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Effects of Solarization and Ammonium Amendments on Plant-Parasitic Nematodes[1]

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Abstract: The effects of soil solarization and ammonium bicarbonate or ammonium sulfate against plant-parasitic nematodes on yellow squash (*Cucurbita pepo*) and on vinca (*Catharanthus roseus*) were evaluated at two sites. Solarization for 3 weeks in the spring suppressed population levels of *Belonolaimus longicaudatus, Criconemella* spp., and *Dolichodorus heterocephalus* throughout the growing season on both crops at both sites. Levels of *Meloidogyne incognita* were suppressed initially, but population densities increased by the end of the crop in several cases. In one site, numbers of *Paratrichodorus minor* resurged following solarization to levels that were greater than those present in unsolarized control plots. The effect of solarization was not enhanced by combination with ammonium amendments, but, in one site, application of ammonium bicarbonate or ammonium sulfate resulted in lower numbers of *B. longicaudatus* than in the unamended control. Additional research and improved efficacy of candidate amendments are required before they can be successfully integrated with solarization for nematode management. Efficacy of solarization against plant-parasitic nematodes was achieved despite a relatively short (3 weeks) solarization period.

Key words: ammonium bicarbonate, ammonium sulfate, *Belonolaimus longicaudatus, Catharanthus roseus, Cucurbita pepo, Dolichodorus heterocephalus,* integrated pest management, *Meloidogyne incognita,* nematode, *Paratrichodorus minor,* squash, sustainable agriculture, vinca.

Soil solarization is becoming increasingly important for managing plant-parasitic nematodes and other soilborne pests and pathogens (Chellemi et al., 1997; McGovern and McSorley, 1997). Solarization has been used successfully against a variety of plant-parasitic nematodes (McGovern and McSorley, 1997), and it seems to be particularly effective against *Rotylenchulus reniformis* (Chellemi et al., 1993; Heald and Robinson, 1987; McSorley and Parrado, 1986). Efficacy against *Meloidogyne* spp. has been less consistent (McGovern and McSorley, 1997), although *M. incognita* was managed successfully by solarization in several recent studies in Florida (McGovern et al., 1998; McSorley and McGovern, 1999). The efficacy of solarization has been enhanced by the use of a double layer of clear plastic in some studies (McGovern and McSorley, 1997; McSorley and McGovern, 1999). In other studies, activity against *M. incognita* was improved when solarization was used in conjunction with chemical fumigation (Chellemi et al., 1997) or amendments such as ammonium phosphate or composted chicken litter (Gamliel and Stapleton, 1993).

The combination of ammonium amendments with solarization may have some potential in pest management. Adverse effects of ammoniacal nitrogen on plant-parasitic nematodes have been reported, although phytotoxicity may be a problem at the rates needed for nematode management (Rodríguez-Kabana, 1986). Ammonium amendments such as ammonium bicarbonate have been used against a variety of different plant pathogens in recent studies (McGovern et al., 1996; Olivier et al., 1998; Punja and Gaye, 1993; Tu et al., 1991). Applied as a soil amendment, ammonium bicarbonate reduced incidence of *Sclerotium rolfsii* on carrot (*Daucus carota*) in North Carolina and Georgia (Punja et al., 1986).

The objective of this study was to determine the effect of solarization and ammonium amendments, alone and in combination, against plant-parasitic nematodes.

Materials and Methods

Experiments were conducted in two fields (Field C and Field O) at the University of

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Florida Gulf Coast Research and Education Center in Bradenton, Florida (27.5°N, 82.6°W). Soil type in both locations was Eugallie sand (97% sand, 1% clay, 2% silt; with 1.9% organic matter). The major difference between the two sites was that Field O had an extremely high density of nutsedge (*Cyperus* spp.) (120 plants/0.09 m^2).

The experimental design for each experiment was a 2 × 3 factorial, with two solarization treatments (solarized or control) and three soil amendment treatments. The six treatment combinations were replicated 4 times in a randomized complete-block design. Individual plot size was 3.0 m × 3.0 m. Plots were cultivated and levelled prior to establishment of treatments.

Soil solarization was achieved by covering appropriate plots with a double layer of 25-µm thick, clear, low-density polyethylene much (Dow Agroscience, Indianapolis, IN). One layer of the plastic mulch was placed directly on the soil surface, while the second layer was raised 0.46–0.51 m above the soil by means of two arches created from PVC pipe anchored in each corner of the plot. The edges of the plastic mulch were buried 10–15 cm deep in soil beyond the plot margin to seal the plastic layers on each plot. Solarization was initiated on 7 April 1999 in Field O and on 9 April in Field C, and terminated by removing the plastic mulch 3 weeks later. Control plots were not solarized.

