INTEGRATED EFFECTS OF SOLARIZATION, SUNN HEMP COVER CROP, AND AMENDMENT ON NEMATODES, WEEDS, AND PEPPER YIELDS

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ABSTRACT

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Two field experiments were conducted in north Florida, U.S.A., to examine the effects of cover cropping, solarization, and amendment on nematode populations, weeds, and pepper (*Capsicum annuum*) yields. Treatments involved two levels (+ or -) of sunn hemp (*Crotalaria juncea*) cover crop, two levels of solarization, and two levels of amendment with dry sunn hemp residue added into transplant holes, for a total of 8 treatment combinations, replicated 6 times. Cover cropping reduced levels of ring nematodes (*Mesocriconema* spp.) but did not affect any other measured variables. Root-knot nematodes (*Meloidogyne incognita*) were unaffected by treatments except for a slight decrease in root galling resulting from amendment in the 2007 experiment. Solarization greatly decreased weed levels in both seasons, especially the high levels of crabgrass (*Digitaria* spp.) present in 2007. Pepper yields were unaffected by treatments in 2006 but were increased by solarization and amendment in 2007. Yield differences in the two seasons were due to the impact of managing much higher weed populations in 2007. In this regard, solarization was much more beneficial than a cover crop in the summer before fall vegetable production. Addition of amendment to planting holes along with pepper seedlings had a positive impact on plant growth and provided a method for introducing relatively small amounts of amendment (rather than broadcast over a large area) to a field site.

Key words: Capsicum annuum, Crotalaria juncea, integrated pest management, *Meloidogyne incognita, Mesocriconema* spp., ring nematodes, root-knot nematodes, sustainable agriculture.

RESUMEN

McSorley, R., K.-H. Wang, and J. J. Frederick. 2008. Efectos integrados de la solarización, cobertura con crotalaria y enmienda, sobre los nematodos, las malezas y el rendimiento del pimiento. Nematropica 38:115-125.

Se condujeron dos experimentos de campo en el norte de Florida, EEUU, para estudiar los efectos de un cultivo de cobertura, la solarización y la enmienda sobre las poblaciones de nematodos, las malezas y el rendimiento del pimiento (*Capsicum annuum*). Los tratamientos fueron dos niveles (+ ó -) de crotalaria (*Crotalaria juncea*) como cultivo de cobertura, dos niveles de solarización, y dos niveles de enmienda con residuos de crotalaria seca adicionados al momento del transplante, para un total de 8 combinaciones de tratamientos, replicados 6 veces. El cultivo de cobertura redujo los niveles de nematodos anillados (*Mesocriconema* spp.) pero no afectó ninguna otra de las variables medidas. Ninguno de los tratamientos afectó al nematodo agallador (*Meloidogyne incognita*), con excepción de una leve disminución en el agallamiento observada con la enmienda en el experimento de 2007. La solarización redujo considerablemente los niveles de malezas ambos años, especialmente los altos niveles de *Digitaria* spp. presentes en 2007. Los tratamientos no afectaron los rendimientos del cultivo en 2006, pero la solarización y la enmienda aumentaron los rendimientos en 2007. Las diferencias en el rendimiento del cultivo entre los dos años se debieron al impacto de la más alta población de malezas en 2007. En este aspecto, la solarización fue mucho más efectiva que el cultivo de cobertura en el verano. La aplicación de la enmienda al momento del transplante tuvo un impacto positivo sobre el crecimiento de las plantas y fue una buena manera de añadir cantidades relativamente pequeñas de enmienda (al aplicar sólo en el hoyo de transplante en vez de en todo el campo).

Palabras clave: Capsicum annuum, Crotalaria juncea, manejo integrado de plagas, *Meloidogyne incognita, Mesocriconema* spp., nematodos anillados, nematodos agalladores, agricultura sostenible.

INTRODUCTION

A variety of non-chemical methods are available for managing plant-parasitic nematodes, weeds, and other soil-borne pest problems (McSorley, 1998; Radosevich *et al.*, 1997; Rechcigl and Rechcigl, 1997). Several important methods that may target plant-parasitic nematodes are useful in managing weeds and improving crop fertility as well. For example, soil solarization has been used for managing nematodes and soil-borne diseases (Katan, 1981; Katan *et al.*, 1976; McGovern and McSorley, 1997), and this practice is also quite effective against weeds (Ellmore, 1991).

