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INFLUENCE OF COVER CROPS IN ROTATION ON IMPROVING OKRA (*ABELMOSCHUS ESCULENTUS* L.) YIELD AND SUPPRESSING PARASITIC NEMATODES

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Abstract. **The influence of growing and incorporating summer cover crops on the subsequent vegetable crop production and on population densities of the root knot nematode, *Meloidogyne incognita,* was investigated in field and pot experiments at Homestead, Florida. The cover crops utilized in the field and pot experiments were sunn hemp (*Crotalaria juncea*), cowpea (*Vigna unguiculata*), velvetbean (*Mucuna deeringiana*) and sorghum sudangrass (*Sorghum bicolor* × *S. bicolor* var. sudanense). A nematode susceptible vegetable crop, okra (*Abelmoschus esculentus*) was grown in rotation with these given cover crops. The results indicated that all four cover crops improved the subsequent okra yields, and especially sunn hemp and velvetbean, which produced large amounts of biomass with high contents of nitrogen (N). The okra fruit yields in the field were increased by 33% and 11% in velvetbean and sunn hemp treatments compared that in the sorghum sudangrass treatment, which is the conventional cover crop treatment in this area. In crop rotation studies conducted in pots, okra fruit yields were increased by 3.6, 3.1 and 1.5 times by rotation with sunn hemp, velvetbean and cowpea, respectively, compared to yields of okra following okra. Populations of root-knot nematodes were substantially suppressed by sunn hemp, cowpea and velvetbean, and this suppression was especially strong by sunn hemp. Moreover, the root knot nematode suppressive effect of sunn hemp persisted to protect a subsequent okra crop. The results indicate that rotating the summer cover crops, sunn hemp or velvetbean, with okra can significantly improve okra yields in addition to suppressing root knot nematodes.**

Plant-parasitic nematodes, especially root-knot nematodes are widely distributed, attack numerous crops and other host plant species and cause significant economic losses in agricultural. Annual global losses due to plant-parasitic nematodes are approximately $78 billion; of which $8 to $12 billion occur annually in the U.S. (Barker et al., 1994). Chemical fumigation, especially with methyl bromide—chloropicrin mixtures, has provided an effective means to control soil nematodes, however, in accordance with the Montreal Protocol, methyl bromide usage ceased at the end of 2004 in developed countries, although certain critical use exemptions have been granted temporarily. In addition, chemical fumigants suppress not only parasitic nematodes, other plant pathogens and weeds, but they also kill beneficial nematodes and microorganisms. Therefore, the soil ecosystem is significantly disturbed, at least temporarily, by chemical fumigation, since it suppresses many species of beneficial organisms in the soil.

Some summer cover crops have been found to reduce populations of plant-parasitic nematodes in the soil (McSorley, 1998; Noe, 1998; Wang et al., 2003). Furthermore, summer cover crops can accumulate and sequester soil nutrients, reduce soil runoff and leaching of nutrients and pesticides throughout the rainy summer, and subsequently after the cover crops have been incorporated into the soil they can supply large amounts of slow released nutrients to the subsequent crop (Wang et al., 2002, 2003).

In previous experiments, Wang et al. (2002) demonstrated that modest populations of various plant parasitic nematodes were suppressed when velvetbean, sunn hemp, sorghum sudangrass and 'Iron clay' cowpea were grown and soil-incorporated prior to transplanting tomato plants. Also, tomato yields were improved significantly by the sunn hemp treatment, but not by the velvetbean treatment, even though velvetbean produced a fairly large amount of biomass and added a considerable amount of N to the soil. This absence of response of tomato to N supplied by velvetbean might be due to the allelopathic effects on tomato of chemical constituents of velvetbean tissues (Caamal-Maldonado et al., 2001; Fujii, 1994, 2000; Wang et al., 2003). Whether a given plant species is negatively affected by velvetbean constituents is probably determined by its detoxication mechanisms and other inherited traits.

Okra (*Abelmoschus esculentus*), a tropical and subtropical vegetable crop, is grown year round in south Florida. Okra production can be fairly profitable, but this plant is highly susceptible to be attacked by the root-knot nematode, *Meloidogyne incognita*. Therefore, soil fumigation with methyl bromide has been commonly used to control soil nematodes and other harmful soil-borne organisms in Florida. However, the Clean Air Act (Environmental Protection Agency, 2004), which implements the Montreal Protocol, forbids the use of methyl bromide after 2004, except temporarily for certain critical uses. On the Karst topography of Miami-Dade County, the only available chemical alternatives to methyl bromide are metam sodium, metam potassium and chloropicrin. Other promising soil fumigants, such as methyl iodide, sodium azide and ethanedinitrile, are still under development. On the other hand certain summer cover crops have the potential to control soil nematodes at low to moderate population densities (Kloepper et al. 1991; McSorley, 1998, 1999; Vargas-Ayala et al., 2000; Wang et al., 2003), and more importantly to improve soil fertility and to increase yields of subsequent crops, e.g., tomato (Wang et al., 2002).

