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# Rotations with Coastal Bermudagrass and Fallow for Management of *Meloidogyne incognita* and Soilborne Fungi on Vegetable Crops[1]

A. W. Johnson,[2] G. W. Burton,[2] J. P. Wilson,[2] and A. M. Golden[3]

*Abstract:* The efficacy of fallow and coastal bermudagrass (*Cynodon dactylon*) as a rotation crop for control of root-knot nematode (*Meloidogyne incognita* race 1) and soilborne fungi in okra (*Hibiscus esculentus* cv. Emerald), squash (*Cucurbita pepo* cv. Dixie Hybrid), and sweet corn (*Zea mays* cv. Merit) was evaluated in a 3-year field trial. Numbers of *M. incognita* in the soil and root-gall indices were greater on okra and squash than sweet corn and declined over the years on vegetable crops following fallow and coastal bermudagrass sod. *Fusarium oxysporum* and *Pythium* spp. were isolated most frequently from soil and dying okra plants. Numbers of colony-forming units of soilborne fungi generally declined as the number of years in sod increased, but were not affected by coastal bermudagrass sod. Yields of okra following 2-year and 3-year sod and squash following 2-year sod were greater than those following fallow. Yield of sweet corn was not different following fallow and coastal bermudagrass sod.

*Key words:* coastal bermudagrass, *Cucurbita pepo, Cynodon dactylon,* fallow, *Hibiscus esculentus,* management, *Meloidogyne incognita,* nematode, okra, root-knot, rotation, squash, sweet corn, *Zea mays.*

Root-knot, caused by *Meloidogyne incognita,* and soilborne fungi are among the principal yield-limiting diseases of vegetable crops (19,21,26). Damage can be so severe that crop failure is common in fields with high population densities of the pathogens. Currently, there are no commercially available cultivars of squash (*Cucurbita pepo*), okra (*Hibiscus esculentus*), or sweet corn (*Zea mays*) resistant to these diseases. Traditionally, control of *M. incognita* and soilborne diseases has been based on the use of broad-spectrum chemicals; however, the number of nematicides and fungicides available to growers is limited and the cost of these pesticides is high (13). A renewed interest in use of cultural and biological control of these pests has developed.

The use of forage crops in rotation with vegetable crops to manage disease problems is especially attractive to growers with cattle operations. Among root-knot nematode-resistant crops that may be used in rotation with susceptible vegetable crops is the perennial bermudagrass (*Cynodon dactylon*) cv. Coastal. Coastal bermudagrass, released in 1943 (3), has been grown in the southeastern United States as a forage crop. In addition, it has been used in crop rotations to reduce damage caused by root-knot nematodes and improve yield and quality of 'Kobe' lespedeza (*Lespedeza striata*) (5); tobacco (*Nicotiana tabacum*) (6); tomato (*Lycopersicon esculentum*), cabbage (*Nicotiana tabacum*) (6); tomato (*Lycopersicon esculentum*), cabbage (*Brassica oleracea* var. *capitata*), onion (*Allium cepa*), and pepper (*Capsicum frutescens*) transplants (5); snapbean (*Phaseolus vulgaris*), cucumber (*Cucumis sativus*), and sweet potato (*Ipomea botatas*) (27); corn (*Zea mays*) (4); and peanut (*Arachis hypogaea*). (23).

Coastal bermudagrass is resistant to *Meloidogyne incognita* race 1, *M. javanica, M. hapla,* and *M. arenaria* (1,9,22). Information on the relative efficacy of coastal bermudagrass for the management of soilborne fungal pathogens is limited (9,23).

The objective of this 3-year study was to determine the effects of coastal bermuda-

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[1] Cooperative investigations of the U.S. Department of Agriculture, Agricultural Research Service and the University of Georgia College of Agricultural and Environmental Sciences, Coastal Plain Station, Tifton, GA.

