NEMATODE MANAGEMENT, SOIL FERTILITY, AND YIELD IN ORGANIC VEGETABLE PRODUCTION†

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ABSTRACT

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Since organic vegetable producers in the United States cannot use synthetic pesticides, they must rely on alternative methods for pest management. In an organic vegetable production system in southwest Florida, summer solarization, compost, summer cover crops, and a resistant cultivar were used to manage *Meloidogyne incognita* and other plant-parasitic nematodes in a double-crop system with susceptible vegetable crops. At the beginning of autumn crops of tomato (*Lycopersicon esculentum*) and pepper (*Capsicum annuum*), population levels of *M. incognita* were lowest following summer solarization, intermediate following summer cover crops of browntop millet (*Panicum ramosum*), 'Iron Clay' cowpea (*Vigna unguiculata*), or marigold (*Tagetes minuta*), and greatest following compost alone or a control (summer weeds). Most treatment differences did not persist into a spring vegetable crop. The exception was a treatment with 'Sanibel' tomato, from which no *M. incognita* were recovered even at the end of the spring crop. In this case, the integration of a summer cowpea cover crop and a resistant cultivar was successful in managing *M. incognita* and improving yield of tomato in rotation with pepper.

Key words: Capsicum annuum, compost, cover crops, crop rotation, *Lycopersicon esculentum, Meloidogyne incognita,* organic amendments, *Paratrichodorus minor,* pepper, pest management, solarization, sustainable agriculture, tomato.

RESUMEN

Mc Sorley, R., M. Ozores-Hampton, P. A. Stansly y J. M. Conner. 1999. Manejo de nematodos, fertilidad del suelo, y rendimiento, en la producción orgánica de hortalizas. Nematrópica 29:205-213.

Los productores orgánicos de hortalizas en Estados Unidos, no pueden usar pesticidas sintéticos, por lo que dependen de metodos alternativos para el manejo de plagas. En un sistema de producción orgánica de vegetales, en el suroeste de la Florida, la solarización de verano, el composteo, la cobertura de cultivos en el verano y una variedad resistente, fueron usados para controlar a *Meloidogyne incognita* y a otros nematodos fitoparasitos de plantas en un sistema de cultivo doble con vegetales susceptibles. Al principio de los cultivos de otoño; tomate (*Lycopersicon esculentum*) y ají (*Capsicum annuum*), los niveles poblacionales de *M. incognita* fueron los menores, siendo intermediarios después de la cobertura de verano, en el mijo (*Panicum ramosun*), 'Iron Clay' cowpea (*Vigna unguiculata*) o calendula (*Tagetes minuta*), y mayores después del composteo solo o en el control (malezas de verano). La mayoría de las diferencias entre los tratamientos no persistieron en la producción de vegetales de primavera. La excepción fue en el tratamiento con tomate Sanibel, en el que no se recuperó *M. incognita* aun en al final del ciclo de primavera. En este caso, la integración de un cultivo de 'cowpea' cubierto durante el verano y de una variedad resistente, tuvo éxito en el manejo de *M. incognita* y en el mejoramiento del rendimiento del tomate en rotación con ají.

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Palabras claves: agricultura sostenible, ají, *Capsicum annuum,* composteo, cultivos cubiertos, *Lycopersicon esculentum,* manejo de plagas, mejoras orgánicas, *Meloidogyne incognita, Paratrichodorus minor,* rotación de cultivos, solarización, tomate.

INTRODUCTION

Vegetable production in the southeastern United States is difficult without successful management of nematodes, soilborne diseases, and weeds. Unfumigated land in Florida's sandy soils may become overwhelmed by high populations of root-knot nematodes (*Meloidogyne* spp.), diseases such as *Sclerotium rolfsii* (causal agent of southern blight), and weeds such as nutsedge (*Cyperus* spp.), after only a few susceptible crops. Methyl bromide is a broad-spectrum soil fumigant widely used to control these pests, but is unavailable to organic growers (who cannot use synthetic pesticides) and may be unavailable to conventional growers in the future.

A variety of alternative methods for nematode management are available, but their efficacy in specific situations must be determined and their use integrated with other sustainable management practices (McSorley, 1996, 1998). Non-chemical techniques for nematode management include: (a) solarization to heat soil sufficiently in summer to suppress pest populations, (b) composts to provide favorable environments for decomposition by-products or beneficial microorganisms that may suppress pathogens and weeds, (c) cover crops and resistant varieties to reduce carryover and buildup of nematode populations (Johnson, 1982; McSorley, 1996, 1998; McSorley and Duncan, 1995; Noling and Becker, 1994; Trivedi and Barker, 1986).

