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Reduction of Phytoparasitic Nematodes on Tomato by Soil Solarization and Genotype[1]

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Abstract: The effects of soil solarization and tomato (*Lycopersicon esculentum*) genotype on populations of plant-parasitic nematodes and bacterial wilt were examined in North Florida. Maximum soil temperatures achieved under solarization treatments using a photoselective polyethylene mulch were 49.5, 46, and 40.5 C at depths of 5, 15, and 25 cm, respectively. Soil solarization reduced ($P < 0.05$) populations of *Paratrichodorus minor, Rotylenchulus reniformis,* and *Criconemella* spp. 85 days after transplanting on the cultivar Solar Set. Soil solarization reduced ($P < 0.10$) populations of *P. minor, R. reniformis,* and *Criconemella* spp. on the breeding line Fla. 7421. Reductions of *P. minor* and *Criconemella* spp. on Solar Set and Fla. 7421 were similar to those achieved by fumigation with a 67:33 mixture of methyl bromide and chloropicrin (448 kg/ha). Fla. 7421 reduced ($P < 0.10$) populations of *R. reniformis* compared with Solar Set. Neither soil solarization nor fumigation reduced the incidence of bacterial wilt on the susceptible cultivar Solar Set. This study demonstrates the ability of soil solarization to provide season-long control of plant-parasitic nematodes of tomato under a climatic regime characterized by periods of abundant rainfall and extended cloud cover.

Key words: bacterial wilt, *Criconemella* spp., *Helicotylenchus* spp., *Lycopersicon esculentum, Meloidogyne incognita,* nematode, *Paratrichodorus minor, Pseudomonas solanacearum, Rotylenchulus reniformis,* soil solarization, tomato.

Chemical fumigants have been widely marketed in the United States since World War II for the control of soilborne pests (9). Due in part to the effectiveness of these materials against a wide range of organisms, their relatively low cost, and their ease of use (18), vegetable production industries in the southeastern United States have become increasingly dependent on them to manage soilborne pests. Environmental concerns have created social and legislative pressure to remove many agricultural pesticides from the market, of which the most recent example is methyl bromide (13). Agricultural industries' reliance on chemical fumigants coupled with potential removal of these materials from the market necessitate evaluation of alternative, nonchemical approaches for the management of soilborne pests.

Soil solarization is one such approach. Solar radiation is used to heat soil beneath polyethylene mulch to temperatures detrimental to nematodes and other soilborne pests. The benefits of solar heating beneath a mulch for nematode control were first recognized in Hawaii in the early 1930s (4). In recent field trials, solarization has been used most effectively against nematodes and other soilborne pests in locations with hot and relatively cloudless conditions during the solarization period, such as Israel (10), California (17), or the Lower Rio Grande Valley of Texas (6). Conditions may be less favorable for solarization in the southeastern United States, where the warmest temperatures occur from June to September, coinciding with periods of maximum rainfall and frequent cloud cover. Nevertheless, nematode management on tomato (*Lycopersicon esculentum*) by solarization has potential in southern Florida, where reductions in populations of *Paratrichodorus minor* and root-knot galling by *Meloidogyne* spp. were reported (11,14). In neither study was solarization as effective as broad-spectrum fumigation in providing season-long suppression of plant-parasitic nematodes.

The objective of this study was to evaluate the potential of soil solarization to pro-

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vide season-long reductions of phytoparasitic nematodes and other soilborne pests on tomato in northern Florida. Unlike previous reports from southern Florida, which were characterized by subtropical conditions, this study was conducted in a physiogeographic region more typical of those found in the southeastern United States. In addition, a photoselective polyethylene mulch was used to reduce the possibility of weed germination and growth under the mulch during periods of extended cloud cover.