[2] Supervisory Research Nematologist, Supervisory Research Geneticist, and Research Plant Pathologist, USDA ARS, Coastal Plain Experiment Station, Tifton, GA 31793.

[3] Research Nematologist/Collaborator, Nematology Laboratory, Plant Sciences Institute, USDA ARS, Beltsville, MD 20705.

grass sod-base rotations and fallow on population densities of soilborne fungi and *M. incognita* race 1 and 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 6.0) infested with *M. incognita* race 1, *Criconemalla ornata, Paratrichodorus minor, Helicotylenchus dihystera, Pratylenchus* spp., and soilborne fungi. The land was previously planted to cowpea (*Vigna unguiculata*) cv. Pinkeye purplehull as a summer cover crop and hairy vetch (*Vicia villosa*) as a winter cover crop.

Test plots, each 1.8 m wide × 15.2 m long, were maintained in the same location and managed similarly for 3 years. Sprigs and rhizomes of coastal bermudagrass were planted on 12 test plots (three test plots within each replicate) on 12 May 1989, and the fourth test plot in each replicate was clean fallow. Treatments were replicated four times in a split-plot-randomized-complete-block design. Whole-plot treatments were i) fallow, ii) 1-year sod, iii) 2-year sod, and iv) 3-year sod. Subplots were squash (*Cucurbita pepo* cv. Dixie Hybrid) planted 30 cm apart, okra (*Hibiscus esculentus* cv. Emerald) planted 15 cm apart, and sweet corn (*Zea mays* cv. Merit) planted 15 cm apart in rows spaced 91 cm apart in different beds 4 April 1990, 8 April 1991, and 2 April 1992. Weeds, insects, and foliar fungal diseases were controlled as needed in all plots with pesticides recommended for the area and cultivation.

The bermudagrass was cut, left on the plots to dry, and burned on all plots on 6 March 1990, 25 February 1991, and 23 March 1992. Fallow and 1-year sod plots were disc-harrowed and plowed 15–25 cm deep with a modified moldboard plow on 6 March 1990. Fallow and 2-year sod plots were prepared similarly on 25 February 1991, and fallow and 3-year sod plots were prepared similarly on 23 March 1992. All plots received 560 kg/ha 5–10–15 fertilizer (nitrogen 5%, phosphoric acid 10%, soluble potash 15%, calcium 9%, and sulfur 7%) plus 336 kg/ha ammonium nitrate (34% N) broadcast after tillage in 1990 and 896 kg/ha 5–10–15 fertilizer broadcast after tillage in 1991 and 1992. The fertilizer was incorporated 5–10 cm deep in the soil with a tractor-mounted rototiller immediately before planting the vegetable crops each year.

Twenty soil cores, 2.5 cm d × 25 cm deep, were collected monthly from the rows of all crops from planting until harvest each year. Soil cores from each plot were mixed and nematodes were assayed from a 150-$cm^3$ subsample by centrifugal flotation (11).

Soil samples collected on 9 August 1990 were evaluated for populations of basidiomycete fungi and *Fusarium* species. For basidiomycete evaluations, soil samples were sieved (0.64 cm) to remove pebbles and plated onto each of 10 plates of tannic acid-benomyl agar (TABA) (25) with a multiple-pellet soil sampler (10). Plates were incubated in the dark for 3 days at 24 C, and isolations were made from areas of brown discoloration of the medium. Isolated fungi were transferred to V8 agar (200 ml V8 juice, 13 ml 1 N KOH, 25 g agar, plus enough water to make 1 liter) or potato dextrose agar (PDA) for identification. For *Fusarium* evaluations, 5 g soil were diluted 1:400 in 0.3% water agar, and 1 ml of the suspension was plated onto each of five plates of modified pentachloronitrobenzene (PCNB) medium (20). *Fusarium* colonies were transferred to PDA for identification. Isolation frequencies and percentage dry soil weights were used to calculate colony-forming units (cfu) per gram dry soil.