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The objectives of this experiment were to determine 1) the effects of various cover crops on okra production, 2) the influence of those summer cover crops on dynamic changes in densities and distributions of soil nematode populations, and 3) the impact of rotation of okra with cover crops on the degree of control of parasitic nematodes.

Materials and Methods

Field experiment. A field experiment with a randomized block design was conducted with two leguminous cover crops, sunn hemp and velvetbean, and a control, non-leguminous cover crop, sorghum sudangrass, a cover crop conventionally grown in the local area. Each cover crop was grown on a 0.7 ha with 3 replicates. The cover crops were sown in June and terminated in September. Seeding rates were 56 kg ha^{-1} for sunn hemp, 34 kg·ha^{-1} for velvetbean and 56 kg·ha^{-1} for sorghum sudangrass with a tye drill seeder. For the legumes, Rhizobium ("EL" Cowpea inoculant from Nitragin Inoculants, Liphatech, Inc., Milwaukee, Wis.) was applied with some syrup to inoculate while seeding. The Krome gravely loam soil on which the okra was grown had the following properties: pH, 8.2; $CaCO_3$, 598 g·kg^{-1}; organic carbon (C), 26.8 g·kg^{-1}; total N, 1103 mg·kg^{-1}; AB-DTPA extractable phosphorus (P), 33.0 mg·kg^{-1}.

Just prior to termination, samples of cover crops were collected to obtain dry weight of biomass and for chemical analysis. The cover crops were terminated by flail-mowing and by roto-tilling the plant residues into the soil. Preplant fertilizer (6 N – 2.6 P – 10 K) was applied and disked into the soil to provide N 150 kg·ha^{-1}. Okra seeds at 10 kg·ha^{-1} were sown in rows 91 cm apart. The okra fruits were harvested from randomly selected 7.3 m long plots of a row every other day beginning in November. Twenty-four harvests from each plot were obtained to establish the total fruit yield. Plant shoots were collected from the same area after harvest for biomass determination.

Pot experiment. The same soil as in the field was placed in 9.5-L black plastic pots and the treatments were replicated four times. The cover crops were sunn hemp, cowpea and velvetbean each grown in rotation with okra. Rhizobium was applied to inoculate the legumes in the same way as in the field experiment. The cover crop growth periods were between 2 and 3 months starting from Aug. 2002. At the end of each growth period, samples were collected to obtain the biomass of each cover crop. The above-ground parts of the cover crops were cut into ca. 2.5 cm-long pieces and incorporated into the soil in the same pots where they had been grown. The crop rotation schemes were shown in Table 1.

The okra plants were individually rated for root galls and egg masses on a 0-5 scale: 0 = 0 galls, 1 = 1-2, 2 = 3-10, 3 = 11-33, 4 = 31-100, 5 > 100 galls or egg masses (Taylor and Sasser, 1978). Soil samples were collected, and the population densities of various nematodes were determined. The data were subject to ANOVA and Duncan's multiple range tests (SAS, 1999).

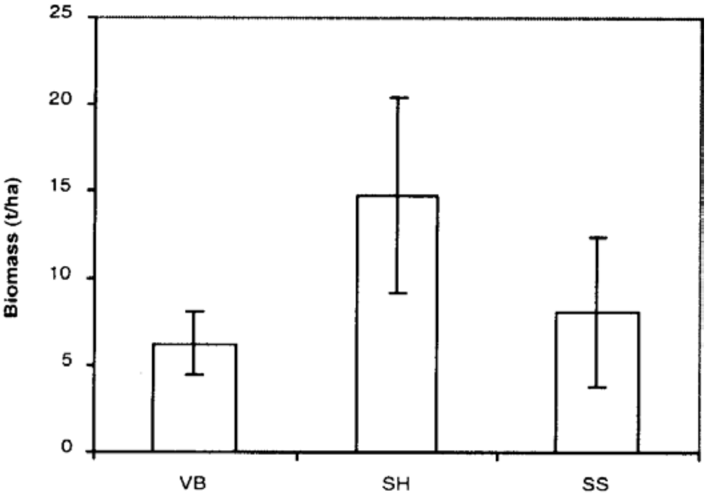

Fig. 1. Biomass (Mg ha^{-1}) produced in the field by sunn hemp (SH), velvetbean (VB) and sorghum sudangrass (SS). Each vertical bar represents the standard deviation of the mean of three replicates.

Results and Discussion

Biomass of various crops grown in the field and in pots. The amounts of biomass produced in the field (Fig. 1) varied among the cover crops. Sunn hemp produced the most biomass (10 to 20 Mg·ha^{-1}), velvetbean produced the least (4 to 8 Mg·ha^{-1}) and sorghum sudangrass produced an intermediate amount (5 to 14 Mg ha^{-1}).