A wide variety of rotation and cover crops has been used to reduce plant-parasitic nematode populations (McSorley, 2001; Rodriguez-Kabana *et al.*, 1988; Wang *et al.*, 2007), and many of these, especially legumes, can benefit soil fertility and nutritional needs of subsequent crops (Cherr *et al.*, 2006). Interest has increased in legumes that are suppressive to key nematode pests such as root-knot nematodes (*Meloidogyne* spp.) (Rodriguez-Kabana *et al.*, 1992; Wang *et al.*, 2002a; 2003; 2008; Weaver *et al.*,1998). Sunn hemp (*Crotalaria juncea* L.) has much potential in this regard, due to its ability to suppress a variety of nematodes when grown as a cover crop (Wang *et al.*, 2002a) and the high nitrogen content supplied per ha due to its large biomass (Cherr *et al.*, 2006). The effects of cover crops on pests and on crop performance can be difficult to separate since both rotation effects and amendment effects may be present. A growing cover crop may suppress nematodes and also may continue to provide additional fertility or other benefits from its residues after the cover crop has been mowed and incorporated. In a recent study in which rotation effects and amendment effects were separated, growing sunn hemp or cowpea (*Vigna unguiculata* (L.) Walp.) did not suppress *Meloidogyne* spp. relative to fallow, but the mulched crop residues were suppressive in some instances (Wang *et al.*, 2008). Mulching strongly increased crop yield, but rotation did not.

Amendments may impact plant-parasitic nematodes, either directly or indirectly. Residues of sunn hemp and related species were toxic or nematostatic to plant-parasitic nematodes (Jourand *et al.*, 2004; Rich and Rahi, 1995; Wang *et al.*, 2002b). However, it is also possible that amendments may stimulate nematode antagonists in the soil food web (Ettema and Bongers, 1993; Jaffee, 2004; Wang *et al.*, 2004a, b).

The main objective of the current study was to compare the effects of solarization, cover crop, and rhizosphere amendment, separately and in combination, on plant-parasitic nematodes and crop yield. Supplemental amendments were applied only in the plant rhizosphere, to reduce the amount needed compared to a broadcast application.

MATERIALS AND METHODS

Field Description

Experiments were conducted at the University of Florida Plant Science

Research and Education Unit (29°24'N, 82°9'W), located near Citra in Marion Co., FL. The soil was Arredondo sand (95% sand, 2% silt, 3% clay) with 1.5% organic matter, and the site had been planted with okra (*Hibiscus esculentus* L.) in 2005. The site (approximately 0.2 ha) was disked and rototilled in spring 2006, prior to establishing experiments in the site in 2006 and 2007.

2006 Experiment

On 9 May 2006, a field experiment was established as a 2 × 2 factorial with six replications in a randomized complete block design. The treatments were combinations of two levels of solarization (+ or -) and summer cover crop (+ or -). Plots were oriented E-W, and individual plots were 12.2 m long and 1.8 m wide.

For the summer cover crop treatment, seed of sunn hemp (*Crotalaria juncea*) was drilled in rows 19 cm apart at a rate of 47 kg/ha on 9 May. Natural rainfall was low, so overhead irrigation was applied to the site as needed. Stand count measured on 12 June was 32.67 plants per m^2. Grasses, particularly *Digitaria* spp., grew well in this site even with sunn hemp present. Therefore clethodin (Select® herbicide, Arysta Life Science Corp., Tokyo, Japan) was applied at 0.19 L/ha to the entire site on 6 July. The sunn hemp cover crop was mowed on 17 July when plants were about 1.0 m tall, and all plots were rototilled on 27 July.

On 1 August, a single raised bed (0.76 m wide at top) was formed in each plot. Beds were either left uncovered or solarized by covering with clear, 25-μm-thick, UV-stabilized, low-density polyethylene mulch (ISO Poly Films, Inc., Gray Court, SC). The polyethylene mulch was removed on 28 August, and all plots, including those not solarized, were covered with opaque, silver reflective plastic mulch (Sonoco Agricultural Films, Hartsville, SC). Holes for future transplants were punched into the plastic in two rows, spaced 30 cm apart, with a spacing of 46 cm between plants in each row.