Materials and Methods

The experiment was conducted in 1992 on a commercial tomato farm in Gadsden County, Florida. The study site was located at 30.3° N and 84.4° W, or approximately 285 km northwest of a previous solarization study in Florida (14). The farm had been removed from tomato production due to a severe epidemic of bacterial wilt (*Pseudomonas solanacearum*) the preceding year. The soil type was an Orangeburg loamy fine sand (Typic Paleudult: Siliceous, thermic) with a pH of 6.8 and an organic carbon content of 4.9%. Soil particle analyses ranged from 73–87% sand, 4–12% silt, and 9–20% clay. Treatments were arranged in a randomized complete block design, with three replications per treatment. Plots were 9 m wide and 30.5 m long. Treatments were solarization, fumigation (448 kg/ha of a 67:33 combination of methyl bromide + chloropicrin), solarization plus fumigation, and an untreated control. Fumigation treatments were applied broadcast with 25 cm-spaced chisels at a depth of 20 cm. The plastic mulch used in solarization and fumigation treatments was a 0.025-mm thick, green polyethylene mulch that selectively blocked 70–75% of the incoming photosynthetically active radiation (AEP Industries, Hackensack, NJ). Sheets of mulch were 3 m wide and sealed together with glue to cover the entire 9 m width of a plot.

Prior to treatment applications on 19 June, the field was deep-plowed and cultivated. Soil moisture was 12% at the time treatments were applied. Treatments were applied on 19 June. Plastic mulch was removed from the fumigation treatment after 48 hours and from the solarization treatments after 32 days. Hourly changes in soil temperature in bare soil and the solarization treatments were monitored at depths of 5, 15, and 25 cm with thermocouple sensors. An electronic data logger automatically processed and recorded analog signals from the sensors (Omnidata International, Logan, UT). Ambient air temperature and daily precipitation totals were obtained from the National Weather Service Reporting Station 3SSW, located approximately 2 km from the experimental site.

Following removal of the solarization film, two raised beds covered by opaque polyethylene mulch were immediately prepared in the center of each plot. Beds were 0.9 m wide, 16 m long, and arranged on 1.8-m centers. Irrigation was provided through drip tubing, with separate connections for each plot to minimize contamination between plots. Thirty plants each of Solar Set and Fla. 7421 were transplanted into the beds on 7 August with a plant spacing of 0.5 m. Solar Set is a hybrid cultivar widely used by commercial industry, and Fla. 7421 is an open-pollinated, heat-tolerant breeding line developed for tolerance to bacterial wilt. Fertilizer was applied as a modified broadcast over the area used to make beds at a rate of 218 kg/ha N, 29 kg/ha P, and 180 kg/ha K.

Soil samples for nematode analysis were collected on 29 October by removing and compositing soil cores 2.5-cm and 20 cm deep from the root zone of each of six plants per plot. Nematodes were extracted from 100-cm^3 soil subsamples with a modified sieving and centrifugation procedure (8). In addition, three root systems removed from each plot and rated for root-knot galling on a 0–5 scale (19), where 0 = 0 galls per root system, 1 = 1–2 galls, 2 = 3–10 galls, 4 = 31–100 galls, and 5 = more than 100 galls per root system.

Nematode data were log-transformed

($\log_{10}[x + 1]$) and subjected to analysis of variance. Where *F*-tests were significant ($P \leq 0.10$ or $P < 0.05$), single degree of freedom orthogonal contrasts were computed to compare treatment differences. Temperature data were expressed as the maximum daily temperature achieved at the various depths and treatments for each day the solarization film was in the field.

The incidence of bacterial wilt was monitored every 2–3 days following transplanting. Yield information was obtained by harvesting all fruit with diameter >57 mm. Fruit was graded as marketable or nonmarketable using USDA tomato grading standards.

Results

A total of 15.4 cm of precipitation was received during the 32-day solarization period. Rain events occurred on 14 days. The maximum ambient temperature was 35.6 C, recorded on 12 July. The maximum temperatures in bare soil were 40.7, 38.2, and 35.6 at depths of 5, 15, and 25 cm, respectively (Fig. 1). In the solarized plots, the maximum soil temperatures were 49.5, 46, and 40.5 at depths of 5, 15, and 25 cm, respectively. Two periods of intermittent temperature reduction from 30 June to 1 July and from 14 July to 16 July were observed. A total of 9.6 cm, 62% of the precipitation received during the entire solarization period, fell during these two periods. Although weed pressure in areas surrounding the plots was intense, no weeds were observed under the solarization film during the 32-day period.