Soil amendment treatments were applied to the plots and incorporated into the soil to a depth of 15–20 cm by rotovation before solarization was initiated. Amendments included an ammonium bicarbonate product, Armicarb 300 (Church & Dwight Co., Inc., Princeton, NJ), applied at 336 kg/ha, or ammonium sulfate applied at 281 kg/ha. Control treatments did not receive soil treatment.

On 30 April, two 1.5-m × 1.5-m subplots were established within each plot. One subplot was planted with 12 three-week-old seedings of vinca (*Catharanthus roseus* cv. Peppermint Cooler). The other subplot received six seedlings of yellow squash (*Cucurbita pepo* cv. Goldie). Plots were watered by a semi-closed irrigation system consisting of shallow ditches located at each side of the plot area. No fertilizers other than the original amendments were applied. Pesticide usage was limited to application of *Bacillus thuringiensis* as needed for management of lepidopterous larvae. Both experiments were terminated on 30 June 1999.

Soil samples for analysis of plant-parasitic nematodes were collected from all plots in both fields on 7 April (before solarization), 30 April (after solarization, at planting), and 30 June (at end of experiment). Each soil sample consisted of four soil cores (2.5-cm diam. × 20-cm depth) collected in a systematic pattern from each plot (April) or subplot (June). The four cores were mixed, and a 100-cm^3 subsample was removed from each soil sample for extraction of nematodes using a modified sieving and centrifugation procedure (Jenkins, 1964). Nematodes were counted under an inverted microscope, and data were subjected to analysis of variance for a factorial design using MSTAT-C software (Michigan State University, East Lansing, MI). Where appropriate, means were separated by Duncan's multiple-range test. Data from the vinca and squash plantings were analyzed separately.

Results

Several different plant-parasitic nematodes occurred at these sites (Table 1). In addition to the plant-parasitic nematodes shown, *Helicotylenchus* spp. and *Tylenchulus graminis* occurred in low numbers (2/100 cm^3 soil by end of crop) at both sites, while *Pratylenchus brachyurus* and *Tylenchorhynchus* spp. were present at low numbers in Field C and *Hemicriconemoides* spp. in Field O (data not shown).

No interactions (at $P \leq 0.10$) between solarization and amendment treatment were observed at either site. Solarization affected ($P \leq 0.05$) most of the nematodes present at these sites. At Field C on 30 April, immediately after solarization, numbers of all plant-parasitic nematodes were suppressed ($P \leq$

TABLE 1. Effect of solarization on soil population levels of plant-parasitic nematodes at two field sites in Bradenton, Florida, 1999.

	Nematodes per 100 cm^3 soil[a]							
					30 June			
	7 April		30 April		Vinca		Squash	
Nematode	Solar	Control	Solar	Control	Solar	Control	Solar	Control
			Field C					
Belonolaimus longicaudatus	2	3	1*	4	1*	4	1*	4
Criconemella spp.	28	31	18*	39	18*	34	27*	57
Dolichodorus heterocephalus	6	6	2*	5	1**	8	2**	13
Hemicycliophora spp.	14	12	2*	11	5	11	6	9
Hoplolaimus galeatus	7	7	9	14	3*	7	10	15
Meloidogyne incognita	53	58	15*	32	6*	10	42	30
Paratrichodorus minor	21	21	3**	18	5	8	16	19
			Field O					
Belonolaimus longicaudatus	<1	<1	<0*	1	<1*	6	<1**	6
Criconemella spp.	1	1	1	1	1*	4	0**	3
Dolichodorus heterocephalus	3	3	1**	8	2**	15	1**	15
Hemicycliophora spp.	1	<1	<1	1	<1**	5	<1**	3
Meloidogyne incognita	14	8	4*	10	15	8	24	10
Paratrichodorus minor	9	11	1**	12	47**	13	54**	13
Tylenchorhynchus spp.	57	61	33*	58	88	109	75**	122

[a] Data are main plot means of four replications. Asterisks (*, **) indicate significant difference from corresponding control at $P \leq 0.05$ or $P \leq 0.01$, respectively.