On 29 August, each plot was split into two equal subplots, thus expanding treatment combinations to solarization (+ or -) × cover crop (+ or -) x amendment (+ or -). Sunn hemp for the amendment had been obtained previously by cutting a summer cover crop (sunn hemp at pre-bloom stage and about 1.5 m tall) from the field border adjacent to the plot sites. The cut sunn hemp hay was dried to constant weight in an oven at 60°C, ground in a Wiley mill to form powder, and then applied at a rate of 6 g per planting hole (5-cm-diam × 7-cm-deep) in subplots receiving the amendment treatment. Analysis of this dried sunn hemp amendment using an aluminum block digester method (Gallaher *et al.*, 1976) revealed N content of 3.27%, equivalent to 4.7 kg N/ha. Cover crop treatments with sunn hemp had already included some amendment during the summer from rototilling the crop residues. However, the purpose of the "amendment" treatment described here was to supply a concentrated supplemental amendment application directly to the crop rhizosphere. Thus the "amendment" treatment in the current study refers only to this rhizosphere application.

Seedlings of 'Aristotle' bell pepper (*Capsicum annuum* L.) obtained from Barnett Partin Plants (Immokalee, FL) were transplanted on 7 September. At the time of transplanting, seedlings were two-months-old and approximately 10-12 cm tall. The transplants were chlorotic, and immediately after transplanting, each plant was fertilized with 2 g of 19-6-12 (N-P_2O_5-K_2O) slow-release fertilizer (Osmocote Smart-Release® Plant Food, Scotts-Sierra Horticultural Products Co., Marysville, OH). This was equivalent to 9.2 kg N/ha in unamended subplots at the time of transplanting, whereas total N applied in amended subplots was 13.9 kg N/ha (4.7 kg N from the sunn hemp amendment). Water was applied daily through a drip irrigation system, and fertilizer applications through the irrigation system were begun on 10 October at a rate of 5.6 kg N/ha per week, increasing to 7.8 kg N/ha per week on 17 October, and finally on 24 October to 11.2 kg N/ha per week for the rest of the season. The total amount of N applied over the season was 123.4 kg N/ha in unamended subplots and 128.1 kg N/ha in amended subplots. Problems with foliar diseases and insects were minimal, but all plots were treated twice with a *Bacillus thuringiensis* product for management of beet armyworm (*Spodoptera exigua* (Hubner).

Numbers of weeds per main plot were counted after solarization on 28 August. The number of planting holes in each subplot that contained weed seedlings was counted on 10 October, after which the weed seedlings were removed. Plant heights were measured from 5 plants per subplot on 10 October. Peppers were harvested 7 times between 14 November 2006 and 3 January 2007. Marketable fruits were picked from 20 plants per subplot and graded into the following categories (Saha et al., 2007): U.S. Fancy grade, U.S. No. 1, and U.S. No. 2 grade.

Soil samples for nematode analysis were collected before cover crop planting (2 May), and from main plots following the cover crop (3 August) and solarization (29 August), and from all subplots at the end of the experiment (10 January). Six soil cores (2.5-cm-diam × 20-cm-deep) were collected from each plot or subplot and combined into one composite sample. Nematodes were extracted from a 100-cm^3 subsample using a modified sieving and centrifugation method. At the final sampling (10 January), 6 plants were removed from each subplot and rated for root galling on a 0 to 5 scale, where 0 = 0 galls per root system; 1 = 1-2 galls; 2 = 3-10 galls; 3 = 11-30 galls; 4 = 31-100 galls; 5 = >100 galls per root system (Taylor and Sasser, 1978).

2007 Experiment

The experiment was repeated in 2007 in the same plots with identical treatments. Protocols and timing of events were similar to 2006, but with several important differences. Sunn hemp was planted at a higher seeding rate (76 kg/ha) in 2007, but produced a lower stand count (23.94 plants per m^2 in 2007 vs. 32.67 in 2006), yet grew more vigorously. The sunn hemp cover crop competed with weeds more effectively in 2007, therefore no herbicide was applied during the cover crop season and no hand weeding was done in the pepper crop in 2007. Higher weed densities occurred in late August in 2007 compared to 2006, so rather than counting weeds directly on 28 August 2007, the percentage surface area of each bed covered by weeds was rated using the 1 to 12 rating scale of Horsfall and Barratt (1945), where 1 = 0%, 2 = 0-3%, 3 = 3-6%, 4 = 6-12%, 5 = 12-25%, 6 = 25-50%, of surface area covered, whereas 7 = 25-50%, 8 = 12-25%, 9 = 6-12%, 10 = 3-6%, 11= 0-3%, and 12 = 0% of area not covered.