Soil solarization has been effective against a number of different nematode species, but root-knot nematodes are the most difficult to manage by this method (Chellemi *et al.*, 1993; McGovern and McSorley, 1997). Weed seed germination and seedling growth is suppressed by high soil temperature (Horowitz,1980). Clear polyethylene plastic under solar radiation can raise soil temperature above the thermal death point for most weed seedlings and seeds, especially where soil moisture is adequate. Solarization has been shown to suppress yellow (*Cyperus esculentus*) and purple nutsedge (*C. rotundus*), which are difficult to control with conventional methods (McSorley and Parrado, 1986).

Organic amendments often have been evaluated for nematode management (Muller and Gooch, 1982; Rodriguez-Kabana, 1986) although performance has been inconsistent and variable (Stirling, 1991). The improved soil environment following amendment application may even favor nematode population increases (McSorley *et al.*, 1997). Phytotoxic compounds from immature composts may also kill weed seeds and seedlings (Ozores-Hampton *et al.*, 1999). Summer cover crops such as certain cultivars of sorghum (*Sorghum bicolor*), cowpea (*Vigna unguiculata*), or marigold (*Tagetes* spp.) may be suppressive to *Meloidogyne incognita* and other species of root-knot nematodes (McSorley, 1996). It is possible that two or more of these methods may be integrated to successfully manage a susceptible crop. In general, such integrated approaches have been underutilized in nematode management (McSorley, 1996; Roberts, 1993).

The objective of this research was to test sustainable techniques for management of nematodes, weeds, and soil fertility on vegetables in an organic production system. Solarization, compost, cover crops and resistant varieties were evaluated, either alone or in combination.

MATERIALS AND METHODS

The experiment was conducted at a certified organic farm on Pine Island in Lee County, Florida. The soil was Immokalee fine sand (sandy, siliceous, hyperthermic Arenic Haplaquods) with 2.5% organic matter, and pH (1:2 soil:water) of 7.7. The experiment was conducted on two consecutive crops, fall 1997 and spring 1998. Main plots consisted of eight treatments that varied in regard to compost, solarization, summer cover crop, and susceptibility to root-knot nematodes (Table 1). Tomato (*Lycopersicon esculentum*) had been grown on the site during the previous spring season.

Each treatment was replicated four times in the fall and three times in the spring. Each plot of the first seven treatments (Table 1) was divided into two subplots, one randomly selected to be planted in fall with tomato ('Solimar' in fall and 'Sunbeam' in spring) and the other with pepper (*Capsicum annuum* 'Jupiter'). Crop order was reversed for the spring crop (pepper followed tomato and tomato followed pepper). The 'Sanibel' tomato treatment was used only in the spring crop. This treatment was planted to pepper in fall and to the root-knot resistant tomato cultivar 'Sanibel' in spring. Solarization in designated beds began 8 June and continued for 90 days prior to planting using clear high-density 0.75-mil polyethylene containing UV light inhibitors (Sonoco Products Co., Orlando, FL). Compost [horticultural waste and chicken litter (2:1 ratio)] containing 23.5% organic matter, 1.1% K, 1.4% P, with pH 7.4, was applied to plots of two treatments (Table 1) on 8 June before solarization at 22.4 Mt/ha and incorporated with a motorized rototiller. Cover crops planted in June included browntop millet (*Panicum ramosum*) at 1.1 kg/ha, 'Iron Clay' cowpea planted at 56 kg/ha, and marigold (*Tagetes minuta*) transplanted as 15-cm-tall seedlings spaced 25 cm apart in a double row at a popula-

Table 1. Summary of main plot treatments.

