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Effects of Soil Solarization on Nematodes Parasitic to Chickpea and Pigeonpea[1]

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Abstract: Solarization by covering the soil with transparent polyethylene sheets during the summer months (April, May, June) in 1984 and 1985 significantly ($P = 0.01$) reduced the population densities of nematodes (*Heterodera cajani, Rotylenchulus reniformis, Helicotylenchus retusus, Pratylenchus* sp., and *Tylenchorhynchus* sp.) parasitic to chickpea and pigeonpea. Population density reductions of 93% of *Heterodera cajani* eggs and juveniles, 99% of *Helicotylenchus retusus*, 98% of *Pratylenchus* sp., and 100% of *R. reniformis* were achieved by solarization in 1984. Irrigation before covering soil with polyethylene improved ($P = 0.01$) the effects of solarization in reducing the population densities of *Heterodera cajani.* Similar trends in population density reductions were observed in 1985, but the solarization effects were not the same. Nematode population reductions in the 1984–85 season were evident until near crop harvest, but in the 1985–86 season the effects on nematode populations were not as great and did not last until harvest. Factors such as rains during the solarization, duration of solarization, and sunshine hours may have influenced the efficacy of solarization. Solarization for two seasons reduced the population densities each year about the same as single season solarization, and residual effects of solarization on nematode populations did not last for more than a crop season.
Key words: Cajanus cajan, Cicer arietinum, Helicotylenchus retusus, Heterodera cajani, India, irrigation, *Pratylenchus* sp., residual effect, *Rotylenchulus reniformis,* solar heating, solarization, *Tylenchorhynchus* sp.

Soil solarization is a hydrothermal method of soil disinfestation using solar heat trapped and conserved through transparent polyethylene mulch. The practice has been used to effectively control verticillium and fusarium diseases in vegetables and *Verticillium dahliae* in pistachio (4). Other beneficial effects are control of weeds and insect pests, release of certain plant nutrients, and increased soil moisture accumulation (3,4,10). This technique also can be useful in ameliorating many soilborne pests, particularly in the semiarid tropics where maximum air temperatures in summer may exceed 40 C for several days. At the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Andhra Pradesh, India, an interdisciplinary team of scientists investigated effects of soil solarization on the growth of pigeonpea (*Cajanus cajan* (L.) Millsp.) and chickpea (*Cicer arietinum* L.) in a vertisol (1). Vertisols are extensive soils in the semiarid tropics that have good water-holding and high buffering capacities. They are derived from augite basalts and other base rich rocks and from colluvium and alluvium derived from these (11). The effects of soil solarization on the plant-parasitic nematodes in a vertisol are reported here.

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MATERIALS AND METHODS

Experiments were conducted on two fields on vertisol (typic pellusterts) at the research farm (545 m elevation) of the ICRISAT Center, Patancheru, Andhra Pradesh, India. Chemical characteristics of the surface soil (0–15 cm) of the two fields varied slightly (Table 1). Except for 40 kg/ha zinc sulphate applied to the chickpea field in 1985–86, no fertilizer was applied to either pigeonpea or chickpea.

Plots were arranged in a split-plot design; there were six replications. Main plots comprised those with irrigation (about 50 mm water was applied) before solarization (covering soil surface with polyethylene sheet) and those without irrigation before solarization. Subplots were factorial combinations of two genotypes (LRG 30 and

TABLE 1. Chemical characteristics of vertisol fields used for solarization tests, ICRISAT Center.

	pH	Electrical conductivity (dSm^{-1})	Available P ($mg\ kg^{-1}$)	NH_4-N ($mg\ kg^{-1}$)	NO_3-N ($mg\ kg^{-1}$)
Chickpea	8.3	0.20	3.9	12.0	12.8
Pigeonpea	8.4	0.18	2.9	37.9	7.0

TABLE 2. Soil temperatures recorded in solarized and unsolarized, irrigated and unirrigated plots, ICRISAT Center, 1984–85.