In 2007, solarization was performed for 5 weeks, compared to 4 weeks in 2006. The sunn hemp hay used as the amendment was chopped into small (ca. 1-2 cm) pieces instead of grinding into powder as in 2006. The pepper transplants were not N-deficient, so the application of slow-release fertilizer at planting was omitted in 2007. A fertilizer rate of 11.2 kg N/ha per week through the drip irrigation system was implemented on 20 September 2007. The total amount of N applied over the season was 89.6 kg N/ha in unamended subplots and 94.3 kg N/ha in amended subplots, including 4.7 kg (5.0%) organic N from the amendment. An important difference between the two seasons was the occurrence of an unusual early freeze on 17 November 2007. Therefore, only two pepper harvests (7 and 20 November) were obtained in 2007, and the experiment was terminated 5 weeks earlier than in the previous year, with final soil samples for nematode analysis collected on 4 December.

Statistical Analysis

Data were analyzed by analysis of variance (ANOVA) using MSTAT-C (Michigan State University, East Lansing, MI) software. A 2 × 2 factorial ANOVA was used when data were collected only from main plots, and a 2 × 2 × 2 design (with amendment split on main plots) was used when data were collected from all subplots. Nematode data were log-transformed by $\log_{10}(x + 1)$ prior to ANOVA, but untransformed arithmetic means are presented for all data.

RESULTS

Nematodes present at the beginning of the experiment in 2006 included root-knot (*M. incognita* (Kofoid and White) Chitwood) averaging 10.8 per 100 cm^3 soil, ring (*Mesocriconema* spp.) at 26.3 per 100 cm^3 soil, and stubby-root (*Paratrichodorus* spp.) at 3.0 per 100 cm^3. No differences occurred among plots at the beginning of the experiment. *Paratrichodorus* spp. declined to 0.7 per 100 cm^3 by the end of summer 2006 and was rarely detected after that point. Levels of *Mesocriconema* spp. were reduced after the sunn hemp cover crop incorporation in late July-early August in 2007 but not in 2006 (Tables 1 and 2). However, at the end of August prior to planting of the pepper crop, significant suppression of *Mesocriconema* spp. by the cover crop was observed in both years (Tables 1 and 2).

Table 1. Effect of sunn hemp cover crop and solarization on plant-parasitic nematodes and weeds, following termination of cover crops and termination of solarization in 2006.

	Nematodes per 100 cm^3 soil		Weeds per plot		
Treatment	*Mesocriconema*	*Meloidogyne*	Grass	Broadleaf	Nutsedge
	Termination of cover crop[y]				
Cover crop	28.5	2.0			
No cover crop	47.7	2.5			
	Termination of solarization[z]				
Cover crop	22.8*	0.2	6.2	5.2	15.3
No cover crop	42.0	0.5	15.2	3.7	8.4
Solarized	29.2	0.6	0*	0**	3.2
Not solarized	35.7	0.2	21.5	8.9	20.6

[y]Data are means of 6 replications.

[z]Data are means pooled across 12 plots.

**,*Indicate significant differences from corresponding non-treated at P ≤ 0.01 and P ≤ 0.05. No significant interactions at P ≤ 0.05.

Table 2. Effect of sunn hemp cover crop and solarization on plant-parasitic nematodes and weed coverage of plots, following termination of cover crops and termination of solarization in 2007.

	Nematodes per 100 cm³ soil		Horsfall-Barratt rating[x]		
Treatment	*Mesocriconema*	*Meloidogyne*	Grass	Broadleaf	Total
	Termination of cover crop[y]				
Cover crop	7.7**	39.2			
No cover crop	72.0	90.2			
	Termination of solarization[z]				
Cover crop	9.5**	0.1	4.00	3.25	4.50
No cover crop	50.2	0.3	3.83	3.33	4.33
Solarized	25.5	0.3	1.00**	1.00**	1.00**
Not solarized	34.2	0.1	6.83	5.58	7.83

[x]Rating on scale from 1 (0% of plot area covered by weeds) to 12 (100% of plot area covered by weeds). See text for complete rating scale.
[y]Data are means of 6 replications.
[z]Data are means pooled across 12 plots.
**Indicates significant difference from corresponding non-treated at $P \leq 0.01$. No significant interactions at $P \leq 0.05$.