Treatment	Compost	Solarization	Summer cover crop	Main crops
Compost + solarization	Yes	Yes	None	Tomato/pepper
Solarization	No	Yes	None	Tomato/pepper
Compost	Yes	No	Weeds	Tomato/pepper
Control (weeds)	No	No	Weeds	Tomato/pepper
Millet cover crops	No	No	Millet	Tomato/pepper
Cowpea cover crop	No	No	Cowpea	Tomato/pepper
Marigold cover crop	No	No	Marigold	Tomato/pepper
'Sanibel' tomato	No	No	Cowpea	Resistant tomato

[z]Plots of the first seven treatments were split, with one half planted to a root-knot-susceptible variety of tomato and the other half with a susceptible variety of pepper during the fall season. The order reversed during the spring season. 'Sanibel' tomato was used only in the spring season, following a fall pepper crop.

tion equivalent to 43 242 plants/ha. Cover crop residues were incorporated with a rototiller in early September.

The fall crop was planted 24 September on raised beds 0.81 m wide, 0.1 m high, and 49 m long, with 1.8 m between centers. Beds were covered with white-faced black polyethylene mulch, except for the solarized beds which were sprayed with a mixture of white latex polyethylene paint: water (6:1) prior to planting. Tomato was planted at 45 cm spacing in a single row and pepper in double rows with 25 cm between plants, giving plant populations of 11 959 and 43 243 plants/ha respectively.

Prior to solarization or planting, all treatments were fertilized with crab meal at 1,340 kg/ha as a nitrogen source and a granular fertilizer formulation of 314 kg/ha K_2SO_4, 12kg/ha B, 63 kg/ha $FeSO_4$, 44 kg/ha $MnSO_4$, and 6 kg/ha $CuSO_4$. Note that the fertilizer had to be added before beds were covered with plastic; therefore the two treatments with solarization received this fertilizer in June. Plots were harvested in early January and replanted during the first week of February 1998. Crops were irrigated occasionally through a drip irrigation system.

Data collection: Soil samples for nematode analysis were collected from each subplot on 18 September 1997 and on 28 January and 18 June 1998. In addition, four pre-treatment samples (one from each replication) were collected on 21 May 1997. Each soil sample consisted of six soil cores 2.5 cm in diameter × 20 cm deep collected from the root zones of plants or from the center of the bed when no plants were present. The six soil cores comprising a sample were mixed and combined into a plastic bag. Samples were transported to the University of Florida campus in Gainesville, where 100-cm^3 subsamples were removed for extraction using a sieving and centrifugation method (Jenkins, 1964).

Soil samples for nutrient analyses were collected before the fall planting and after harvesting the spring crop. Samples were oven-dried, passed through a 1-mm screen, and extracted with Mehlich-I solution. The extract was analyzed for Ca, Mg, P, and K (Hanlon and DeVore, 1989). Soil pH was determined in a 1:2 dilution (v:v) with water, and organic matter (OM) was determined by ignition (Dellavalle, 1992).

Weed populations were visually evaluated only on solarized beds. Percent weed ground cover was estimated at 60 and 100 days after treatments (solarization, compost) were applied. Number and weight of marketable peppers or tomatoes were recorded from each plot in January for the fall crop, and number of marketable fruit was recorded in June for the spring crop.

Data were subjected to analysis of variance (ANOVA) with mean separation by Duncan's Multiple Range Test (SAS Institute, Cary, NC). Percent weed ground cover data were transformed by the arcsin-square-root transformation and nematode data were transformed by $\log_{10}(x + 1)$ prior to analysis. Untransformed data are reported in all tables.

RESULTS AND DISCUSSION

Nematodes: Pre-treatment mean nematode population levels per 100 cm^3 soil were: 653 *Meloidogyne incognita*, 5.8 *Paratrichodorus minor*, 1.5 *Criconemella* spp., 0.8 *Helicotylenchus* spp., and 0.2 *Hemicycliophora* spp. Following the summer treatments, *M. incognita* numbers were reduced more than 2 orders of magnitude (Table 2). Solarization was effective in reducing populations of the other nematodes as well. In contrast, high numbers of *M. incognita* persisted in soil in which weeds were allowed to grow. Numbers *M. incognita* were intermediate in treatments following cover crops, and there were no significant differences among cover crop treatments.

Table 2. Population levels of plant-parasitic nematodes in soil collected from experimental plots before planting fall crops, 18 September 1997.

Treatment	Nematodes per 100 cm^3 soil		
	Meloidogyne incognita	*Paratrichodorus minor*	*Criconemella* spp.
Compost + solarization	4 c[z]	0 b	1 c
Solarization	2 c	0 b	2 c
Compost	594 a	19 a	44 ab
Control (weeds)	429 a	28 a	38 ab
Millet cover crop	67 b	16 a	76 a
Cowpea cover crop	34 b	14 a	8 bc
Marigold cover crop	71 b	29 a	49 ab

[z]Data are means of four replications. Means in columns followed by the same letter do not differ ($P \leq 0.05$) according to Duncan's multiple-range test performed on log-transformed data.