In 1991, isolations were made from diseased vegetable seedlings on 24 April, 6 May, and 28 May. Only okra and sweet corn seedlings appeared to be diseased, and isolations were made from these crops. Up to five dead or dying seedlings per plot were collected and washed under running tap water. A 2-cm section of diseased stem and root tissue was surface disinfested for 1 minute in 0.5% NaOCl. Plant tissue was plated on V8 agar and incubated under continuous fluorescent lighting at 24 C. Fungi growing from plant tissue were transferred to either PDA or V8 agar for purification and identification.

In 1992, soil samples, taken at planting and after harvesting vegetable crops, were assayed for *Fusarium* spp. as described for 1990, except 1-ml soil suspensions were plated onto each of 10 plates of PCNB agar. The average number of colonies isolated per plate was used to calculate numbers of cfu per g dry soil.

Heights of 20 randomly selected plants per plot were measured on 29 May and 21 June 1991. Stand counts within a marked 3.04-m section of each plot were determined on 24 April, 2 May, 10 May, 17 May, 31 May, 14 June, and 30 July. Heights of up to 20 randomly selected plants from each vegetable plot were measured on 10 June 1992. An additional measurement of okra plants was recorded 6 August 1992. Stand counts from all plots were determined on 22 and 29 April and 8, 15, and 21 May 1992 except for squash or sweet corn, which were recorded on 29 June 1992. Stand counts of okra were recorded on 28 May; 4, 10, 17, and 25 June; and 8, 15, 22, and 28 July 1992.

Fruit of squash was harvested by hand twice each week from 17 May to 18 June 1990, 3 June to 28 June 1991, and 20 May to 24 June 1992; counted; separated into marketable grades; and weighed. Pods of okra were harvested by hand twice each week from 23 July to 9 August 1990, 12 June to 29 July 1991, 26 June to 3 August 1992, and weighed. Sweet corn was hand-harvested, counted, weighed, shucked, ear length measured, and percentage ear fill calculated on 18 June 1990, 17 June 1991, and 22 June 1992.

After the final harvest of each crop, 20 plants were dug from each plot and rated on the following scale for percentage roots galled by *M. incognita:* 1 = no galling, 2—1–25, 3 = 26–50, 4 = 51–75, and 5 = 76–100.

Due to recent establishment, bermudagrass from 1-year sod was not cut for hay. The bermudagrass from 2-year and 3-year sod was cut for hay four times in 1990 (15 May, 20 June, 14 August, and 14 November), dried to approximately 16% moisture, and weighed. The bermudagrass from 3-year sod was cut for hay three times in 1991 (13 May, 9 July, and 5 September).

In 1990, data from the fallow plots and those following 1-year sod plots with vegetable subplots were analyzed to determine if a single year of sod-base rotation affected the parameters measured. In 1992, plant stand declines were summarized by linear regression. Prior to analysis of variance, cfu were transformed to square root (cfu + 1) for at-planting and log (cfu + 1) for at-harvest soil samples to reduce the association between means and variances. All other data were subjected to analysis of variance for split-plot designs (24). The Waller-Duncan k ratio *t*-test was used for mean separations (28). Only significant ($P \leq 0.05$) differences are discussed unless stated otherwise.

## RESULTS

*Meloidogyne incognita* race 1 was the most prevalent plant-parasitic nematode in the soil. Numbers of *M. incognita* J2 in soil ranged from 0–91/150 $cm^3$ in all plots in April and May each year and were not different between fallow and sod rotations. Numbers of *M. incognita* J2 increased to the highest numbers on vegetable crops in June each year (Table 1). Numbers of *M. incognita* J2 were greater in plots of squash than okra and sweet corn plots on 26 June 1990 following 1-year fallow, but were not different among vegetable crops following 1-year sod. Numbers of *M. incognita* J2 in plots of okra following fallow and 2-year sod were greater than those in plots of squash. The *M. incognita* J2 population densities were low in all plots on 29 June 1992 following 3-year fallow and 3-year sod and were not different between treatments or among crops. Squash supported the largest numbers of *M. incognita* J2 followed by okra and sweet corn. The lowest