0.05) by solarization, with the exception of *Hoplolaimus galeatus* (Table 1). Season-long suppression of *Belonolaimus longicaudatus, Criconemella* spp., and *Dolichodorus heterocephalus* was achieved on both crops at Field C. At this site, suppression of *H. galeatus* and *Meloidogyne incognita* was observed at the end of the season on vinca, but not on squash. *Paratrichodorus minor* was suppressed initially (30 April) by solarization but recovered by 30 June on both crops at Field C.

At Field O, most plant-parasitic nematodes were suppressed initially (30 April) by solarization, except for the relatively uncommon *Criconemella* spp. and *Hemicycliophora* spp. (Table 1). Suppression of *B. longicaudatus, Criconemella* spp., *D. heterocephalus,* and *Hemicycliophora* spp. was observed at the end of the season on both crops. *Meloidogyne incognita,* which was suppressed on 30 April, recovered by the end of the season on both crops, while *P. minor* resurged past levels present in the control plots on both crops at Field O (Table 1).

Effects from the ammonium amendments were infrequent and occurred only for two nematodes at Field C (Table 2). Population densities of *B. longicaudatus* were reduced ($P \leq 0.10$) by both amendments at planting (30 April) and throughout the season. Ef-

TABLE 2. Effect of ammonium amendments on soil population levels of *Belonolaimus longicaudatus* and *Criconemella* spp. at Field C, Bradenton, Florida, 1999.

	Nematodes per 100 cm^3 soil[a]			
			30 June	
Amendment	7 April	30 April	Vinca	Squash
	Belonolaimus longicaduatus			
None	4 a	5 a	5 a	5 a
Ammonium bicarbonate	1 a	1 b	2 b	1 b
Ammonium sulfate	2 a	1 b	1 b	2 b
	Criconemella spp.			
None	31 a	37 a	35 a	46 a
Ammonium bicarbonate	17 a	22 a	10 b	22 a
Ammonium sulfate	41 a	28 a	33 a	57 a

[a] Data are subplot means, pooled across 2 main plots × 4 replications. For each nematode, means in columns followed by the same letter do not differ ($P \leq 0.10$) according to Duncan's multiple-range test.

fects of amendments on *Criconemella* spp. were inconsistent (Table 2). Ammonium amendments did not affect any of the nematodes at Field O (data not shown).

Discussion

Conditions for solarization were not optimal in Field O due to the extremely high population of nutsedge. Although much nutsedge was killed by solarization, weed populations recovered during the weeks following removal of the plastic mulch, reaching levels near those found in control plots. In addition, the 3-week solarization period was much shorter than that used in most solarization studies (McGovern and McSorley, 1997). Nevertheless, several nematode species were suppressed by solarization, even under these conditions. Season-long suppression of *Meloidogyne incognita* was better on vinca, a poor host (McSorley and Frederick, unpubl.), at Field C, where solarization conditions were better than at Field O. However, even at Field C, *M. incognita* recovered on squash, a highly susceptible host, by the end of the season. The most difficult nematode to manage by solarization was *Paratrichodorus minor*. Levels of this nematode were reduced immediately after solarization at both sites but recovered within 2 more months on both crops at Field C. At the end of the experiment at Field O, numbers of *P. minor* in solarized plots were 3 to 4 times those present in nonsolarized control plots, confirming a recent report of the resurgence of *P. minor* following solarization (McSorley et al., 1999). The resurgence of this nematode following soil fumigation had been reported earlier (Weingartner et al., 1983). Nevertheless, the suppression of most of the other plant-parasitic nematodes under these difficult conditions and with an extremely short (3 weeks) solarization period is encouraging.

Ammonium amendments did not enhance the efficacy of solarization in these experiments, as indicated by the lack of any solarization × amendment interactions. In general, the amendments had little or no effect on most of the plant-parasitic nematodes present at these sites. However, the rather consistent suppression of *B. longicaudatus* numbers at Field C indicates that further evaluation of ammonium amendments against this species may be warranted.

These experiments illustrate some of the difficulties involved in managing a polyspecific assemblage of plant-parasitic nematodes. The response of *B. longicaudatus* to ammonium amendments and the resurgence of *P. minor* following solarization were not typical of the responses observed for the majority of nematodes present. While it is well known that different species and isolates of nematodes may respond differently to management practices like crop rotation and cover cropping (McSorley, 1998), differential responses to other types of management practices must also be considered. Distinguishing and understanding these responses will be essential in optimizing the use of solarization, amendments, and other tactics in nematode management.

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