APPLICATION OF SOIL SOLARIZATION TO ROCKDALE SOILS IN A SUBTROPICAL ENVIRONMENT[1]

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ABSTRACT

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Efficacy of soil solarization, achieved by covering bedded soil with transparent polyethylene for 9 wk, was compared with three other summer management strategies (covering with opaque polyethylene, rototilling, or maintenance of a summer weed cover) on a Rockdale series soil in southern Florida. Compared to the other methods studied, soil solarization resulted in significantly higher soil temperatures during the summer, lower populations of *Rotylenchulus reniformis* Linford & Oliveira at the end of the summer, and lower populations of nut-grass, *Cyperus* spp., than in control plots. The significant differences in *R. reniformis* populations by summer management treatment were not maintained through a subsequent tomato crop in autumn, but significant differences in *Cyperus* spp. and root-knot nematode galling were evident up to harvest of the tomato crop. However, root galling was further lowered by fumigation (67% methyl bromide, 33% chloropicrin). Fumigation following summer management resulted in significantly ($P=0.05$) increased tomato yields when beds had been covered with opaque polyethylene or weeds. Similar yield increases with fumigation were not observed following solarization or rototilling, since weed and nematode densities were already very low following these two summer management strategies. A second test revealed that the efficacy of the soil solarization procedure was unaltered by adding water to the beds prior to covering or by changing the time during which beds were covered from 9 wk during the summer to 6½ wk during the early or late summer.

Additional key words: Meloidogyne incognita, nematode management, Rotylenchulus reniformis, soil fumigation, summer management, tomato, weed management.

RESUMEN

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La eficacia de la solarización del suelo, obtenida cubriendo el terreno, previamente preparado en camas, con polietileno transparente por 9 semanas fue comparada con otras prácticas de manejo de verano (cobertura con polietileno blanco-sobre-negro, aradura por rotación del suelo y mantenimiento de la cobertura de malezas) en los suelos de la serie Rockdale del Sur de la Florida. Comparado con otros métodos estudiados la solarización del suelo produjo significativamente temperaturas más altas durante el verano, poblaciones de *Rotylenchulus reniformis* Linford & Oliveira más bajas al final del verano y poblaciones de *Cyperus* spp. más bajas que en los lotes testigos. Las diferencias significativas en las poblaciones de *R. reniformis* obtenidas por la solarización durante el verano no se mantuvieron a través de la subsiguiente cosecha de tomate en el otoño, pero las diferencias significativas en al población de *Cyperus* spp. y nódulos de nematodos en las raíces fueron evidentes hasta el momento de la cosecha de tomate. Sin embargo, la nodulación en las raices fué reducida más por la fumigación (67% bromuro de metilo, 33% cloropicrina). La fumigación después de las estrategias de verano aumentó significativamente los rendimientos de tomate quando los canteros fueron cubiertos con polietileno opaco ó dejaron con malezas. No se observaron aumentos similares en los rendimientos por la fumigación después de la solarización ó por la aradura por rotación, debido a que las malezas y la densidad de nematodos estaron ya bien bajas como consecuencia de esas dos estrategias de verano. El segundo experimento reveló que la eficacia del proceso de solarización del terreno no se alteró por la adición de agua a las camas antes de cubrirlas o por el cambio del tiempo durante el cuál las camas estuvieron cubiertas de 9 semanas durante el verano a 6½ semanas durante el principio o final del verano.

Palabras claves adicionales: Meloidogyne incognita, manejo de los nematodos, Rotylenchulus reniformis, fumigación del suelo, prácticas de manejo de verano, tomate, manejo de las yerbas.

INTRODUCTION

Soil solarization is an innovative technique recently developed for the suppression of pest populations in soil (8). In this technique, moist soil is covered by transparent polyethylene for a period of time, usually more than 4 weeks, during the warmest part of the year. The high soil temperatures achieved beneath the clear polyethylene are lethal to a variety of plant pathogens (8). The method has been used successfully in Israel and California for control of a variety of soilborne diseases and weeds (5,7,8).