Soil treatment has a significant effect ($P < 0.05$) on populations of *P. minor*, *Criconemella* spp., and *R. reniformis* but not *Helicotylenchus* spp. and *M. incognita*. Tomato genotype had a significant effect ($P < 0.10$) on populations of *R. reniformis*, with significantly fewer numbers present on Fla. 7421 (Table 1). No significant interactions ($P < 0.10$) between genotype and treatment were observed for any nematode species.

For Solar Set, solarization significantly reduced populations of *P. minor*, *R. reniformis*, and *Criconemella* spp. below levels observed in the control plots but had no

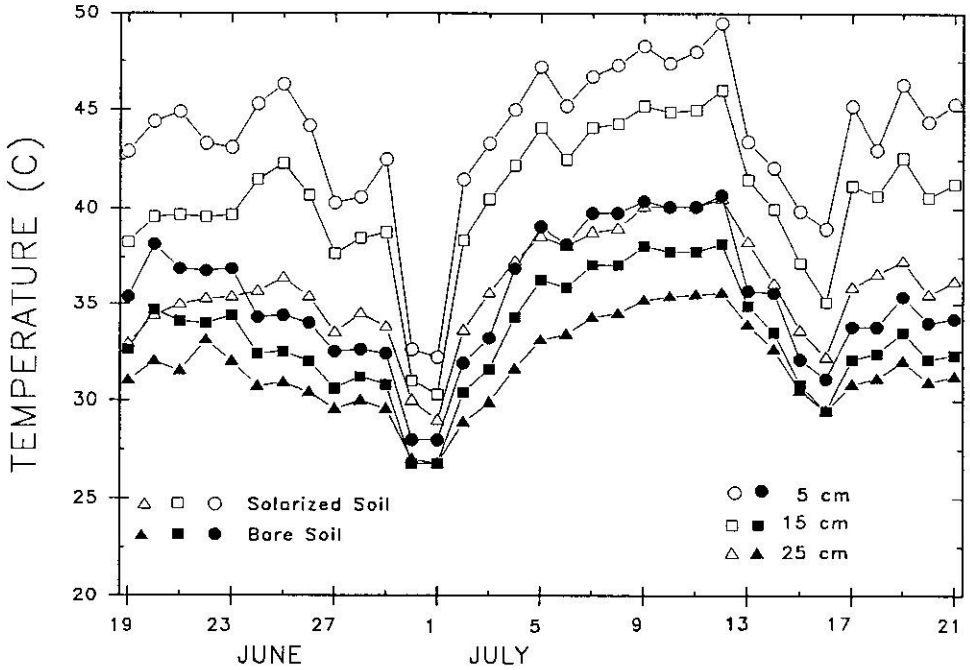

FIG. 1. Daily maximum temperatures recorded in bare soil and under the solarization treatments at three depths during a 32-day solarization period in June–July, 1992.

TABLE 1. Effect of solarization, fumigation,† and tomato genotype on densities of phytoparasitic nematodes at harvest.

Treatment	Nematodes per 100 cm³ soil	
	Fla 7421	Solar Set
	Paratrichodorus minor	
Control	153.0	149.3
Solarization + fumigation	17.3	16.3
Solarization	15.0*	6.0*
Fumigation	27.7	12.0
	Helicotylenchus spp.	
Control	14.7	2.0
Solarization + fumigation	2.0	0
Solarization	0	0
Fumigation	0	0
	Rotylenchulus reniformis	
Control	186.0	860.7
Solarization + fumigation	0.3	86.7
Solarization	50.7*‡	16.3*‡
Fumigation	0.7	2.3
	Criconemella spp.	
Control	3.7	3.3
Solarization + fumigation	0	0
Solarization	0*	0.3*
Fumigation	0	0

Data are arithmetic means of three replications. Data analyses were performed on log-transformed data. Asterisk (*) indicates contrast between control and solarization treatments was significant at $P < 0.05$.