Soil depth (cm)	Temperature (C)		Days with maximum temperature >45 C
	Maximum	Mean	
	Irrigated, solarized		
5	54.1	49.9	48
10	48.0	44.4	23
20	42.0	38.8	0
	Irrigated, unsolarized		
5	44.6	40.5	0
10	38.5	35.8	0
20	34.3	32.3	0
	Unirrigated, solarized		
5	60.7	53.9	49
10	51.0	46.6	39
20	42.3	38.3	0
	Unirrigated, unsolarized		
5	47.7	43.7	22
10	40.2	37.6	0
20	34.1	32.4	0

ICP 8863 for pigeonpea; ICCV 1 and JG 74 for chickpea) with and without solarization. In 1984 polyethylene covers were applied to pigeonpea plots 13 April and to chickpea plots 17 April, and covers were removed from both crop plots on 4 June. Pigeonpea genotypes were planted 25 June and harvested 6 February 1985. Chickpea was planted 2 November and harvested 18 February 1985. In 1985–86 plots were divided into three blocks and treatments were as follows: 1) residual solarization (solarization in 1984 but not in 1985), 2) no solarization (no solarization in either year), 3) single solarization (no solarization in 1984 but solarization in 1985), and 4) double solarization (solarization in both years). In 1985 solarization was imposed on pigeonpea plots on 26 April and chickpea plots on 22 April; for both the crops it was terminated by removing the polyethylene sheets on 6 June. Pigeonpea genotypes were planted 25 June and harvested 23 January 1986; chickpea genotypes were planted 17 October and harvested 10 February 1986.

Subplots in all the experiments were 6 × 6 m. A 3-m buffer zone was maintained between plots. Clear polyethylene sheets 100 μm thick (94 g/m^2 and 400 gauge) and 6 m wide were placed on the plots for the solarization treatment. Soil was placed around the edges of the polyethylene sheets to secure them. Inter-row spacing was 75 cm for pigeonpea and 30 cm for chickpea. Within-row plant spacing for pigeonpea was 30 cm in 1984–85 and 15 cm in 1985–86; for chickpea it was 10 cm both seasons.

Soil temperature was monitored using copper-constantan thermocouples buried 5, 10, and 20 cm deep in the soil; temperatures were recorded using a Campbell Scientific CR 5 data logging device (Table 2) (1). Soil moisture content was measured gravimetrically before and after solarization. Average soil moisture content (%, weight:weight) in 0–15 cm soil profile on 13 April 1984 was 28.8 in irrigated plots and 10.6 in unirrigated plots. On 4 June 1984 the moisture content was 16.0% in irrigated solarized plots, 6.8% in irrigated unsolarized plots, 7.3% in unirrigated solarized plots, and 6.3% in unirrigated unsolarized plots. Rainfall, air temperatures, and sunshine hours during the solarization experiments were recorded (Table 3).

Soil was sampled for nematodes by taking six 2.5-cm-d cores 20 cm deep from each plot. The nematode populations were extracted from 200-cm^3 samples by suspending them in water, pouring them through nested sieves (850, 180, and 38 μm pore), and placing the residue from the 38-μm-pore sieve on modified Baermann funnels (7). Cysts were collected on a 180-μm-pore sieve. The nematode populations were assessed before solarization (April), after solarization (June), at regular intervals during crop growth, and at harvest.

TABLE 3. Rainfall, air temperature, and hours of sunshine during the solarization experiment, ICRISAT Center, 1984–85 and 1985–86.

	Rainfall (mm)	Temperature (C)				Hours of sunshine, average
		Av. max.	Av. min.	Max.	Min.	
April 1984	0.5	37.4	23.1	40.4	20.7	10.0
1985	0.0	39.8	24.9	40.9	23.5	9.9
May 1984	0.0	40.9	26.3	43.2	20.2	10.0
1985	19.4	39.5	25.3	41.9	21.7	9.3
June 1984	0.0	39.5	27.3	40.0	26.0	7.6
1985	17.1	34.6	23.9	36.5	23.0	6.7

Data were $\log_e$ transformed and subjected to analysis of variance. The plant-parasitic nematode community in the pigeonpea field consisted of *Heterodera cajani* Koshy, *Helicotylenchus retusus* Siddiqi and Brown, *Pratylenchus* sp., *Rotylenchulus reniformis* Linford and Oliveira, and *Tylenchorhynchus* sp. *Heterodera cajani* was the most numerous. Nematode species were the same in the chickpea field, but *Helicotylenchus retusus* was the predominant nematode, accounting for 62% of the total plant-parasitic nematode population.