Early results with soil solarization for nematode control have been variable, particularly with *Meloidogyne* spp. (7,8). Yield increases of 39.5% over unsolarized controls have been reported from solarized plots on sandy soils in which both *Meloidogyne incognita* (Kofoid & White) Chitwood and *Verticillium albo-atrum* Reinke & Berthold were present (14). In California, populations of a variety of nematodes on several crops have been reduced by solarization, and in several cases, population reductions after solarization exceeded those achieved by fumigation with 1,3-dichloropropene (18). Reductions in populations of *Rotylenchulus reniformis* Linford & Oliveira were achieved by soil solarization in Texas (3), and growth of subsequent autumn (cowpea) and winter (lettuce) crops was improved. Solarization has shown efficacy even in cool climates, based on the reduction of *Globodera rostochiensis* (Woll.) Stone populations in some cases in New York (10). Thermal mortality of nematodes may be enhanced in moist soils compared to dry soils (9).

Since results of soil solarization tests on plant-parasitic nematodes have been generally less predictable and effective than results with plant pathogens, additional research on efficacy of soil solarization on nematodes has been recommended (8). Application of soil solarization to management of nematodes on Rockdale series soils (2) in southern Florida is of particular interest for several reasons. The land is not used for vegetable planting during the hot summer season, and so the method could be adapted to local cultural conditions. At this time in southern Florida, alternatives to soil fumigation, such as summer fallow or growth of certain cover crops, are being sought and have resulted in nematode population reductions (12). The shallow nature of the soil (2), often with less than a 15-cm depth to the limestone substratum, may permit solarization of the entire cultivated soil, without worry of reinfestation from deeper, unsolarized soil. On the other hand, the loose, rocky nature of the soil could interfere with heat conduction. With one exception (14), soil solarization has not been adequately tested in warm regions with distinct rainy seasons; most successful results have been reported from regions with relatively dry, cloudless climates, such as Israel or California. Results during the summer rainy season in subtropical southern Florida may be more indicative of the expected performance of solarization under tropical conditions.

The purpose of the current research was to compare soil solarization to other summer management strategies and preplant soil fumigation, and to compare the effects of soil moisture enhancement and duration of solarization on the performance of the soil solarization technique.

MATERIALS AND METHODS

Two experiments were carried out on Rockdale fine sandy loam soil (2), pH=7.3-7.8, at the Tropical Research and Education Center in Homestead, Florida. Each test consisted of two portions: application of solarization and/or other off-season management practices to the plots in the summer of 1985, followed by growth of a tomato (*Lycopersicon esculentum* Mill.) crop in each test site during the 1985-86 autumn/winter vegetable growing season.

Test 1. This experiment was a 4x2 factorial design, replicated 5 times, with 4 summer management practices and 2 fumigation treatments. Each plot consisted of a raised bed 12.2 m long by 1.2 m wide. The summer management practices imposed on the beds were: 1) covering with transparent polyethylene (1.52 m wide, 19 μm thick) from 9 July to 10 Sept. (63 days); 2) covering with opaque, white-on-black polyethylene (1.68 m wide, 32 μm thick) for the same time period; 3) rototilling beds on 29 July and again on 23 Aug.; 4) a control in which summer weed growth was permitted. The transparent or opaque polyethylene coverings used were an experimental polyethylene film, XU64430.01 (Dow Chemical Co., Midland, MI). Prior to its application, the beds to be covered were drenched with 192 kL water/bedded ha, which increased the soil moisture from 10% to 20.2%. This test was performed during the summer rainy season, typified by clear days with buildup of cloud cover and showers in the late afternoon. Rainfall (trace amounts or greater) occurred on 60% of the 63 days of solarization, giving some indication of the incidence of the late afternoon cloud cover, which was not monitored directly.

On 13 Sept., the surfaces of all beds were lightly rototilled to remove weed growth. To minimize bed disruption and possible contamination, weeds growing near the margins of the beds were removed by hand. On 25 Sept., fertilizer (2240 kg/bedded ha of 8-16-16) was applied to each of the beds. On the next day, half of the beds were fumigated with 252 kg/bedded ha of Terr-O-Gas® 67 (67% methyl bromide, 33% chloropicrin), and half left unfumigated. All beds were covered with a commercial black-on-white, opaque polyethylene. On 2 Oct., 3-week-old 'Flora-Dade' tomato seedlings were transplanted into holes punched 0.3 m apart along the center of each bed. Plants were irrigated twice per week via overhead sprinklers, and were sprayed with non-nematicidal materials on an as-needed basis to control insects and foliar diseases. Other than the soil fumigant, no herbicide was used in the beds.