TABLE 1. Number of *Meloidogyne incognita* second-stage juveniles (J2) in soil and root-gall indices of vegetable crops grown in fallow and coastal bermudagrass sod rotations.

| Year/crop | Number J2 per 150 $cm^3$ soil[a] | | Root-gall indices | |
|---|---|---|---|---|
| 1990 | Fallow | 1-year sod | Fallow | 1-year sod |
| Okra | 388 b | 800 a | 4.50 a | 3.90 a |
| Sweet corn | 403 b | 148 a | 1.60 b | 1.38 b |
| Squash | 3,343 a | 1,933 a | 4.85 a | 4.03 a |
| 1991 | Fallow | 2-year sod | Fallow | 2-year sod |
| Okra | 269 a | 2,788 a | 3.58 a | 2.83 a |
| Sweet corn | 85 ab | 528 ab | 1.00 b | 1.00 b |
| Squash | 10 b | 243 b | 3.35 a | 2.43 a |
| 1992 | Fallow | 3-year sod | Fallow | 3-year sod |
| Okra | 6 a | 0 a | 2.30 b | 1.53 ab |
| Sweet corn | 50 a | 6 a | 1.00 c | 1.00 b |
| Squash | 75 a | 6 a | 3.38 a | 1.90 a |
| Crop means across treatments | | | | |
| Okra | | 709 b | | 3.10 a |
| Sweet corn | | 204 c | | 1.16 b |
| Squash | | 935 a | | 3.32 a |
| Treatment means across crops | | | | |
| Fallow | | 515 b | | 2.84 b |
| 1-year sod | | 960 a | | 3.10 a |
| 2-year sod | | 1,186 a | | 2.08 c |
| 3-year sod | | 4 c | | 1.48 c |

Data are means of four replications. Means in columns followed by the same letter are not different ($P = 0.05$) according to Waller-Duncan k ratio *t*-test.

[a] Soil samples collected in June each year.

numbers of *M. incognita* J2 occurred in plots following 3-year sod, were intermediate in those following fallow, and were highest in those following 1-year and 2-year sod.

The root-gall indices of okra and squash were consistently greater than those of sweet corn in all plots (Table 1). A few galls were observed on roots of sweet corn following 1-year fallow and 1-year sod, but none thereafter. The root-gall indices of squash and okra were numerically lower following sod than fallow, but differences were not significant. Root-gall indices of vegetable crops were greatest following 1-year sod, intermediate following fallow, and lowest following 2-year and 3-year sod.

Numbers of *C. ornata, P. minor, H. dihystera,* and *Pratylenchus* spp. ranged from 0–385/150 $cm^3$ soil and were not different between treatments or among crops ($P = 0.05$).

Fungi isolated from soil samples in 1990 included *Laetisaria arvalis, Rhizoctonia solani, R. zeae, Fusarium oxysporum, F. chlamydosporum, F. equiseti, F. moniliforme, F. solani,* and *F. semitectum.* Analysis of variance did not indicate any differences in isolation of these fungi from plots following fallow and 1-year sod. The percentage of *F. oxysporum* from dying okra seedlings were 60 (fallow) and 27 (2-year sod) in 1991 and 44 (fallow) and 43 (3-year sod) in 1992, but not different between treatments ($P = 0.05$). *Pythium* spp. were also isolated from okra seedlings in all treatments. The percentages of *Pythium* spp. from okra seedlings ranged from 10–18 and were not affected by treatments on the first two samplings dates 24 April, 6 May 1991, and 14 and 21 May 1992. The remaining percentages of isolations from okra seedlings were less than 15 for the other fungi and were not affected by treatments. No fungi commonly considered pathogenic were isolated from corn seedlings in 1991 or 1992.