When grown in pots (Table 1) sunn hemp produced significantly the largest amount of biomass in the first rotation (109.9 g/pot), followed by velvetbean (86.5 g/pot), and cowpea (47.5 g/pot). Fumigation with methyl bromide-chloropicrin (MC-33) as compared to the control significantly improved the amount of okra biomass produced, i.e., 39.4 g/pot in fumigated soil vs. 9.7 to 12.5 g/pot in untreated soil (Table 1). Growing okra following a cover crop improved okra growth and production. For example, in the second rotation, amounts of biomass of okra produced were 18.2 g/pot after sunn hemp, 15.1 g/pot after cowpea, 12.5 g/pot after velvetbean, but only 4.9 and 5.7 g/pot after okra (Table 1).

Yield and biomass of okra grown in the field. Okra fruit yield in the field (Table 2) was significantly improved when okra

Table 1. Amounts of biomass (g pot^{-1}) of okra, sunn hemp, velvetbean or cowpea produced in each rotation.

Rotation scheme	O-O-O[z]	O-S-O	O-C-O	O-V-O	S-O-S	C-O-C	V-O-V	O-O-S[y] (MC-33)
1st rotation	10.2 d[x]	12.5 d	9.7 d	11.2 d	109.9 a	47.5 c	86.5 b	39.4 c
2nd rotation	4.9 c	14.6 a	11.5 ab	12.8 ab	18.2 a	15.1 a	12.5 ab	5.7 c
3rd rotation	7.6 c	13.0 c	5.9 c	10.9 c	72.2 a	82.9 a	40.3 b	36.7 b

[z] Abbreviations and rotation schemes: O-okra, S-sunn hemp, V-velvetbean, C-cowpea; O-O-O means okra grown in 3 successive crop cycles, O-S-O means okra followed by sunn hemp, which in turn is followed by okra, etc.

[y] The soil for this treatment was fumigated with MC-33 prior to the experiment.

[x] Mean values within a row followed by same letters represent insignificant differences ($P \leq 0.05$).

Table 2. Okra fruit yields and dry weight of biomass produced in the field following different cover crops.

Cover crop	Okra Fruit yield (kg ha^{-1})	Okra Biomass (kg ha^{-1})
Velvet bean	10,024.5 a^{z}	252.7 b
Sunn hemp	8,370.1 b	603.1 a
Sorghum sudangrass	7,536.7 b	330.1 ab

^{z}Mean values within a column followed by same letters represent insignificant differences ($p \le 0.05$).

followed velvetbean compared with okra grown after sorghum sudangrass and sunn hemp, even though velvetbean itself had produced the lowest amount of biomass (Fig. 1). On the other hand, the biomass of okra produced was significantly higher in the sunn hemp treatment than in the velvetbean treatment (Table 2).

In the field experiment, sorghum sudangrass produced a higher amount of biomass than velvetbean but contributed a smaller amount of N to the soil to be used by the subsequent crop, okra. This occurred because velvetbean consisted of 2.58% N, vs. 0.92% N in sorghum sudangrass. Therefore in this experiment velvet contributed 160 kg ha^{-1} of N vs. 74 kg·ha^{-1} contributed by sorghum sudangrass. However the response of okra crop was unexpected in that the amount of okra biomass produced in the velvetbean treatment appeared to be less than in the sorghum sudangrass treatment, although this difference was not significant statistically.

The yield of okra grown in pots was somewhat different from that observed in the field (Fig. 2). The yield of okra grown in pots following sunn hemp or velvetbean was significantly higher than that following okra but no significant difference was observed among cover crops, especially between sunn hemp and velvetbean. Okra yields were increased by ca. 4.6 by sunn hemp and velvetbean and 2.5 fold by cowpea (Fig. 2).

In previous field experiments in which tomato was grown following various cover crops, Wang et al. (2002, 2003) found that the tomato fruit yields were significantly improved by the sunn hemp treatment, but not by the velvetbean even when similar amounts of biomass of these two cover crops were produced. One possible reason to cause the difference in yield response to cover crop treatments by okra and tomato grown in the field is that velvetbean posses ca. 2-fold higher lignin content than sunn hemp, i.e., 72 g·kg^{-1} (DW) in velvetbean leaves vs. 37 g·kg^{-1} in sunn hemp (Wang et al., unpublished data). The high lignin content in velvetbean may lead to a slower rate of decomposition of velvetbean plant residues, and thus a slower release of nutrients to the subsequent crop. Since okra has a relatively longer growth period than tomato in this area, okra might derive greater nutritional benefits from decomposing velvetbean residues than tomato. A second possible reason is that velvetbean contains and secretes compounds that produce allelopathic effects on some plants but not the others (Casini and Olivero, 2001; Fujii, 1994, 2000). Tomato production seems to be affected adversely by velvetbean (Caamal-Maldonado et al., 2001; Wang et al., 2003), but okra shows no indication of being affected adversely. The longer and the larger that velvetbean plants are allowed to grow, the greater the amounts of allelopathic substances likely to be produced. Thus in the field experiment velvetbean is likely to have produced a greater amount of allelopathic substances than that grown in pots.