These effects persisted to a lesser extent ($P \leq 0.10$) through the subsequent pepper crop until the end of each experiment (2006: 6.7/100 cm^3 soil with cover crop; 12.9/100 cm^3 without cover crop; 2007: 35.9/100 cm^3 with cover crop; 54.7/100 cm^3 without cover crop). Root-knot nematode juveniles in soil were not affected by any of the treatments (Tables 1 and 2). However, root galling was reduced ($P \leq 0.05$) by the amendment treatment in the 2007 experiment, averaging 3.50 in plots with amendment and 3.74 in plots without amendment. Root galling was unaffected by amendment in 2006 and averaged only 1.76 across all plots (data not shown).

In both years, weeds were greatly reduced by solarization but not by the cover crop (Tables 1 and 2). The predominant weed was crabgrass (*Digitaria* spp.). The most common broadleaf weeds present were carpetweed (*Mollugo verticillata* L.), hairy indigo (*Indigofera hirsuta* L.), purslane (*Portulaca* spp.), and Florida pusley (*Richardia scabra* L.), with traces of pigweed (*Amaranthus* spp.). Nutsedge (predominately *Cyperus rotundus* L. with some *C. esculentus* L.) was present in late summer of 2006 but not in 2007. In general, weeds were much more abundant in 2007 than in 2006 (Tables 1 and 2). In 2006, a few small weed seedlings occurred in the planting holes along with the pepper plants, but these were not affected by treatments (Table 3). In 2007, much growth of crabgrass occurred in the planting holes along with the pepper plants in non-solarized plots (Table 3), reducing the stand count of pepper plants (0.67 missing plants in solarized, 2.42 missing plants in non-solarized plots; $P \leq 0.01$).

The sunn hemp amendment increased the early-season height of pepper plants in 2007 (Table 3) but only

Table 3. Effect of cover crop, solarization, and amendment on plant height and number of planting holes with weeds, 2006 and 2007.[z]

	Planting holes with weeds			Plant height (cm)		
Treatment	10 Oct. 06	2 Oct. 07	25 Oct. 07	10 Oct. 06	2 Oct. 07	25 Oct. 07
Cover crop	11.9	11.5	12.5	15.3	17.4	23.5
No cover crop	11.8	12.3	14.1	15.6	16.9	22.5
Solarized	11.8	2.0**	3.8**	16.5**	16.9	22.1*
Not solarized	11.8	21.8	22.8	14.4	17.4	23.9
Amendment	11.7	12.0	12.5	15.7	17.9**	23.6
No amendment	12.0	11.8	14.1	15.2	16.4	22.3

[z]Data are means pooled across 24 subplots.
**,*Indicate significant differences from corresponding non-treated at $P \leq 0.01$ and $P \leq 0.05$, respectively. No significant interactions at $P \leq 0.05$.

marginally in 2006 ($P \leq 0.10$). Solarization also increased plant height in the 2006 experiment but decreased plant height in 2007. Pepper plants in non-solarized plots in 2007 were etiolated because of severe weed competition. Pepper yields were not affected by any of the treatments in 2006 (data not shown). However in 2007, pepper yields in all grades were greatly improved by solarization (Table 4). Amendment treatment improved yields for the two largest grades of fruit, but not for the lowest grade (U.S. No. 2). A significant solarization x amendment interaction occurred for both number and weight of U.S. No. 1 fruit in 2007 (Table 5). In both cases, amendment significantly improved yield of pepper plants in solarized plots, but not in non-solarized plots.

Table 4. Effect of cover crop, solarization, and amendment on pepper harvest (grade, number, weight), 2007 experiment[z].