Soil temperature was monitored periodically during the summer by inserting a thermometer through the polyethylene to a depth of 15 cm. After each measurement, the small hole formed in the polyethylene was sealed with duct tape. Counts of nut-grass (a mixture of *Cyperus esculentus* L. and *C. rotundus* L.) plants per bed were made on 29 Jul., 15 Oct., 25 Oct., and 25 Nov. On 12 Dec., the number of plants growing in the holes with 10 tomato plants were counted. Soil samples for plant-parasitic nematodes were collected from each bed on 9 Jul., 25 Sept., 30 Oct., and 30 Dec. Each soil sample consisted of soil collected with a hand trowel to a depth of 12-15 cm from 10 locations per bed. Each sample was passed through a 2.0-mm sieve to remove rock, and nematodes were then extracted from a 100-cm^3 subsample by a modification (11) of Jenkins' (6) sieving and centrifugation method.

Pink and mature green fruit were harvested, graded, and weighed on 12 Dec., 17 Dec., and 2 Jan. from 10 adjacent tomato plants per plot (3.0 m of row). The root systems of 6 of these plants were removed and rated for galling and root browning, and an average value of each computed per plot. Galling from *Meloidogyne incognita* (Kofoid & White) Chitwood was rated on a 0-5 scale, where 0=0 galls per root system, 1=1-2 galls, 2=3-10 galls, 3=11-30 galls, 4=31-100 galls, and 5= more than 100 galls per root system (19). Browning and discoloration from soilborne diseases was rated on Horsfall and Barratt's (4) 1-12 scale, where 1=0% of root surface covered by disease, 2=0-3%, 3=3-6%, 4=6-12%, 5=12-25%, 6=25-50%, 7=50-75%, 8=75-88%, 9=88-94%, 10=94-97%, 11=97-100%, and 12=100% of root surface covered by disease.

Data were analyzed by using the analysis of variance (ANOVA) appropriate for a factorial design (1) to determine significant main effects (summer management, fumigant) and interaction (summer management x fumigant). Since no significant main effects due to fumigant or interactions were evident in any data collected prior to 26 Sept. when the fumigant was applied, summer data were pooled by summer management method and separations among methods indicated by the Waller-Duncan k-ratio test (1).

Test 2. This experiment was a 3 x 2 factorial replicated 5 times, involving 3 different times during which beds were covered with transparent polyethylene (early season cover = 8 Jul.-22 Aug., 45 days; long season cover = 8 Jul.-9 Sept., 63 days; late season cover = 26 Jul.-9 Sept., 45 days), and 2 water treatments (application of 192 kL water/bedded ha before covering, or no addition of water). Addition of water to the beds prior to covering increased soil moisture from 15.4% to 32.3%. The polyethylene film used was the 19-μm-thick transparent material described previously, and the bed size was 10.7 m x 1.2 m. Rainfall incidence (trace amounts or greater) was 49% from 8 Jul.-22 Aug., 59% from 8 Jul.-9 Sept., and 62% from 26 Jul.-9 Sept.

In Sept., weeds were removed and fertilizer applied as in the previous test. Beds were covered with the commercial black-on-white polyethylene on 24 Sept., but no fumigants were applied to any beds. Three-week-old 'Flora-Dade' tomato seedlings were transplanted into the beds on 27 Sept. Plot management and collection of soil temperature data was as described for Test 1.

Populations of *Cyperus* spp. per bed were measured on 2 Aug., 20 Oct., and 26 Nov. Soil samples for plant-parasitic nematodes were collected on 8 Jul., 9 Sept., 28 Oct., and 23 Dec., and extracted as described previously. Fruit from 10 adjacent plants per bed were harvested, graded, and weighed on 12 Dec., 16 Dec., and 26 Dec. Average ratings of 6 plants per plot were also obtained on 26 Dec. for root galling on a 0-5 scale (19) and browning from soilborne diseases on a 1-12 scale (4). Data analysis was by factorial ANOVA.

RESULTS

Test 1. When several different summer management strategies were compared, application of clear polyethylene to the beds for soil solarization always resulted in the highest soil temperatures (Table 1). This

Table 1. Effect of summer management on soil temperature. Test 1, summer 1985.