In 1992, numbers of cfu of *F. oxysporum* were lower in most plots at planting and at harvest following 3-year sod than fallow (Table 2). Numbers of *F. oxysporum* cfu per gram of dry soil increased from planting to harvest in most okra and squash plots and declined in most plots of sweet corn. More cfu of *F. oxysporum* occurred on okra followed by squash and sweet corn. Numbers of *F. oxysporum* cfu per gram of dry soil generally declined as the number of years in sod increased.

Good stands of squash and sweet corn were obtained each year in all plots. Acceptable initial stands of okra were obtained each year except 1992. Due to poor stands, okra was replanted on 24 April 1992. After replanting, okra stands in all plots declined throughout the harvest season (Fig. 1). Linear regression analysis indicated that stands of okra declined at a slower rate and remained the highest during the harvest period in plots that followed 3-year sod. For all treatments, the relationships between stand of okra and days after planting were better fit by quadratic than linear regression. Regression analysis indicated that during the harvest periods of 26 June–9 August, initial stands of okra decreased by 58%, 53%, 38%, and 8% following fallow, 1-year sod, 2-year sod, and 3-year sod, respectively.

Okra plants following 2-year and 3-year sod were consistently taller than those following fallow (Table 3). Plant heights of squash were not affected by 2-year sod, but were taller following fallow than 3-year sod. Height of sweet corn plants was not different between fallow and 3-year sod.

Yields of okra in metric tons per hectare following 2-year and 3-year sod and squash following 2-year sod were greater than those following fallow (Table 4). The number and weight of sweet corn ears and the number of squash per hectare were not different between fallow and sod plots for any year. The weight of squash following 2-year sod was greater than those following fallow. The mean ear length of sweet corn ranged from 20–22 cm, and percentage fill ranged from 84–86% each year; neither differed between fallow and sod treatments.

The total yield of bermudagrass hay was 19,193 kg/ha from 2-year sod and 22,633 kg/ha from 3-year sod in 1990 and 11,058 kg/ha from 3-year sod in 1991.

## Discussion

Numbers of *M. incognita* J2 in the soil and root-gall indices of okra, sweet corn, and squash declined each year following fallow and coastal bermudagrass. Bermudagrass did not support *M. incognita*, whereas okra and squash supported high population densities. These results agree with reports on the resistance of coastal bermudagrass (1,5,22) and the susceptibility of okra, squash, and sweet corn as hosts for *M. incognita* (12,16–18). The few galls and mature females with eggs that occurred on roots of sweet corn in 1990 and

TABLE 2. Colony-forming units of *Fusarium oxysporum* per gram dry soil from plots at planting and at harvest of vegetable crops in fallow and coastal bermudagrass sod-vegetable rotations, 1992.

| | Okra | | Squash | | Sweet corn | |
|---|---|---|---|---|---|---|
| Rotation | Planting | Harvest | Planting | Harvest | Planting | Harvest |
| Fallow[a] | 1,568 a | 1,445 a | 638 a | 967 a | 388 a | 560 a |
| 1-year sod | 354 b | 772 ab | 488 ab | 389 ab | 886 a | 372 ab |
| 2-year sod | 258 b | 545 ab | 184 b | 471 ab | 434 a | 269 bc |
| 3-year sod | 161 b | 500 b | 172 b | 355 b | 259 a | 134 c |

Data are means of four replications. Mean separations were based on square root (cfu + 1) transformation at planting and log (cfu + 1) transformation at harvest. Means in each column followed by the same letter are not different ($P = 0.05$) according to Waller-Duncan k ratio *t*-test.

[a] Plots were clean fallow 2 years before planting vegetable crops.