	Fancy		U.S. No. 1		U.S. No. 2	
Treatment	No.	Wt. (kg)	No.	Wt. (kg)	No.	Wt. (kg)
Cover crop	0.21	0.03	3.08	0.38	12.38	0.52
No cover crop	0.25	0.04	2.42	0.30	10.17	0.45
Solarized	0.42*	0.07*	4.62**	0.58**	16.83**	0.71**
Not solarized	0.04	0.01	0.88	0.11	5.71	0.25
Amendment	0.33	0.06	4.12**	0.52**	12.62	0.55
No amendment	0.12	0.02	1.38	0.16	9.92	0.41

[z]Data are means pooled across 24 subplots, total of 2 harvests.
**,*Indicate significant differences from corresponding non-treated at $P \leq 0.01$and $P \leq 0.05$, respectively. See Table 5 for significant interactions.

Table 5. Interactions of solarization and amendment on pepper harvest (number and weight of U.S. No. 1 grade), 2007 experiment[z].

Treatments		No.	Wt. (kg)
Solarized	Amendment	6.92**	0.89**
Solarized	No amendment	2.33	0.27
Not solarized	Amendment	1.33	0.16
Not solarized	No Amendment	0.42	0.05

[z]Data are means pooled across 12 subplots, total of 2 harvests.
** Indicates significant difference from corresponding non-amended at $P \leq 0.01$. No other interactions were significant at $P \leq 0.05$.

DISCUSSION

Fewer peppers were harvested in 2007 than in 2006 because an early freeze in 2007 limited the number of harvests. Another important difference between the two years was the weed pressure. In 2006, herbicide was used over the entire site during the cover cropping period, which greatly reduced levels of crabgrass. Subsequent solarization further reduced the weeds, but their numbers were still relatively low, even in non-solarized plots (Table 1), with a density of only 2.32 weeds per m^2 in plots with the highest weed densities. The further reduction of these relatively low weed levels by solarization did not have any effect on the crop yield. In contrast, management of the high weed populations and heavy infestation of crabgrass by solarization in 2007 had great impact on crop yield.

Nematode population densities were not affected much by solarization. This was somewhat surprising since solarization has been used to reduce nematode population levels (McGovern and McSorley, 1997). However, the solarization periods used here (4 wk and 5 wk) were somewhat shorter than the 6 wk or more used in some other studies in Florida (McGovern *et al.*, 2002; McSorley *et al.*, 1999). Recent work has shown that a 4-wk solarization period was as effective as 6-wk solarization for weed management (Seman-Varner, 2006), but this is not true for nematodes, based on the results from the shorter solarization times used here. Regardless of solarization efficacy or duration, root-knot nematode levels typically recover by the end of a susceptible vegetable crop (McSorley *et al.*, 1999). *Mesocriconema* spp. was consistently affected by cover cropping in both experiments. During the 2 months when cover crops were present, it is likely that the crabgrass growing in the plots without cover crop provided a better host for *Mesocriconema* spp. than the sunn hemp cover crop. Cover crops had no impact on pepper yield in either season. In 2007, when weeds were managed only by the experimental treatments (and not by herbicide), relatively few weeds occurred in the sunn hemp cover crop. However, once the sunn hemp was removed, crabgrass grew quickly in the site and the previous cover crop was of no benefit for subsequent weed management. In an experiment conducted in south Florida, *M. incognita* was suppressed more by solarization than by various cover crops (McSorley *et al.*, 1999). In another study on peppers in Florida, integration of solarization with a cowpea cover crop resulted in suppression of *M. incognita* equivalent to that achieved by soil fumigation with methyl bromide (Saha *et al.*, 2007). However, solarization alone was much better than the combination with cover crop in managing *Pythium* spp., so yield was greatest with solarization alone (Saha *et al.*, 2005; 2007).