Treatment effects on nematode numbers were less consistent following the fall and spring crops (Tables 3 and 4). Numbers of *P. minor* on tomato were greatest following the compost + solarization treatment in both the fall and spring crops (Tables 3, 4). The resurgence of stubby-root nematode populations following soil

Table 3. Population levels of plant-parasitic nematodes in soil collected at the end of the first tomato and pepper crops, 28 January 1998.

Treatment	Nematodes per 100 cm^3 soil					
	Tomato			Pepper		
	Meloidogyne incognita	*Paratrichodorus minor*	*Criconemella* spp.	*Meloidogyne incognita*	*Paratrichodorus minor*	*Criconemella* spp.
Compost + Solarization	27 a[z]	185 a	1 a	83 a	33 ab	7 b
Solarization	32 a	45 ab	24 a	71 a	58 a	17 ab
Compost	14 a	169 ab	6 a	20 ab	2 c	29 ab
Control (weeds)	64 a	36 b	6 a	4 b	8 bc	15 ab
Millet cover crop	8 a	144 ab	14 a	19 ab	3 c	46 a
Cowpea cover crop	10 a	15 b	8 a	1 b	6 c	2 c
Marigold cover crop	34 a	134 ab	6 a	11 b	2 d	24 ab

[z]Data are means of four replications. Means in columns followed by the same letter do not differ ($P \leq 0.05$) according to Duncan's multiple-range test performed on log-transformed data. There were no differences ($P \leq 0.10$) between numbers on tomato and pepper.

Table 4. Population levels of plant-parasitic nematodes in soil collected at the end of the second tomato and pepper crops, 18 June 1998.

	Nematodes per 100 cm³ soil					
	Tomato			Pepper		
Treatment	*Meloidogyne incognita*	*Paratrichodorus minor*	*Criconemella* spp.	*Meloidogyne incognita*	*Paratrichodorus minor*	*Criconemella* spp.
Compost + Solarization	146 a[z]	48 a	1 a	20 a	3 a	1 a
Solarization	59 a	17 ab	2 a	2 a	3 a	<1 a
Compost	247 a	6 b	0 a	3 a	2 a	0 a
Control (weeds)	105 a	4 b	0 a	4 a	0 a	2 a
Millet cover crop	31 a	6 b	<1 a	5 a	<1 a	0 a
Cowpea cover crop	230 a	10 ab	<1 a	6 a	<1 a	5 a
Marigold cover crop	124 a	7 b	1 a	10 a	3 a	1 a
'Sanibel' tomato	0 a	5 b	<1 a	—	—	—

[z]Data are means of three replications. Means in columns followed by the same letter do not differ ($P \leq 0.05$) according to Duncan's multiple-range test performed on log-transformed data. Dashes (—) indicate treatment not included in Spring planting.

fumigation is well-known (Weingartner *et al.*, 1983). The current data suggest that resurgence of this nematode may occur after solarization as well.

Lack of consistent trends and relatively low populations of *M. incognita* after the fall and spring crops may have been partly due to unseasonable weather. Heavy rainfall occurred during the fall crop, submerging plots on several occasions. Conversely, conditions were unusually dry during the spring crop, which affected the size of the pepper plants. However, in general, it appeared that the initial beneficial effects of cover crops and solarization on root-knot nematode populations were largely lost once a susceptible vegetable crop like tomato or pepper was grown. Final population densities of *M. incognita* across treatments were relatively uniform following the first tomato crop (Table 3). These results are consistent with previous observations that the beneficial effects of these treatments may last for only a single crop (McSorley, 1996, 1998).