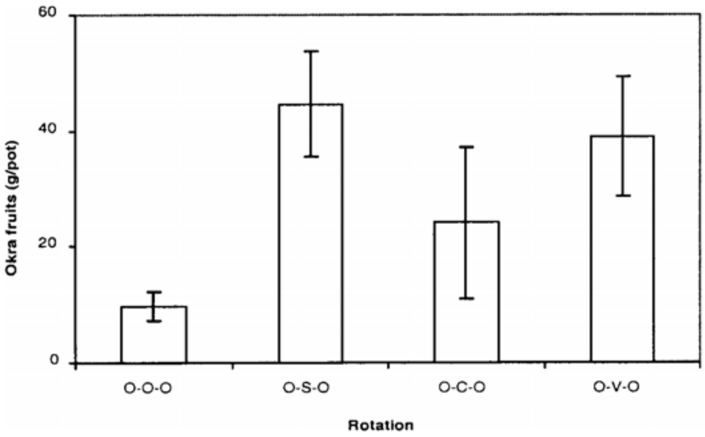

Fig. 2. Fruit yields of okra from the final rotation with various crops grown in pots. O-O-O means okra grown in 3 successive crop cycles, O-S-O means okra followed by sunn hemp and then okra, O-C-O means okra followed by cowpea and then okra, O-V-O means okra followed by velvet bean and then okra. Each vertical bar represents the standard deviation of the mean of three replicates.

In the pot experiment, the second rotation extended from early Nov. through Jan., and the amount of biomass produced by all of summer cover crops was relatively low. During this winter period velvetbean produced only 12.8 g/pot of biomass compared to 86.5 g/pot during the first rotation or to 40.3 g/pot in the last rotation (Table 1). Likewise sunn hemp produced only 14.6 g/pot of biomass in the winter rotation compared to 109.9 g/pot in first rotation and 72.2 g/pot in the last one. Furthermore, there was not any okra fruit produced during this period because of the low temperature. Doubtlessly the poor growth of cover crops during the winter produced less beneficial effects on okra than those grown during the summer.

Changes in nematode population densities observed in the potted soil. At the outset of the experiment, the density of nematodes in the potted soil ranged from 140 to 2100 per 250 mL soil, and the average number of J2 larvae of the root-knot nematode, *Meloidogyne incognita*, in the soil was 480 per 250 mL soil (Fig. 3). Data in Table 3 show population changes of different nematodes after each rotation, and data in Table 4 show that the average number of all plant-parasitic nematodes was initially over 700 per 250 mL soil.

After the first rotation, the densities of root-knot nematode J2 larvae grown in the presence of okra ranged from 308 to 524 per 250 mL of soil, and thus had not changed much. However, when nematode development occurred in the presence of the summer cover crops, the densities of the J2 larvae were significantly reduced, and ranged from 65 to 150 per 250 mL soil. Soil fumigation with methyl bromide-chloropicrin (MC-33) prior to the rotation, okra-okra-sunn hemp, effectively suppressed all taxa of soil nematodes with the exception of the saprophytes, which were unaffected by the fumigant (Table 3).

After the second rotation the densities of almost all taxa of plant-parasitic nematodes were found to have been reduced in the presence of the crops including okra, but in the MC-33-fumigated soil (O-O-S) the densities of all distinguished taxa had increased. Thus after the second rotation no significant difference was found in the population of *Meloidogyne* J2 larvae with different crop treatments (Table 3).

Possibly the failure of populations of plant parasitic nematodes to increase even in the okra treatment is related to the