Summer Management	Soil temperature (°C, 15-cm depth) by date and time[z]													
	22 Jul. 1430	29 Jul. 1130	29 Jul. 1530	2 Aug. 1045	7 Aug. 0830	7 Aug. 1100	7 Aug. 1330	7 Aug. 1530	13 Aug. 0930	16 Aug. 0900	16 Aug. 1530	23 Aug. 1530	26 Aug. 0900	26 Aug. 1530
Transparent Polyethlene	32.3 a	37.3 a	49.3 a	37.5 a	27.9 a	34.5 a	38.5 a	42.1 a	33.1 a	33.3 a	51.6 a	48.9 a	28.9 a	39.9 a
Opaque polyethylene	28.7 b	32.9 b	37.6 c	31.5 b	26.2 b	30.3 b	31.4 c	32.9 c	29.5 c	28.6 b	37.9 c	37.1 c	27.0 b	32.2 b
Rototilled	28.5 b	32.1 b	37.6 b	30.8 b	25.4 c	29.8 b	31.1 c	32.5 c	30.0 b	28.8 b	39.9 b	39.1 b	26.4 c	32.0 b
Weeds	28.7 b	31.9 b	39.2 b	30.8 b	25.5 c	30.6 b	32.0 b	33.7 b	30.1 b	29.0 b	39.7 b	39.6 b	26.2 c	31.5 c

[z]Data are means of 10 replications. Means in columns followed by the same letter are not significantly ($P=0.05$) different, according to the Waller-Duncan test.

trend was observed at all times of the day, although maximum temperatures were achieved in the mid- to late-afternoon. Observed afternoon maxima occasionally exceeded those observed in solarization trials in California (18), but only the mean of 51.6 C compared favorably with the generally higher (53-54 C) soil temperatures from solarized plots in Texas (3). Of the two types of polyethylene used, the transparent material was more durable, with no small holes or tears observed, compared to 13.9 tears/bed observed for the opaque polyethylene on 8 Aug.

Solarization under transparent polyethylene was highly effective in reducing populations of *R. reniformis* during the summer (Table 2). However, both rototilling and covering with opaque polyethylene also reduced populations of this nematode compared to control plots in which summer weed populations were left undisturbed. Other nematodes observed at very low densities included *Quinisulcius acutus* (Allen) Siddiqi and *Helicotylenchus dihystera* (Cobb) Sher, although the latter species was significantly more abundant in control (weed) plots. Populations of all three nematode species increased after plots were cropped to tomato during the following autumn (Table 3). Although there were significant differences on 30 Oct. in *R. reniformis* populations depending on the summer management techniques used (Table 3), fumigation was a more important determinant of soil populations, with

Table 2. Effect of summer management on nematode and weed populations. Test 1, summer 1985.

Summer management	Nematodes per 100 cm^3 soil[y] *Rotylenchulus reniformis*		*Helicotylenchus dhystera*	*Quinisulcius acutus*	*Cyperus* spp. plants/bed
	9 Jul.[z]	25 Sep.	25 Sep.	25 Sep.	29 Jul.
Transparent polyethylene	112 a	3 a	0 a	1.0 a	15 a
Opaque polyethylene	134 a	29 c	0 a	0.5 a	122 a
Rototilled	76 a	14 b	0.5 a	1.5 a	549 b
Weeds	48 a	104 d	8.5 b	2.0 a	467 b

[y]Data are means of 10 replications. Means in columns followed by the same letter are not significantly (P=0.05) different, according to the Waller-Duncan test.

[z]Before covering with polyethylene.

Table 3. Effect of summer management and soil fumigation on soil nematode populations. Test 1, autumn 1985.