In the current experiment, amendment treatment improved yield but cover crop rotation did not. Results were similar to a recent experiment in which rotation and amendment effects were distinctly separated, with the finding that amendment greatly benefitted vegetable yield while summer rotation did not (Wang *et al.*, 2008). In the current study, addition of sunn hemp amendment to the planting holes just prior to transplanting resulted in some increase in early-season plant height and increased number and weight of the U.S. No. 1 fruit grade in 2007. The amendment could stimulate plant growth in several ways; it contains N and other nutrients, and the amendment could enrich the soil food web, increasing microbes, free-living nematodes, and possibly nematode antagonists. It is likely that the former mechanism (nutrient release) was more important in the current study, as suggested by the early-season growth stimulation. Nutrient release from an amendment could occur relatively quickly and likely benefit a plant during its first month of growth. Stimulation of antagonists such as predatory and omnivorous nematodes should take more time and show effects later (McSorley and Frederick, 1999; Wang *et al.*, 2004b). Many nematode-antagonistic fungi also require some time before they can reduce nematode population levels (Chen and Dickson, 2004). No effect of amendment on plant-parasitic nematodes was observed, other than a slight reduction in root galling in 2007. Yield benefits from amendment were observed in 2007 but not in 2006. It is likely that the sunn hemp amendment was more persistent in 2007, providing opportunity for nutrient release over a longer period of time, since chopped material was used in 2007 and powdered form in 2006. It is not clear if root-knot nematodes had much impact on crop yield in the current experiment, but the slight reduction in galling from amendment treatment is consistent with possible reduction of nematodes by antagonists or other means, so this idea cannot be completely ruled out. The possibility of using amendments to consistently stimulate natural enemies and ultimately reduce plant parasites will require further research and testing. The delivery of amendments into planting holes directly targets the plant rhizosphere and concentrates, yet greatly reduces, the total amount of amendment needed compared to broadcast treatment of an agricultural site. This should reduce the amounts and costs of materials needed for research and future application of amendment products.

Of the management treatments evaluated, solarization had the greatest impact on crop yield, mainly due to its efficacy against weeds. For the most part, treatments acted independently, and interactions and synergistic effects were rare. Such effects occurred only with U.S. No. 1 grade pepper yield in 2007, with a great benefit from the combination of solarization and amendment that resulted in three times the yield levels observed with any of the other treatment combinations. Plants grown in solarized soil may have been in a better position to benefit from the additional nutrients supplied by the amendments, compared to the non-solarized plants which suffered competition from the high levels of crabgrass. Of course, future results with any combination of similar treatments would depend on the pest complexes present. Based on current results, it is likely that a solarization period of 6 weeks or more is needed for nematode management. Combining solarization with a cover crop may take 4 months or more. In the present case, devoting extra time during the summer season to a cover crop in addition to solarization did not provide any additional benefits.

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LITERATURE CITED

Chen, S., and D. W. Dickson. 2004. Biological control of nematodes by fungal antagonists. Pp. 979-1039 *in* Z. X. Chen, S. Y. Chen, and D. W. Dickson, eds. Nematology Advances and Perspectives. Tsinghua University Press, Beijing, China.

Cherr, C. M., J. M. S. Scholberg, and R. McSorley. 2006. Green manure approaches to crop production: A synthesis. Agronomy Journal 98:302-319.

Ellmore, C. L. 1991. Weed control by solarization. Pp. 61-72 *in* J. Katan and J.E. DeVay, eds. Soil Solarization. CRC Press, Boca Raton, FL.

Ettema, C. H., and T. Bongers. 1993. Characterization of nematode colonization and succession in disturbed soil using the maturity index. Biology and Fertility of Soils 6:79-85.

Gallaher, R. N., C. O. Weldon, and F. C. Boswell. 1976. A semi-automated procedure for total nitrogen in plant and soil samples. Soil Science Society of America Proceedings 40:887-889.

Horsfall, J. G., and R. W. Barratt. 1945. An improved grading system for measuring plant diseases. Phytopathology 35:655.

Jaffee, B. A. 2004. Do organic amendments enhance the nematode-trapping fungi *Dactylellina haptotyla* and *Arthrobotrys oligospora*? Journal of Nematology 36:267-275.

Jourand, P., S. Rapior, M. Fargette, and T. Matielle. 2004. Nematostatic effects of a leaf extract from *Crotalaria virgulata* subsp. *grantiana* on *Meloidogyne incognita* and its use to protect tomato roots. Nematology 6:79-84.

Katan, J. 1981. Solar heating (solarization) of soil for control of soilborne pests. Annual Review of Phytopathology 19:211-236.

Katan, J., A. Greenberger, H. Alon, and A. Grinstein. 1976. Solar heating by polyethylene mulching for the control of diseases caused by soil-borne pathogens. Phytopathology 66:683-688.