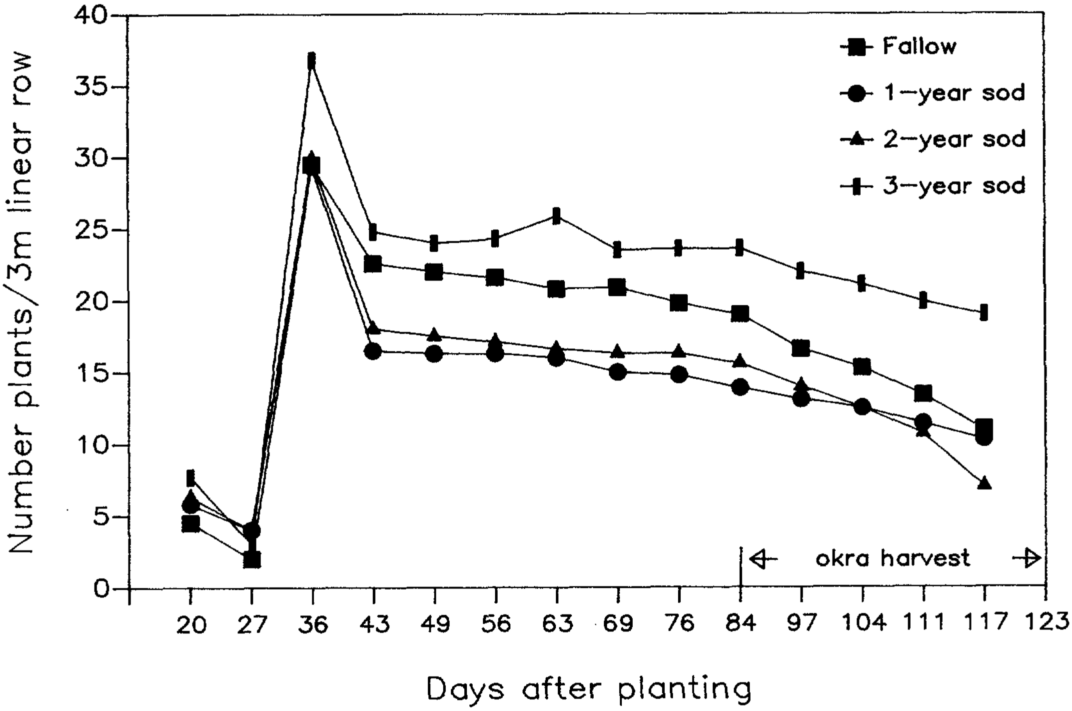


FIG. 1. Stands of okra following fallow, 1-year, 2-year, and 3-year coastal bermudagrass sod.

1991 indicate that *M. incognita* infects sweet corn and could become a potential problem in short-term cropping systems with *Meloidogyne*-susceptible crops.

Although coastal bermudagrass was not a good host for *M. incognita,* population densities were maintained during the first 2 years of the experiment. The numbers of *M. incognita* J2 in the soil on bermudagrass were similar to those in fallow plots.

TABLE 3. Mean heights (cm) of vegetable plants following fallow and coastal bermudagrass sod 55 days after planting.

| Year/crop | Treatment | |
|---|---|---|
| 1991 | Fallow | 2-year sod |
| Okra | 26 a | 62 b |
| Sweet corn | 152 a | 145 b |
| Squash | 30 a | 34 a |
| 1992 | Fallow | 3-year sod |
| Okra | 19 b | 25 a |
| Sweet corn | 178 a | 185 a |
| Squash | 50 a | 46 b |

Data are means of four replications. Means in rows followed by the same letter are not different ($P = 0.05$) according to LSD analysis.

*Meloidogyne incognita* survives as J2 and eggs in fallow plots for several weeks in the absence of a host (12,14,15). On land in North Carolina infested with *Meloidogyne* spp., 2-year rotations, with a susceptible crop grown alternately with a single resistant crop, gave adequate nematode control (7). Our results agree with those farther south, that where conditions are more favorable for nematode development, 3-year rotations or longer with resistant crops are needed to reduce root-knot damage (9).