	Nematodes per 100 cm^3 soil							
	Rotylenchulus reniformis				*Helicotylenchus dihystera*		*Quinisulcius acutus*	
	30 Oct.		30 Dec.		30 Dec.		30 Dec.	
Summer management	F[y]	C[y]	F	C	F	C	F	C
Transparent polyethylene	0 a	0 b	569 a	1160 a	5 a	21 a	5 a	0 b
Opaque polyethylene	1 a	8 a	484 a	1447 a	9 a	28 a	1 a	18 a
Rototilled	0 a	1 b	244 a	1113 a	4 a	18 a	3 a	4 b
Weeds	2 a	20 a	622 a	533 a	7 a	9 a	7 a	6 b
Significant effects from ANOVA:[z]								
Summer management	F=3.60*		n.s.		n.s.		n.s.	
Fumigant	F=5.91*		F=4.62*		F=7.72**		n.s.	
Summer management x fumigant	n.s.		n.s.		n.s.		F=3.03*	

[y]F = fumigated with 252 kg/ha of methyl bromide; C = unfumigated control.

[z]Data are means of 5 replications. Asterisks (**, *) indicate significant F values at P=0.01 and P=0.05, respectively; n.s. = not significant. Means in columns followed by the same letter or means in rows underscored by the same line are not significantly (P=0.05) different, according to the Waller-Duncan test.

significant differences persisting to the end of the tomato crop in one treatment (opaque polyethylene).

Density of *Cyperus* spp. was suppressed during the summer in beds covered by either type of polyethylene (Table 2). Throughout the subsequent tomato crop, significant differences among summer management treatments were still evident in unfumigated plots (Table 4), with lowest densities following the transparent polyethylene treatment and highest densities following undisturbed weed growth. Significant reductions with soil fumigation were also apparent in most cases for three of the four summer management techniques. The very low *Cyperus* spp. populations present following the transparent polyethylene treatment were not significantly reduced by fumigation, however. Differences among the other summer management treatments observed in the unfumigated plots were obscured by the very effective fumigation treatment, which reduced *Cyperus* spp. populations to low levels in fumigated plots regardless of the previous summer treatment (Table 4).

Significant differences in yield were found with fumigation but not with summer management method despite trends toward higher yields in solarized plots (Table 5). However, yield was significantly enhanced by fumigation only following the opaque polyethylene and weed treatments, but not following transparent polyethylene or rototilling. The latter two methods were more effective in lowering pest populations (Tables 2-4), and thus less response to fumigation would be anticipated, especially following the most effective summer treatment, solarization with transparent polyethylene. A similar pattern to the yield data was observed with browning and discoloration resulting from soilborne diseases (Table 5). Incidence of specific root diseases was not determined, since a complex of several fungal pathogens, including *Rhizoctonia solani* Kühn, *Fusarium* spp., and *Pythium* spp., typically exists in these soils (16). Galling from *M. incognita* was detected at harvest, despite the absence of this nematode from soil samples collected throughout the summer and autumn. Damage to tomatoes at population levels undetected by soil sampling is not unusual for *M. incognita* on tomatoes in southern Florida (13). The root gall index of 4.5 observed in unfumigated plots following summer weed growth was significantly higher than the values of 2.0-2.3 observed following other strategies (Table 5). Root gall indices were reduced to near zero in all fumigated plots, however, regardless of the summer management methods used.

Test 2. Addition of water to beds prior to covering with transparent polyethylene appeared to be of little benefit in increasing soil temperature, for enhancing control of nematodes, weeds, or soilborne diseases, or in increasing tomato yield. Likewise, a slight variation in the time period during which solarization occurred had few meaningful effects

Table 4. Effect of summer management and soil fumigation on populations of *Cyperus* spp. Test 1, autumn 1985.

	Cyperus spp. plants per bed[x]							
	15 Oct.		25 Oct.		25 Nov.		12 Dec.	
Summer management	F[y]	C[y]	F	C	F	C	F	C
Transparent polyethylene	0 a	5.2 a	0.2 a	4.6 b	4.0 a	16.4 a	0.6 a	1.8 a
Opaque polyethylene	0.6 a	29.8 b	0.6 a	19.8 b	6.6 a	35.6 b	0 a	3.6 a
Rototilled	0.4 a	14.8 a	0.4 a	15.0 ab	5.8 a	31.2 ab	0 a	2.4 a
Weeds	1.8 a	71.8 c	1.2 a	60.8 c	10.0 a	65.2 c	0 a	9.4 b
Significant effects from ANOVA:[z]								
Summer management	F=23.6***		F=16.6***		F=7.00***		F=3.71*	
Fumigant	F=91.4***		F=63.2***		F=49.4***		F=22.8***	
Summer management x fumigant	F=21.2***		F=15.5 ***		F=4.27*		F=4.37*	

[x]Counts for 15 Oct., and 25 Nov. are per 12.2-m bed; counts for 12 Dec. are per 10 tomato plants to be harvested.
[y]F = fumigated with 252 kg/ha of methyl bromide; C = unfumigated control.
[z]Data are means of 5 replications. Asterisks (***, *) indicate significant F values at P=0.001 and P=0.05, respectively. Means in columns followed by the same letter or means in rows underscored by the same line are not significantly (P=0.05) different, according to the Waller-Duncan test.