RESULTS

Soil temperatures were higher in the solarized than in unsolarized plots and higher in unirrigated than in irrigated plots. Soil temperatures higher than 45 C were recorded at 5-cm and 10-cm depths in the solarized plots (Table 2). In the unsolarized plots the number of days with temperature above 45 C were fewer. Similar trends were observed in 1985; however, the number of days with soil temperatures higher than 45 C in the solarized plots were fewer than in 1984.

Soil samples collected in June 1984 revealed a reduction ($P = 0.01$) in the population densities of plant-parasitic nematodes in the solarized plots (Fig. 1). Population density reductions were 93.4% for *Heterodera cajani,* 98.5% for *Helicotylenchus retusus,* and 97.4% for the total plant-parasitic nematode population after solarization. The population density of *R. reniformis* was below the detectable level (Table 4). Solarization with irrigation was most effective in reducing *H. cajani* population densities (Fig. 1C). The population densities of eggs and juveniles of *Heterodera cajani* within and outside the cysts were reduced significantly ($P = 0.01$). Nematode population densities remained low in samples taken during crop growth (October and December 1984) and at maturity (February 1985) in solarized plots (Fig. 1). In unsolarized plots, the nematode numbers decreased significantly ($P = 0.01$) for a short period then increased again to the original level (Table 4, Fig. 1). Reductions in nematode population densities in the solarized chickpea plots were 99.4% in *Helicotylenchus retusus,* 97.5% reduction in *Pratylenchus* sp., and 99.8% in total numbers of plant-parasitic nematodes. In unsolarized plots, population densities increased rapidly even before chickpea was planted in October (Fig. 1). Rates of reproduction of *Heterodera cajani* on the pigeonpea genotypes and of *Helicotylenchus retusus* and *Pratylenchus* sp. on the chickpea genotypes were similar.

Data collected in the 1985–86 season indicated that solarization for two seasons reduced the nematode population densities each year about the same as the single season solarization (Table 5). Reduced nematode numbers as a result of solarization did not remain low until crop maturity (Fig. 2). When pigeonpea plots were sampled 4 months after solarization, there were no significant differences between population densities of *Heterodera cajani* and other plant-parasitic nematodes in solarized and unsolarized plots. Solarization in the 1984–85 season did not influence the nematode population densities in the 1985–