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 to these nematode species. Similar results were reported with these nematode genera; however, coastal bermudagrass is highly susceptible to *Belonolaimus longicaudatus* (9).

*Fusarium oxysporum* and *Pythium* spp. were frequently isolated from dead and dying okra and squash seedlings and contributed to seedling decline and stunting following both fallow and coastal bermudagrass sod. These results agree with earlier

TABLE 4. Yield of vegetable crops following fallow and coastal bermudagrass sod rotations.

| Year/crop | Number (×1,000) per hectare | | Metric tons per hectare | |
|---|---|---|---|---|
| 1990 | Fallow | 1-year sod | Fallow | 1-year sod |
| Okra | —[a] | — | 1.84 a | 3.95 a |
| Sweet corn | 59.7 a | 56.0 a | 16.93 a | 16.47 a |
| Squash | 192.2 a | 188.4 a | 22.57 a | 22.89 a |
| 1991 | Fallow | 2-year sod | Fallow | 2-year sod |
| Okra | — | — | 3.81 b | 27.37 a |
| Sweet corn | 45.3 a | 29.1 a | 17.54 a | 11.46 a |
| Squash | 74.8 a | 105.8 a | 12.92 b | 19.86 a |
| 1992 | Fallow | 3-year sod | Fallow | 3-year sod |
| Okra | — | — | 3.96 b | 11.81 a |
| Sweet corn | 48.0 a | 40.8 a | 11.24 a | 11.46 a |
| Squash | 186.0 a | 230.0 a | 26.22 a | 33.84 a |

Data are means of four replications. Means in rows followed by the same letter are not different ($P = 0.05$) based on LSD analysis.
[a] Numbers of okra pods were not determined.

reports in which *F. oxysporum, Pythium* spp., and *Rhizoctonia solani* were commonly found in the soil and caused seedling decline and stunting in okra and squash (8,16). Rodriguez-Kábana et al. (23) reported coastal bermudagrass rotation had no effect on the incidence of southern blight, caused by *Sclerotium rolfsii,* on peanut. Our results showing population densities of most fungi declined in plots of sweet corn following fallow and coastal bermudagrass, and no fungi commonly considered pathogenic were isolated from sweet corn seedlings differ from those reported by Sumner et al. (26). They reported large cfu numbers of *Pythium* spp., *F. oxysporum,* and *F. solani* on sweet corn, with populations of *F. oxysporum* negatively correlated with both growth and yield and populations of *F. solani* negatively correlated with plant growth but not yield. These differences may be due to different cultivars of sweet corn used in the studies. Although major soilborne fungal pathogens, such as *F. oxysporum,* declined following 3 years of coastal bermudagrass sod compared to fallow, population densities remained large enough to cause damping-off, seedling decline, and stunting of susceptible crops of okra and squash.

Rotations with coastal bermudagrass proved beneficial for okra and squash yields following 2- and 3-year sod. The plant response and yield increase were attributed to lower numbers of soilborne fungi in the soil and lower root-gall indices of plants following 2- and 3-year coastal bermudagrass.

Rotations with coastal bermudagrass have been beneficial for control of root-knot nematodes in flue-cured tobacco (6), sweet potato (27), and some vegetable crops (5). An additional benefit is the value of hay yields, which range from 11–22 metric tons/ha each year. Rotations with coastal bermudagrass were proposed as a general solution for the crop damage and yield losses caused by root-knot nematodes in the southeastern United States (2). Our results do not support the general solution and indicate clearly that there are differences among vegetable crops following coastal bermudagrass for the management of *M. incognita* and diseases caused by soilborne fungi. Studies are in progress to determine the influence of nematicides integrated into coastal bermudagrass rotations on *M. incognita* and soilborne fungi on root-knot-resistant vegetable crops.

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