Table 5. Effect of summer management and soil fumigation on harvest data. Test 1, autumn 1985.

Summer management	Tomato yield (kg per plot)						Root gall index[w]		Root browning index[x]	
	Marketable		Unmarketable		Total					
	F[y]	C[y]	F	C	F	C	F	C	F	C
Transparent polyethylene	9.36 a	7.55 a	2.13 a	1.54 a	11.49 a	9.09 a	0.27 a	2.00 a	3.7 a	4.4a
Opaque polyethylene	10.18 a	6.88 a	3.10 a	1.92 a	13.28 a	8.81 a	0.17 a	2.30 a	3.3 a	4.9 a
Rototilled	8.72 a	7.34 a	2.84 a	2.06 a	11.55 a	9.40 a	0.10 a	2.00 a	4.0 a	5.0 a
Weeds	10.45 a	5.00 a	3.29 a	1.56 a	13.75 a	6.59 a	0.40 a	4.50 b	3.9 a	5.5 a
Significant effects from ANOVA:[z]										
Summer management	n.s.		n.s.		n.s.		F=7.05***		n.s.	
Fumigant	F=15.7***		F=11.2**		F=21.6***		F=98.6***		F=24.3***	
Summer management	n.s.		n.s.		n.s.		F=4.92**		n.s.	

[w]Root galling rated on Taylor and Sasser's 0-5 scale (19).

[x]Root browning by soilborne diseases rated on Horsfall and Barratt's 1-12 scale (4).

[y]Fumigant treatments: F = fumigated with 252 kg/ha of methyl bromide; C = unfumigated control.

[z]Data are means of 5 replications. Asterisks (***, **) indicate significant F values at P=0.001 and P=0.01, respectively; n.s. = not significant. Means in columns followed by the same letter or means in rows underscored by the same line are not significantly (P=0.05) different, according to Waller-Duncan test.

on the results. The patterns observed with *Cyperus* spp. populations (Table 6) were typical of most data collected during this test, since in the autumn samples, no significant effects were observed with duration of cover or with addition of water. A significant effect observed in *Cyperus* spp. populations on 2 Aug. (Table 6) resulted because few plants had emerged in the late-season treatment, since the treatment was initiated on 26 Jul., only a few days before sampling. Later in the year, no significant differences in *Cyperus* spp. populations were evident (Table 6).

Similarly, soil temperatures in covered beds varied by only 1-2°C, regardless of cover duration or water addition. Few consistent treatment differences in populations of *R. reniformis, Q. acutus,* and *H. dihystera* were evident in autumn-collected samples (9 Sep., 28 Oct., 23 Dec.). Populations of all three species were low (≤26/100 cm^3, soil) prior to planting the tomato crop, but *R. reniformis* populations had risen to very high levels (1440-3661/100 cm^3 soil) at harvest (23 Dec.), although there were no significant differences with treatment. At harvest, yields of mar-

Table 6. Effect of cover season and watering on populations of *Cyperus* spp. in beds covered by transparent polyethylene. Test 2, summer + autumn 1985.

Treatment		*Cyperus* spp. plants per 10.7-m bed		
Cover[x]	Water[y]	2 Aug.	20 Oct.	26 Nov.
Early	+	4.4	4.0	20.0
	–	9.4	3.8	22.4
Long	+	2.8	2.4	17.8
	–	3.2	4.0	12.4
Late	+	0	3.2	13.0
	–	0.4	3.4	13.4
Significant effects from ANOVA:[z]				
		Cover F=6.84**	n.s.	n.s.

[x]Dates of transparent plastic cover on beds: early season cover = 8 Jul.-22 Aug.; long season cover = 8 Jul.-9 Sep.; late season cover = 26 Jul.-9 Sep.