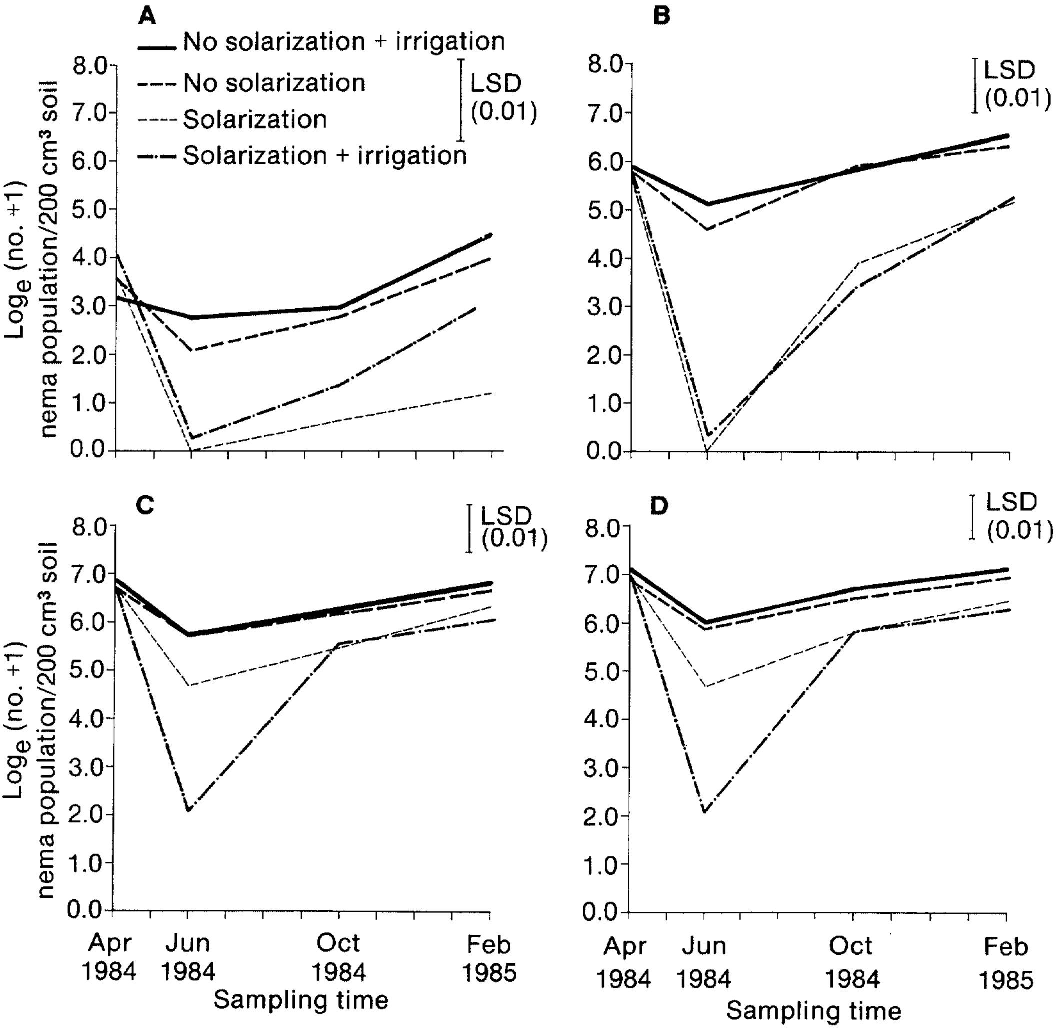

FIG. 1. Changes in population densities of plant-parasitic nematodes on chickpea and pigeonpea following solarization of soil, ICRISAT Center 1984–85. A) *Helicotylenchus retusus* on chickpea. B) Total plant-parasitic nematodes on chickpea. C) *Heterodera cajani* eggs and juveniles on pigeonpea. D) Total plant-parasitic nematodes on pigeonpea.

86 season. As in the 1984–85 season, solarization in combination with irrigation was more effective in reducing the egg and juvenile population densities of *H. cajani, R. reniformis,* and other plant-parasitic nematodes than was solarization without irrigation. Nematode population levels did not decrease significantly in the unsolarized plots. Population levels of encysted eggs and juveniles of *H. cajani* were reduced significantly only in the irrigated solarized plots. A slight increase in nematode population densities was observed in plots that were solarized in 1984–85 and fallowed in 1985–86. Results from chickpea plots were similar to those from pigeonpea. The reduction in population density was greater in the chickpea plots than in pigeonpea plots (Table 5). The adverse effects of solarization on the nematodes were not detectable at harvest, and the nematode population densities were lower ($P = 0.05$) in the solarized plots until October (Fig. 2A).

Soil solarization markedly increased dry matter production and seed yield of pigeonpea. The increases were greater in the presence of irrigation. The residual effects

TABLE 4. Nematode population densities in solarized and unsolarized plots, ICRISAT Center, 1984–85.