† 448 kg/ha of a 67:33 mixture of methyl bromide:chloropicrin.

‡ Contrast between solarization and fumigation treatments were significant at $P < 0.10$.

effect on *Helicotylenchus* spp. (Table 1). Similar levels of performance were observed for the solarization and fumigation treatments, with no significant ($P < 0.10$) contrasts between these treatments observed for any nematode species.

For Fla. 7421, solarization significantly reduced densities of *P. minor, R. reniformis,* and *Criconemella* spp. below levels observed in the control (Table 1), but had no effect on *Helicotylenchus* spp. Densities of *R. reniformis* were lower ($P < 0.10$) following fumigation than following solarization, but levels of other nematodes following these two treatments were similar.

Galling from *M. incognita* was observed on only two plants, one Fla. 7421 and one Solar Set. Both plants were obtained from control plots. High densities of *M. incognita* juveniles in soil (299 and 181 per 100 cm³ soil on Fla. 7421 and Solar Set, respectively) were observed in control plots, compared with densities of <9 per 100 cm³ in all other treatments. However, the high densities were confined mainly to one replication, precluding statistical analysis.

Soil solarization did not affect the incidence of bacterial wilt on the susceptible cultivar Solar Set (Fig. 2). Disease incidence in both the control and solarization treatments was 36%. Fumigation reduced the incidence of disease to 22%. When fumigation was combined with solarization, the incidence of bacterial wilt was further reduced to 6%. The incidence of bacterial wilt in Fla. 7421 was <4% in the control treatment and <2% in all other treatments (Fig. 3).

Yield data are presented from a single harvest on 21 October (Table 2). Soil treatment had a significant effect ($P < 0.05$) on yield of Solar Set. Tomato yields following solarization + fumigation and fumigation were significantly higher than in control plots. Yields from solarization and control plots did not differ. No significant differences in fruit quality, as determined by percentage packout, were observed. Soil treatment had no effect on yield or fruit quality of Fla. 7421.

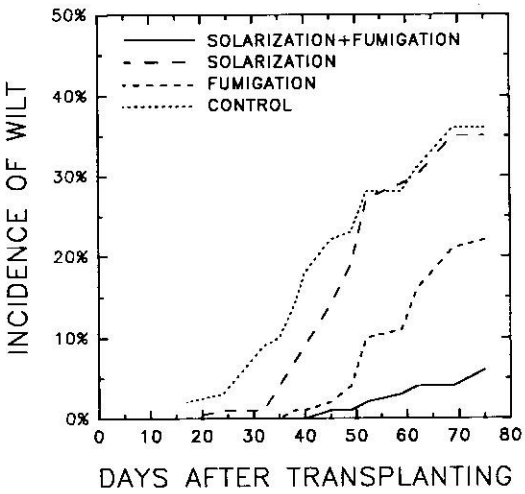

FIG. 2. Progression of bacterial wilt of tomato from transplanting until the first harvest date on the tomato cultivar Solar Set.

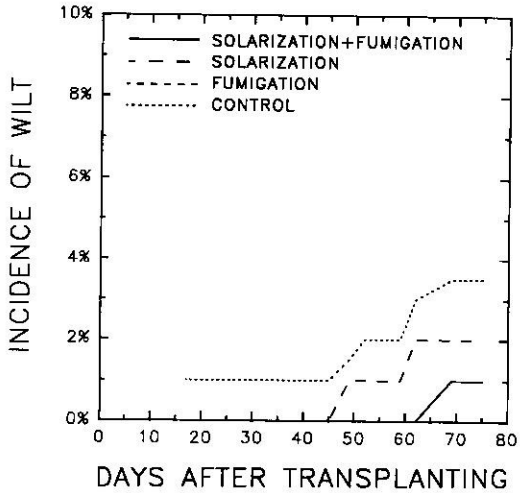

FIG. 3. Progression of bacterial wilt of tomato from transplanting until the first harvest date on the tomato breeding line Fla. 7421.