'Sanibel' tomato was included only in the spring experiment. On 28 January, prior to planting, nematode numbers per 100 cm³ soil in plots receiving this treatment averaged 47 *M. incognita*, 63 *P. minor*, and 38 *Criconemella* spp. These numbers were fairly high compared to numbers present in other plots (Table 3) at that time. Variability in *M. incognita* numbers among various plots on 18 June 1998 did not permit any separations among treatments at that time with ANOVA and Duncan's multiple range test. However for *M. incognita* numbers on 18 June 1998, the contrast between the 'Sanibel' tomato treatment vs. all other treatments (which had 'Sunbeam' tomato) was highly significant ($F = 9.5$; $P \leq 0.01$). The fact that no root-knot nematodes were found in any sample from 'Sanibel' tomato was encouraging, especially during a time of year (May, June) when warm temperatures occurred. High soil temperatures are associated with the loss of resistance to root-knot nematodes in some plants (Dropkin, 1969; Sydenham *et al.*, 1997).

Yields: Yields also did not show consistent treatment effects, again possibly due to erratic growing conditions and resulting variability among plants (Table 5). Yields were low for the spring crop, during which dry conditions prevailed. The most significant effect observed in the spring experiment was the higher yield of 'Sanibel' tomato, more than double that of 'Sunbeam' tomato in the other plots. While this observation appears consistent with the root-knot nematode levels reported here, the yield potential of 'Sanibel' vs. 'Sunbeam' under field conditions without root-knot nematodes should be investigated further.

Soil properties and nutrients: Mean values of soil organic matter in plots receiving the various treatments ranged from 2.1-2.8% in June 1997 and from 3.0-3.3% in June 1998. Soil pH ranged from 7.4-7.7 in June 1997 and from 7.4-7.6 in June 1998. In June 1997, ranges in concentrations of macronutrients in soil were: 903-1125 mg/kg for P, 41-224 mg/kg for K, 133-192 mg/kg for Mg, and 1.01-1.33% for Ca. In June 1998, ranges were: 915-1036 mg/kg for P, 131-207 mg/kg for K, 190-227 mg/kg for Mg, and 1.00-1.16% for Ca. At the end of the experiment in June 1998, no differences ($P \leq 0.10$) with treatment were observed in organic matter, pH, or levels of any macronutrient. It appears that the treatments had no effect on the soil properties measured.

Weeds: Both solarization treatments were populated primary by grass species. However, the presence of compost during solarization reduced weed cover for 60 and 100 days after treatment compared with solarization alone. At 60 days, weed cover averaged 14.7% in plots with compost vs. 38.3% in plots without compost ($P \leq 0.05$), whereas at

Table 5. Influence of solarization, compost, and cover crop on yield of pepper and tomato.

Treatment	Pepper			Tomato		
	Fall crop		Spring crop (number/plot)	Fall crop		Spring crop (number/plot)
	Marketable yield (MT/ha)	Fruit size (g/fruit)		Marketable yield (MT/ha)	Fruit size (g/fruit)	
Compost + Solarization	3.96 a[z]	150 a	320 ab	2.19 a	141 a	324 b
Solarization	1.25 c	82 c	282 b	0.94 a	132 a	296 b
Compost	1.83 bc	118 ab	267 b	0.88 a	141 a	251 b
Control	1.12 c	104 bc	210 b	1.14 a	136 a	255 b
Millet cover crop	1.84 bc	118 ab	267 b	1.27 a	154 a	216 b
Cowpea cover crop	1.35 c	95 bc	417 a	1.34 a	141 a	303 b
Marigold cover crop	3.01 ab	127 ab	318 ab	1.08 a	173 a	282 b
'Sanibel' tomato	—	—	—	—	—	683 a

[z]Data are means of four replications. Means in columns followed by the same letter do not differ ($P \leq 0.05$) according to Duncan's multiple-range test. Dashes (—) indicate treatment not included in experiment.

100 days, weed cover was 30.0% in plots with compost vs. 56.6% in plots without compost ($P \leq 0.05$). A suppressive effect on weeds of short-chain organic acids generated by immature composts has been previously documented (Ozores-Hampton *et al.*, 1999).

In summary, significant reductions in populations of *M. incognita* and other plant-parasitic nematodes occurred following three months of solarization. Cover crops were also effective in reducing numbers of *M. incognita.* However, reductions in nematode populations clearly did not persist through the spring crop. On the other hand, a clear yield benefit was obtained with the 'Sanibel' tomato cultivar used in the spring crop. Low populations of *M. incognita* in soil in which 'Sanibel' was grown provided evidence that this yield benefit could be due to nematode resistance. Therefore, it would appear that the combination of solarization or cover crops with a nematode-resistant cultivar may provide the organic vegetable grower with a viable means for managing root-knot nematodes.

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