	Treatment	Nematode numbers/200 cm³ soil: Pre-solarization (April)	Nematode numbers/200 cm³ soil: Post-solarization (June)	Reduction in population density (%)	CV (%)
		Pigeonpea			
Heterodera cajani eggs and juveniles	No solarization	895.0 ± 226.8	305.0 ± 77.0†	65.9	4.5
	Solarization	885.0 ± 224.5	58.4 ± 14.8†‡	93.4	
Rotylenchulus reniformis	No solarization	91.8 ± 22.3	11.4 ± 2.7†	87.6	20.5
	Solarization	72.2 ± 17.5	0.0†‡	100.0	
Helicotylenchus retusus	No solarization	73.7 ± 20.1	15.0 ± 4.1†	79.6	29.4
	Solarization	75.4 ± 20.5	1.2 ± 0.3†‡	98.5	
Total plant-parasitic nematodes	No solarization	1,130.0 ± 170.1	383.8 ± 57.8†	74.6	5.2
	Solarization	1,141.4 ± 171.8	29.4 ± 4.4†‡	97.4	
		Chickpea			
H. retusus	No solarization	223.6 ± 49.6	88.2 ± 19.6†	60.5	6.5
	Solarization	206.4 ± 45.0	1.2 ± 0.3†‡	99.4	
R. reniformis	No solarization	28.5 ± 6.9	4.5 ± 1.1†	84.2	37.0
	Solarization	27.1 ± 6.6	0.0†‡	100.0	
Pratylenchus sp.	No solarization	29.1 ± 8.9	11.2 ± 3.4	61.5	33.3
	Solarization	47.9 ± 14.6	1.2 ± 0.4†‡	97.5	
Total plant-parasitic nematodes	No solarization	343.8 ± 76.2	125.2 ± 27.8†	63.6	11.3
	Solarization	343.8 ± 76.2	1.2 ± 0.3†‡	99.8	

Data were $\log_e$ (no. + 1) transformed for analysis; actual data in table.
† Significant ($P = 0.01$) differences between pre- and post-solarization nematode populations.
‡ Significant ($P = 0.01$) differences in post-solarization nematode population densities between no solarization and solarization.

of solarization on total dry matter and seed yield were not significant. There were no differences between solarization for two seasons and single season solarization. Growth and yield of chickpea were poor because of drought stress. Nevertheless, large effects of solarization were apparent (Y. S. Chauhan, pers. comm.).

DISCUSSION

Soil solarization using transparent polyethylene mulch during the hot summer months was effective in reducing population densities of plant-parasitic nematodes. Solarization increased the soil temperatures which is probably largely responsible for reduction in nematode numbers. The solarization effects varied between the two cropping seasons. Population density reductions in the 1984–85 season continued until near harvest but solarization effects on nematode populations in the 1985–86 season were not as great and did not last until harvest. Factors such as rains during the solarization treatment, fewer sunshine hours (Table 2), shorter duration of solarization treatment, and fewer days when the maximum soil temperature was above 45 C in the solarized plots in 1985–86 than in 1984–85 might have affected the efficacy of the solarization treatment. Heald and Robinson (2) also reported significant reduction in *R. reniformis* population density immediately after solarization, but the nematode then multiplied rapidly and the effects of solarization were not detectable at harvest. Summer fallow (unsolarized plots) did not reduce the nematode population densities in 1985–86. Rains during solarization may have enhanced the growth

TABLE 5. Population densities of all plant-parasitic nematodes in solarized and unsolarized plots, ICRISAT Center, 1985–86.

Treatment†	Nematode numbers/200 cm³ soil: Pre-solarization (April)	Nematode numbers/200 cm³ soil: Post-solarization (June)	Reduction in population density (%)	CV (%)
		Pigeonpea		
Control	595.9 ± 126.1	368.7 ± 78.0	38.1	
Residual solarization	343.8 ± 72.7	459.4 ± 97.2	0.0	
Single solarization	445.9 ± 94.3	164.0 ± 34.7*	63.2	
Double solarization	601.9 ± 127.3	110.0 ± 23.3*	81.7	9.6
		Chickpea		
Control	267.7 ± 78.7	196.4 ± 57.7	26.6	
Residual solarization	239.8 ± 70.5	162.4 ± 47.8	32.3	
Single solarization	156.0 ± 45.9	5.9 ± 1.7*	96.2	
Double solarization	210.6 ± 61.9	5.2 ± 1.5*	97.5	20.2