McGovern, R. J., and R. McSorley. 1997. Physical methods of soil sterilization for disease management including soil solarization. Pp. 283-313 *in* N. A. Rechcigl and J. E. Rechcigl, Eds. Environmentally Safe Approaches to Crop Disease Control. CRC Lewis Publishers, Boca Raton, FL.

McGovern, R. J., R. McSorley, and M. L. Bell. 2002. Reduction of landscape pathogens in Florida by soil solarization. Plant Disease 86:1388-1395.

McSorley, R. 1998. Alternative practices for managing plant-parasitic nematodes. American Journal of Alternative Agriculture 13:98-104.

McSorley, R. 2001. Multiple cropping systems for nematode management: A review. Soil and Crop Science Society of Florida Proceedings 60:132-142.

McSorley, R., and J. J. Frederick. 1999. Nematode population fluctuations during decomposition of specific organic amendments. Journal of Nematology 31:37-44.

McSorley, R., M. Ozores-Hampton, P. A. Stansly, and J. M. Conner. 1999. Nematode management, soil fertility, and yield in organic vegetable production. Nematropica 29:205-213.

Radosevich, S., J. Holt, and C. Ghersa. 1997. Weed ecology. Implications for management. 2nd Ed., John Wiley and Sons, New York.

Rechcigl, N. A., and J. E. Rechcigl, Eds. 1997. Environmentally safe approaches to crop disease control. CRC Lewis Publishers, Boca Raton, FL.

Rich, J. R., and G. S. Rahi. 1995. Suppression of *Meloidogyne javanica* and *M. incognita* on tomato with ground seed of castor, *Crotalaria*, hairy indigo, and wheat. Nematropica 25:159-164.

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

Rodriguez-Kabana, R., J. W. Kloepper, D. G. Robertson, and L. W. Wells. 1992. Velvetbean for the management of root-knot and southern blight in peanut. Nematropica 22:75-80.

Saha, S. K., R. McSorley, K.-H. Wang, and R. J. McGovern. 2005. Impacts of extreme weather and soil management techniques on disease development of *Pythium* spp. in field grown pepper. Proceedings of the Florida State Horticultural Society 118:146-149.

Saha, S. K., K.-H. Wang, R. McSorley, R. J. McGovern, and N. Kokalis-Burelle. 2007. Effect of solarization and cowpea cover crop on plant-parasitic nematodes, pepper yields, and weeds. Nematropica 37:51-63.

Seman-Varner, R. 2006. Ecological effects of solarization duration on weeds, microarthropods, nematodes, and soil and plant nutrients. M.S. thesis, University of Florida, Gainesville, FL.

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

Wang, K.-H., B. S. Sipes, and D. P. Schmitt. 2002a. *Crotalaria juncea* as a cover crop for nematode management: A review. Nematropica 32:35-57.

Wang, K.-H., B. S. Sipes, and D. P. Schmitt. 2002b. Management of *Rotylenchulus reniformis* in pineapple, *Ananas comosus*, by intercycle cover crops. Journal of Nematology 34:106-114.

Wang, K.-H., R. McSorley, and R. N. Gallaher. 2003. Host status and amendment effects of cowpea on *Meloidogyne incognita* in vegetable cropping systems. Nematropica 33:215-224.

Wang, K.-H., R. McSorley, and R. N. Gallaher. 2004a. Effect of *Crotalaria juncea* amendment on squash infected with *Meloidogyne incognita*. Journal of Nematology 36:290-296.

Wang, K.-H., R. McSorley, A. J. Marshall, and R. N. Gallaher. 2004b. Nematode community changes associated with decomposition of *Crotalaria juncea* amendment in litterbags. Applied Soil Ecology 27:31-45.

Wang, K.-H., R. McSorley, R. N. Gallaher, and N. Kokalis-Burelle. 2008. Cover crops and organic mulches for nematode, weed, and plant health management. Nematology 10:231-242.

Wang, Q., Y. Li, Z. Handoo, and W. Klassen. 2007. Influence of cover crops on populations of soil nematodes. Nematropica 37:79-92.

Weaver, D. B., R. Rodriguez-Kabana, and E. L. Carden. 1998. Velvetbean and bahiagrass as rotation crops for management of *Meloidogyne* spp. and *Heterodera glycines* in soybean. Supplement to the Journal of Nematology 30:563-568.

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