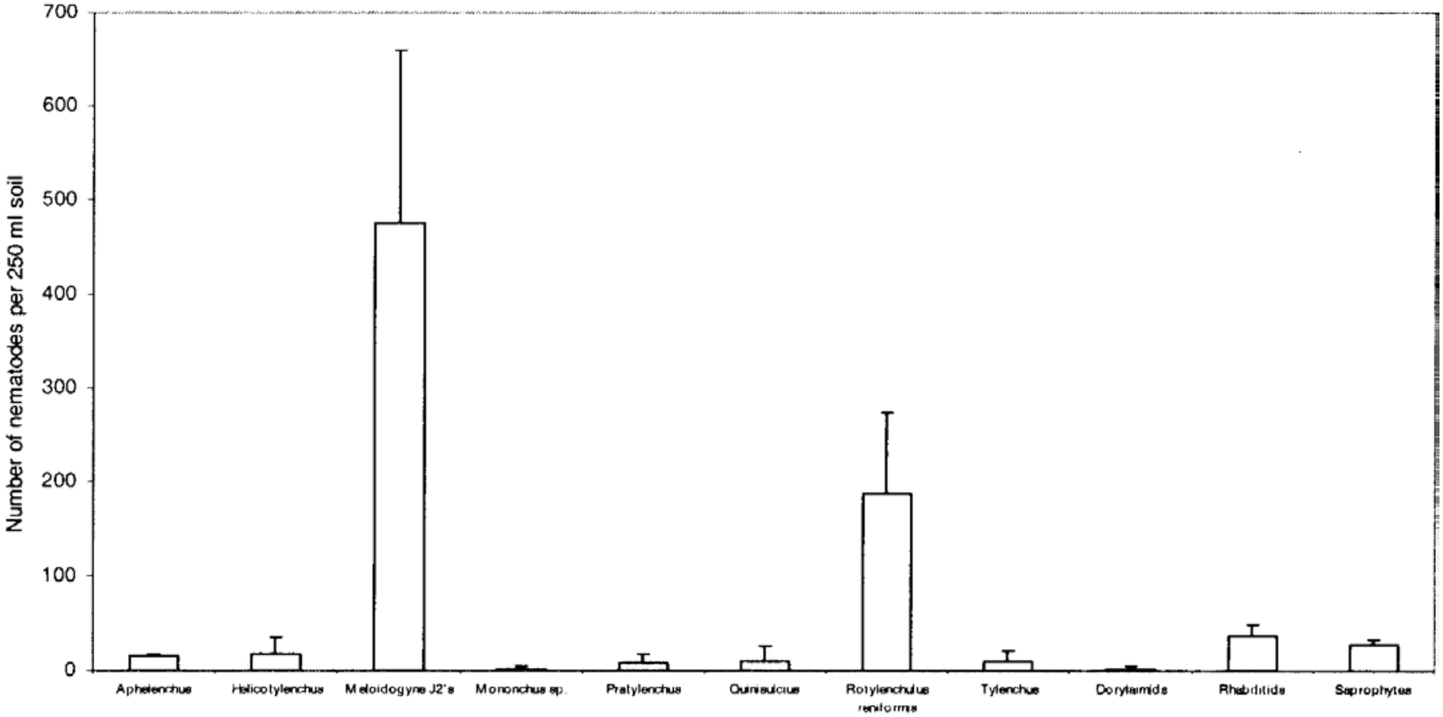

Fig. 3. Population densities of soil nematodes in different taxa before the first rotation started. Each vertical bar represents the standard deviation of the mean.

diminished plant growth at reduced temperatures and day lengths during November through January, when the second rotation occurred. The reduced soil temperatures in pot may have been unfavorable for the reproduction and development of plant-parasitic nematodes. It should be noted that during these winter months the population densities of Dorylaimids, Mononchus, and the saprophyte category generally increased.

In most treatments by the end of the third rotation, the total densities of nematodes were increased dramatically compared with the densities at the end of second rotation with the exception of the rotation of O-O-S (Table 3). Also in the S-O-S rotation, sunn hemp had effectively suppressed the population densities of the almost all soil nematode taxa. However in spite of the sunn hemp or other nematode-suppressive cover crops and the absence of suitable host plants, the densities of root-knot nematode J2 larvae had increased many folds after the third rotation compared to the second one (Table 3). This increase might be attributed to low-temperature induced delayed hatching of *Meloidogyne* eggs produced largely during the 2nd rotation (McSorley, 2003). Nevertheless, when sunn hemp was the last crop in a rotation, lower densities of *Meloidogyne* J2 larvae were produced than those when cowpea or velvetbean was the last in the rotation.

The population densities of the aggregate plant-parasitic nematode taxa in different treatments after the first rotation were quite similar with the exception of that following okra grown in soil that was fumigated initially with MC-33 (Table 4). In the latter treatment the aggregate density of populations of plant-parasitic nematode taxa was only one-fifth as great as that of the next lowest case. However, after the second rotation the population densities of the aggregate plant-parasitic nematode taxa were substantially suppressed in all instances except in the MC-33-fumigated treatment (O-O-S) in which the aggregate population was doubled (Table 4), which indicates that root knot nematodes can be built up easily by growing okra even though the soil was fumigated initially. The build-down of aggregate population densities in most instances after the second rotation might be attributed to the lower temperature during November through February.