Data were $\log_e$ (no. + 1) transformed for analysis; actual data in table.
* Indicates significant differences at $P = 0.01$.
† Treatment: control = no solarization in 1984 or in 1985. Residual solarization = solarization in 1984 but not in 1985. Single solarization = no solarization in 1984 and solarization in 1985. Double solarization = solarizations in 1984 and in 1985.

of weeds (*Convolvulus* sp., *Cynodon* sp., *Cyperus* sp., and others) that were hosts of the nematode species. In the 1984–85 cropping season the summer fallow was of relatively longer duration and was free from rains, resulting in a 60–90% reduction in nematode population densities. Nematode numbers increased rapidly in these plots, however. Covering the soil surface with a polyethylene sheet almost eradicated the nematode populations, and nematode population increase was low in these plots during the crop growth. This may be due to sublethal heating of the nematodes in the soil profile resulting in reduced pathogenic potential, lower subsequent reproduction or egg hatching, and possibly induced biocontrol (4,9,10).

Irrigation before covering the soil is generally recommended to increase the effectiveness of solarization (4). Maintenance of high soil moisture results in significant

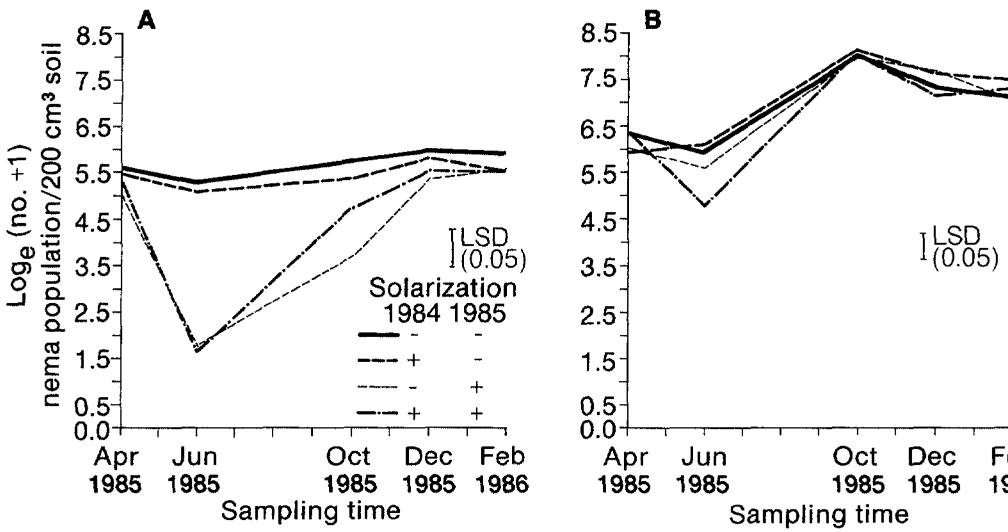

FIG. 2. Changes in population densities of all plant-parasitic nematodes on chickpea (A) and pigeonpea (B) following solarization of soil, ICRISAT Center 1985–86; (+) and (−) indicate solarization and no solarization, respectively, in the corresponding years.

reduction in the population levels of plant-parasitic nematodes by soil solarization (9). We also observed that although solarization was effective in reducing the nematode population densities even without irrigation in the 1984–85 crop season, its effectiveness in reducing the *H. cajani* population levels improved with irrigation. Survival of the encysted juveniles of *Globodera rostochiensis* also was significantly less in solarized irrigated soil than in soil without irrigation (6).

Population densities of *H. cajani* in the pigeonpea plots were above the damage threshold level. An initial juvenile population density of $3.0/cm^3$ soil can cause 25% reduction in pigeonpea biomass (8). The damage threshold of *Helicotylenchus retusus* on chickpea has not been determined. This study indicated that soil solarization reduced the preplant nematode population densities in the vertisol and thus insured less crop damage from plant-parasitic nematodes, but solarization may not result in long-term nematode control. Solarization should be combined with other treatments such as application of neem cake or other organic amendments and (or) planting of resistant cultivars or nonhosts after solarization (5) to determine if there are interactive effects on the population densities of plant-parasitic nematodes. Under semi-arid tropical conditions, this method may be of great use for high value crops where the control of multiple pests and diseases is needed.

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