
	−	2.58 a	1.86 a	11 a	7 b
Pepper	+	7.40 a	3.07 a	9 aY	59 aX
	−	7.09 a	3.63 a	10 aY	63 aX
1994		Fallow	2-year sod	Fallow	2-year sod
Okra	+	0.12 aY	1.38 aX	9 a	2 a
	−	0.37 aY	1.38 aX	10 a	2 a
Snapbean	+	10.53 a	7.12 a	8 a	2 a
	−	8.80 a	8.29 a	10 a	1 a
Pepper	+	0.04 aY	0.65 aX	26 aX	16 aY
	−	0.11 aY	0.76 aX	30 aX	13 aY
1995		Fallow	3-year sod	Fallow	3-year sod
Okra	+	3.48 aY	17.00 aX	10 a	0 a
	−	3.51 aY	15.28 aX	11 a	0 a
Snapbean	+	5.79 aY	9.98 aX	9 a	0 a
	−	5.29 aY	10.19 aX	11 a	0 a
Pepper	+	4.66 aY	9.96 aX	61 aX	1 aY
	−	4.24 aY	10.65 aX	52 aX	1 aY

Data are means of four replications.

[a] + = Fenamiphos 3 SC applied broadcast at 6.7 kg a.i./ha and incorporated 6 to 8 cm deep with a tractor-mounted rototiller prior to planting each crop; − = untreated.

[b] Means in columns for a given rotation followed by the same letter are not different ($P = 0.05$) according to the Waller-Duncan k-ratio *t*-test. Paired means in rows with letters X and Y differ ($P = 0.05$) according to a Least Significant Difference test.

densities of *M. incognita* antagonists. More research is needed to prove this hypothesis.

Numbers of *M. incognita* J2 in the soil and root-gall indices increased most on okra, were intermediate on snapbean, and least on pepper each year following fallow and coastal bermudagrass. These results agree with reports on the susceptibility of okra as a host for *M. incognita* (Johnson et al., 1977, 1995; Thies, 1996). The few galls and mature females with eggs that occurred on roots of snapbean in 1994 and 1995 indicate that cultivar NemaSnap is resistant but not immune to *M. incognita* as reported by Wyatt et al. (1980, 1983). The lack of galls on roots of pepper agrees with other reports (Dukes and Fery, 1997) that demonstrated cultivar Charleston Hot to be highly resistant to root-knot nematodes. Severe stunting and yield losses occur in nearly all other pepper cultivars when grown in root-knot nematode-infested soil (Johnson and Fassuliotis, 1984).

Although coastal bermudagrass is resistant to *M. incognita* race 1 (Bertrand et al., 1985; Good, 1972; Riggs et al., 1962), population densities were maintained in sod plots throughout the experiment. Numbers of *M. incognita* J2 in the soil in August and root-gall indices of all crops, except okra in 1995, were similar when following fallow and bermudagrass sod. One explanation for the number of *M. incognita* J2 in sod plots is that the nematode feeds and reproduces on crab grass (*Digitaria sanguinalis* L.), goose grass (*Eleusine indica* L.), and yellow nutsedge that were present in sod plots and are common weed problems in newly established coastal bermudagrass (A. W. Johnson, unpubl.).

Meloidogyne incognita survives as J2 and eggs in fallow plots for several weeks in the absence of a host in southern Georgia (Johnson and Motsinger, 1990; Johnson et al., 1992a, 1992b, 1995). Also, fields infested with this pathogen in Georgia and planted to susceptible crops following 3-year bermudagrass sod resulted in more effective *M. incognita* management than shorter rotations (Johnson et al., 1995).

Ectoparasitic nematodes did not increase to large numbers on 2- and 3-year bermudagrass sod, which indicates that coastal bermudagrass is not a good host for these parasites. Similar results were reported with these nematode species in other studies (Johnson et al., 1995).

Pythium spp. and *R. solani* AG-4 were frequently isolated from the soil, but population densities generally were not affected by cropping system or fenamiphos treatment. Both pathogens caused more postemergence damping-off in okra than in snapbean and pepper. These results agree with earlier reports in which *Pythium* spp. and *R. solani* were commonly found in the soil and caused seedling decline in okra and other crops (Johnson et al., 1977, 1995).

The extremely low yields of pepper and okra in 1994 were caused by cool, wet soil conditions following a hurricane and poor-quality pepper transplants. Rotations with coastal bermudagrass were beneficial for okra and pepper yields following 2- and 3-year sod and for snapbean yield following 3-year sod. The yield increase was attributed to lower numbers of nematodes in the soil and lower root-gall indices of plants following 2- and 3-year bermudagrass sod, and a low incidence of *Fusarium* wilt in okra (Johnson et al., 1977).

Population densities of yellow nutsedge decline in coastal bermudagrass plots, primarily from competition. Numbers of nutsedge plants increased in pepper but not in snapbean or okra following fallow because trifluralin is not as effective as metolochlor in controlling yellow nutsedge. These results support those reported by Johnson and Mullinix (1997).

Rotations with coastal bermudagrass have been beneficial for managing root-knot nematodes on many crops (Johnson et al., 1995). Our data indicate no yield advantage from the use of fenamiphos on *M. incognita*-resistant crops following coastal bermudagrass sod. The benefits from using this type of crop production system includes reduced use of nematicides. An additional benefit is the value of hay yields, which range up to 50.3 tons/ha each year.

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