After the third rotation, the population densities of the aggregate plant-parasitic nematode taxa increased in most of the treatments, and more than 5-fold in the okra-okra-okra and cowpea-okra-cowpea rotation schemes. However this increase was minimal in the sunn hemp-okra-sunn hemp treatment (Table 4). Growing sunn hemp before growing okra again significantly moderated the rate of buildup of parasitic nematode populations, e.g., 487 nematodes per 250 mL of soil in O-S-O vs. 827 per 250 mL in the rotation of O-O-O. All of the summer cover crops had reduced the rate of buildup of plant-parasitic nematodes after the third rotation (S-O-S, C-O-C, V-O-V and O-O-S), but sunn hemp had a significantly greater suppressive effect than either cowpea or velvetbean (Table 4).

The data in Table 4 indicate that the suppressive effect of sunn hemp on plant-parasitic nematodes, more so than that of velvetbean, has a sufficient duration to protect the subsequent crop. For example, the population density of plant-parasitic nematodes in aggregate was 1.7 fold greater at the end of the O-O-O rotation than at the end of the O-S-O rotation (Table 4). 'Iron and Clay' cowpea appears to suppress plant-parasitic nematodes as well, for instance, the final population density of plant parasitic nematodes observed in the sequence O-O-O was 826.7 versus 428.3 nematodes per 250 mL at the end of the C-O-C sequence. However the carry-over suppressive action of cowpea seemed somewhat erratic, e.g., after the 2nd rotation of the C-O-C sequence, strong suppression of plant-parasitic nematodes was observed, i.e., reduction from

Table 3. Changes in population densities of various nematode taxa (number per 250 ml soil) after rotations with different crops grown in pots.

Rotation Scheme	O-O-O[z]	O-S-O	O-C-O	O-V-O	S-O-S	C-O-C	V-O-V	O-O-S[y] (MC-33)
After the 1st rotation (Aug. to Oct.)								
Aphelenchus	5.7 b[x]	8 ab	10 ab	9 ab	22.3 a	23.3 a	11.3 ab	8.3 ab
Helicotylenchus	0 c	0 c	0 c	0 c	23.3 b	10.7 bc	50 a	12.7 bc
Meloidogyne J2's	524 a	308.3 b	346.7 b	352 b	110 c	65.3 c	155 c	44 c
Mononchus	16 ab	20 a	20 a	23 a	3.7 c	2.3 c	5.7 bc	0 c
Quinisulcius	5 ab	1 b	0 b	2 b	4 ab	7.3 ab	30 a	20 ab
Rotylenchulus reniformis	236.7 bc	135 cd	53.3 d	126.3 cd	360 b	530 a	350 b	10.3 d
Dorylaimids	14 ab	13 ab	16.7 a	14.5 ab	10.7 ab	10 ab	15.7 a	6 b
Saprophytes	50 a	45 a	40 a	42 a	55 a	33.3 a	35 a	53.3 a
Total/250 mL	851.4 a	530.3 b	486.7 b	568.8 b	589 ab	682.2 ab	652.7 ab	154.6 c
After the 2nd rotation (Nov. to Jan.)								
Aphelenchus	4.3 b	0 b	1 b	2 b	0 b	1.5 b	0 b	66.5 a
Helicotylenchus	5 a	0 a	0 a	0 a	—	—	—	—
Meloidogyne J2's	61.7 a	65 a	31.7 a	52.5 a	61.7 a	8.5 a	61 a	86.7 a
Mononchus	48.3 a	68.3 a	55 a	60.3 a	53.3 a	22.5 a	33.3 a	43.3 a
Quinisulcius	2.7 a	0 a	0 a	0 a	—	—	—	—
Rotylenchulus reniformis	4 b	0 b	96.7 a	42.3 b	0 b	15 b	15 b	—
Dorylaimids	41.7 a	51.7 a	15 a	32.5 a	30 a	22.5 a	43.3 a	33.3 a
Saprophytes	119 b	463.3 a	160 b	216.3 ab	96.7 b	127.5 b	236.7 ab	206.7 ab
Total/250 mL	286.7 ab	648.3 a	359.4 ab	403.9 ab	241.7 b	197.5 b	389.3 ab	436.5 ab
After the 3rd rotation (Feb. to May)								
Aphelenchus	0 a	7.3 a	2.5 a	3.7 a	—	—	—	—
Helicotylenchus	0 b	5 ab	0 b	2.3 b	10 ab	—	32.5 a	—
Meloidogyne J2's	341.7 a	215 abc	283.3 ab	225.3 abc	100 d	190 bcd	235 abc	110 cd
Mononchus	70 a	66.7 a	75 a	82.3 a	21.7 b	21.7 b	18.3 b	5.3 b
Rotylenchulus reniformis	325 a	15 c	128.3 b	85.3 b	0 c	173.3 b	111.7 b	—
Dorylaimids	90 c	185 b	270 a	214.3 ab	60 c	43.3 c	43.3 c	23.3 c
Saprophytes	250 bc	916.7 a	883.3 ab	885.3 ab	366.7 abc	300 abc	561.7 abc	140 c
Total	1076.7 b	1410.7 ab	1642.4 a	1498.5 a	558.4 cd	728.3 c	1002.5 b	278.6 d

[z] Abbreviations and rotation schemes: O-okra, S-sunn hemp, V-velvetbean, C-cowpea; O-O-O means okra grown in 3 successive crop cycles, O-S-O means okra followed by sunn hemp, which in turn is followed by okra, etc.