DISCUSSION

Solarization increased temperatures by as much as 9, 8, and 5 C over temperatures in bare soil at depths of 5, 15, and 25 cm, respectively. The daily maximum temperature range in solarization treatments at 15 cm was 30–46 C. Although this was not as large as the range of 28–52 C reported by McSorley and Parrado (11) in southern Florida, soil temperatures were approximately 4 C higher than those reported by Overman (14) and several degrees higher than those reported by Heald and Robinson (6) in the Lower Rio Grande Valley of Texas.

TABLE 2. Effect of solarization and fumigation† on tomato yield in plots harvested 21 October 1992.

Treatment	Yield‡	Packout
Solar Set		
Solarization + Fumigation	21.8*	88%
Fumigation	18.2	90%
Solarization	11.6	91%
Control	8.5	93%
Fla. 7421		
Solarization + Fumigation	18.0	94%
Solarization	16.4	96%
Fumigation	14.5	93%
Control	17.3	92%

† 448 kg/ha of a 67:33 mixture of methyl bromide: chloropicrin.

‡ Yield measured in metric tons per acre. Packout equals the ratio of marketable yield to total yield. Asterisk (*) indicates contrast between control and combined solarization and fumigation treatments was significant at $P < 0.05$.

Season-long reductions of *R. reniformis* by solarization were reported on lettuce and chickpea in the Lower Rio Grande Valley (6), where climatic conditions are more typical of those found in arid regions of the world. This is the first report of season-long control of *R. reniformis* on tomato in the southeastern United States. The soil temperatures at 15-cm depths in this study were above the threshold of 42.5 C selected by Heald and Robinson (6) as the maximum daily temperature required to achieve lethal conditions for *R. reniformis*.

Solarization significantly reduced populations of *P. minor*. This agrees with results obtained by Overman (14). Solarization also reduced populations of *Criconemella* spp. This is a first report for solarization control of *Criconemella* spp. in the southeastern United States.

Unlike previous reports from southern Florida (11,14), the level of nematode population reduction achieved by solarization in our test was similar to that obtained from soil fumigation, except in the case of *R. reniformis* on Fla. 7421.

The damaging effects of root-knot nematodes on tomato are well recognized and documented (12). Trichodorid nematodes have been reported to be pathogenic to tomato (15). Although less well documented, *R. reniformis* can also cause significant reductions in yield of tomato (5).

The reduction of *R. reniformis* by Fla. 7421 was unexpected because resistance to this nematode in tomato has not been reported previously. Fla. 7421 was developed from Hawaii 7997, a tomato breeding line that is highly resistant to bacterial wilt (16). It is not known whether any genetic linkage exists between resistance to bacterial wilt and *R. reniformis*.

The large yield differences among treatments for Solar Set were attributed to the influence of bacterial wilt. Yields were significantly lower in the solarization and control plots, which also had a much higher incidence of bacterial wilt. On Fla. 7421, soil treatments had no effect on yield.

Fumigation with methyl bromide–chloropicrin does not provide season-long control of bacterial wilt of tomato in the southeastern United States (1). Solarization of plastic greenhouses failed to control bacterial wilt of tomato in Japan (7). The effect of soil solarization on bacterial wilt in field-grown tomatoes is unknown. Neither solarization nor fumigation provided season-long control of bacterial wilt in our study. When the treatments were combined, the incidence of bacterial wilt on the susceptible cultivar was reduced to levels observed on the resistant breeding line. A synergistic effect of fumigation and solarization has been reported on several soilborne pests (2,3). This is the first report of a synergistic effect on a soilborne bacterial disease.

While the results obtained in this study are preliminary, they indicate that soil solarization, even when interrupted by cloud cover and rainfall, can provide season-long suppression of plant-pathogenic nematodes in the southeastern United States. Additional studies will be conducted to evaluate and improve the potential of soil solarization as a nonchemical approach for managing soilborne pests, including nematodes.

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