[y]Water treatments: +, bed drenched with water before covering; –, not drenched before covering.

[z]Data are means of 5 replications. Asterisks (**) indicate significant F values at P=0.01; n.s. = no significant F values for main effects (cover, water) or interaction (cover x water).

ketable tomatoes ranged from 7.33-9.64 kg/plot, total yields from 10.32-12.72 kg/plot, root gall index (19) from 0-0.26, and the index of root browning (4) from 2.7-3.9, although no significant differences with cover duration or water addition were observed for any of these parameters.

DISCUSSION

The generally negative results obtained in Test 2 suggest that the efficacy of soil solarization under the conditions studied here is not affected much by slight changes in the time period during which solarization occurred, nor by addition of supplementary water. Moist soil is considered important for proper heat conduction (7,8), and although addition of moisture to solarized soil may enhance performance in dry climates, the moisture levels achieved during the summer rainy season in southern Florida are probably adequate for heat conduction.

The highest soil temperatures achieved in our studies were comparable to those achieved in Israel (7,8), California (18), and Texas (3) and were sufficient to achieve some control of nematodes and weeds. However, this control was not effective for as long a time period as that observed with soil solarization in other areas, where yields of two successive crops were enhanced by the process (3,8).

Populations of nematodes, particularly *R. reniformis,* recovered during the autumn tomato crop, achieving high populations. This recovery or recolonization of solarized soil is reminiscent of the rapid recolonization of fumigated soils by nematodes (15). A similar buildup of *R. reniformis* in solarized soil was observed in Texas (3), although numbers there were still much lower than those observed in unsolarized plots. Recolonization of solarized plots in our test could be attributed to contamination or to incomplete control, although neither hypothesis could be proved or disproved by the data presented. Efforts were made to minimize interplot contamination, and while some nematodes could have been introduced to solarized plots in minute amounts of soil, it is unlikely that substantial amounts of the root pieces and large seeds of *Cyperus* spp. were introduced to solarized plots, yet the control and recolonization patterns of both *Cyperus* spp. and nematodes were similar. It is possible that the large pieces of rock characteristic of this soil may have interfered with heat conduction to the extent that refugia with favorable microclimates were formed, from which nematodes and weeds could recolonize the beds. Furthermore, the existence of frequent cloud cover (rainfall on ca. 60% of days during solarization) may have resulted in fluctuations to lower temperatures or in a shorter duration of maximum temperatures (Table 1), thereby enhancing pest survival, at least in some portions of the beds.

Although long-term benefits through several crop seasons are not anticipated from solarization under the subtropical conditions examined here, it is evident that useful short-term reductions in populations of various pest groups (nematodes, weeds, root diseases) could be achieved. Under the conditions of this study, the favorable effect of soil solarization on yield of the subsequent crop was not as marked as in relatively cloud-free areas (3,8) or in locations with high levels of soilborne diseases (14), which generally respond more readily than nematodes to control by solarization (8). Nevertheless, although tomato yields in unfumigated plots were not significantly different under the summer management strategies examined here, there was a trend toward increased yields following solarization or rototilling, and application of a soil fumigant following either of these strategies did not provide the significant increases in yields observed when control plots not receiving solarization or rototilling treatments were fumigated. In general, solarization under transparent polyethylene reduced pest populations to the extent that fumigation of solarized plots to achieve additional reductions was impractical. Only in the case of galling by *M. incognita* did fumigation provide a significant decrease in pest levels present in solarized plots.

Recently, there has been emphasis on finding alternatives to soil fumigation as available fumigants become increasingly restricted. However, nonchemical alternatives cannot adequately replace fumigation in some systems, as for example, in Alabama peanut fields, where corn and sorghum rotations, although effective in reducing populations of *M. arenaria* (Neal) Chitwood, could not fully substitute for the greater efficacy of soil fumigation (17). While soil fumigation remains the most effective control measure for the entire spectrum of soilborne pests in the subtropical tomato production system discussed here, it is evident that solarization or even summer fallow achieved by rototilling can provide practical alternatives, recognizing the limitations involved. The major limitation is that control of root-knot nematodes, achieved to some extent by solarization, is not as great as that achieved by fumigation.

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