[y] The soil was fumigated with MC-33 for this treatment before the experiment.

[x] Mean values within a column followed by same letters represent insignificant differences ($p \leq 0.05$).

615.6 to 68.5 nematodes per 250 mL. On the other hand after the 3rd rotation in the O-C-O sequence the population density of nematodes grew from 198.4 to 756.6 nematodes per 250 mL (Table 4).

With respect to the non-plant-parasitic nematodes, growing sunn hemp or cowpea between two growth periods of okra (O-S-O and O-C-O) seemed to stimulate the growth of non-parasitic nematode populations resulting in final popula-

Table 4. Changes in population densities of plant-parasitic and non-parasitic nematode populations (numbers per 250 mL soil) initially present and after each crop rotation in pots.

Rotation Scheme	O-O-O[z]	O-S-O	O-C-O	O-V-O	S-O-S	C-O-C	V-O-V	O-O-S[y] (MC-33)
Plant-parasitic nematodes[x]								
Initially present 713.3								
1st rotation	781.7 aw	464.3 b	420.0 b	503.3 b	501.0 b	615.6 ab	590.7 ab	87.0 c
2nd rotation	163.4 a	185.0 a	198.4 a	187.6 a	145.0 a	68.5 b	152.6 a	163.3 a
3rd rotation	826.7 a	486.7 b	756.6 a	609.5 ab	191.7 c	428.3 b	440.8 b	138.6 c
Non-parasitic nematodes								
Initially present 46.4								
1st rotation	69.7 a	66.0 a	66.7 a	65.5 a	88.0 a	66.6 a	62.0 a	67.6 a
2nd rotation	123.3 c	463.3 a	161.0 c	216.3 b	96.7 c	129.0 c	236.7 b	273.2 b
3rd rotation	250.0 bc	924.0 a	885.8 a	889.7 a	366.7 b	300.0 b	561.7 ab	140.0 c

[z] Abbreviations and rotation schemes: O-okra, S-sunn hemp, V-velvetbean, C-cowpea; O-O-O means okra grown in 3 successive crop cycles, O-S-O means okra followed by sunn hemp, which in turn is followed by okra, etc.

[y] The soil for this treatment was fumigated with MC-33 prior to the experiment.

[x] Plant-parasitic nematodes in this experiment included *Helicotylenchus*, *Meloidogyne*, *Quinisulcius*, and *Rotylenchulus reniformis*.

[w] Mean values within a row followed by same letters represent insignificant differences ($p \leq 0.05$).

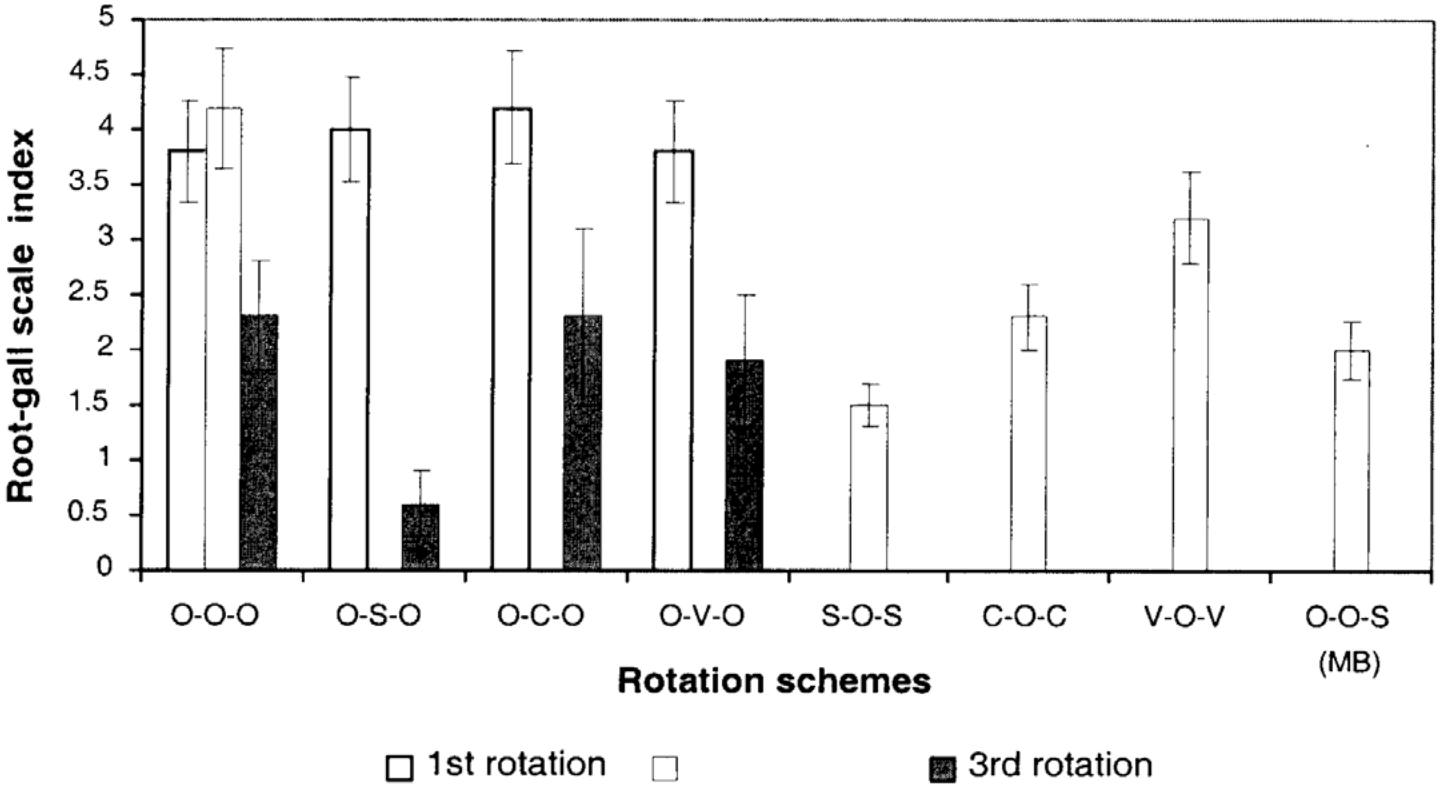

Fig. 4. Okra root gall indices following various crop rotations. O-O-O means okra grown in 3 successive crop cycles, O-S-O means okra followed by sunn hemp and then okra, O-C-O means okra followed by cowpea and then okra, O-V-O means okra followed by velvet bean and then okra, etc. Root galls were observed on okra roots only. Each vertical bar represents the standard deviation of the mean of three samples.

tion densities of 924 and 886 nematodes per 250 mL (Table 4). In contrast the O-O-O sequence resulted in a final population of only 250 nematodes per 250 mL. However when sunn hemp or cowpea were the last in the sequence (O-O-S, S-O-S and C-O-C) the population densities of non-parasitic nematodes were not increased (Table 4). Achieving high population densities of non-plant-parasitic nematodes may be beneficial to the subsequent crop since some of these nematodes feed on plant pathogens and on plant-parasitic nematodes. Populations of these non-plant-parasitic nematodes can be built up quickly if they are provided with ample food in the soil environment. Rotations of okra and summer cover crops used in this study appeared to be much more effective in building up populations of non-plant-parasitic nematodes than growing continuous okra (Table 4).

Root galls on okra are caused by female root-knot nematodes, usually *Meloidogyne* spp., and the Taylor-Sasser scale (Taylor and Sasser, 1978) is useful for indexing the degree of attack of a host plant by those nematodes. The bar graphs in Fig. 4 show that the root-gall index of okra in the first rotation in various cropping sequences except the treatment with MC-33 ranged from 3.7 to 4.3, and that in the O-O-O sequence, the number of root galls had increased by the end of the 2nd rotation but then declined quite sharply by the end of the 3rd rotation. This decline in the 3rd rotation may be related to the build up of the non-plant-parasitic nematodes (Table 4). However, if the first crop in the sequence of rotation was, sunn hemp (S-O-S), cowpea (C-O-C), or velvetbean (V-O-V), the root gall index on okra as the second crop decreased substantially, especially when sunn hemp and cowpea preceded okra (S-O-S and C-O-C). Whenever okra was the 3rd crop in the sequence preceded by one of the summer cover crops (e.g., O-S-O, O-C-O, and O-V-O), the root gall index declined, and this decline was especially drastic when sunn hemp preceded okra in the sequence of rotation (Fig. 4).

From the above results, we can simply conclude that growing summer cover crops, sunn hemp and velvetbean or rotating them with okra can dramatically improve the subsequent yield of this vegetable crop. These leguminous cover crops grown and incorporated into the soil stimulate production of the subsequent vegetable crop, okra, by releasing large amounts of N into the soil after they have been incorporated in the soil and have decomposed. In addition these cover crops, especially sunn hemp, effectively suppress plant-parasitic nematodes, and this suppression carries over to protect the subsequent cash crop, okra.

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