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Effectiveness of Soil Solarization in Furrow-Irrigated Egyptian Soils.

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A B S T R A C T

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Plant Disease.

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Soil solarization of furrow-irrigated soils in Egypt effectively controlled weeds, broomrape, Rotylenchulus reniformis, other nematodes and corky root and root knot diseases in tomatoes. It also improved plant growth and increased the yields by 25 to 432% in broadbeans, onions, tomatoes and strawberries in various types of soils in experimental and farmers plots. In one experiment with broadbeans, Rhizobium nodulation was adversely affected by solarization and the plants were stunted but recovered later.

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Solarization had a long term effect (two or three seasons) in both disease control and yield increase. It also decreased soil salinity.

Additional key words: Electrical conductivity, Meloidogyne, Orobanche, plastic mulching, Pyrenochaeta lycopersici, solar heating, tarping.

Soil solarization is a relatively new method for controlling soilborne pests(14). It was tested with a variety of crops and diseases, in several countries, frequently with successful results for both short and long terms (7,8,10,12,13,14,15,16,19,20 and others). Since most of these studies were carried out under sprinkler or drip irrigation, they do not ensure similar success in furrow-irrigated soils, where pathogen spread is enhanced (6), leading to possible recontamination of disinfested soils. In Egypt, furrow irrigation is very common, many soils have a long history of cropping and the agricultural regimes for certain crops differ from those in countries where solarization was tested. Increased plant growth (IGR) by solarization is a common phenomenon, evident even in the absence of known pathogens (1, 10,22). Higher quantities of mineral nutrients were recorded in solutions of the solarized soils, but other factors might be also involved in the IGR phenomenon.

The purpose of this study was to investigate the short and long term effects of solarization, in furrow-irrigated soils in Egypt, on soilborne pests, plant growth and yield and soil salinity. Solarization of farmers plots was also studied.

MATERIALS AND METHODS

Field experiments and demonstration plots were set up, during 1981-5, in various furrow-irrigated sites in Egypt with a variety of crops. The selected plots had a long history of cropping. Soil types were clay loam at Giza and loamy sandy or sandy in the other sites.

Experiment design: All experiments, carried out in 4-5 replicates were based on a basic unit (replicate) consisting of a bed 7m wide and 14 to 24 long, devided by eight irrigation furrows. Irrigation water was directed either separately to each plot or from solarized to nonsolarized plots to reduce the chances of contamination. The supply canals were also solarized.

Soil solarization: Solarized and nonsolarized plots were flooded and 1-4 days later, according to soil type, irrigation furrows were opened manually. Solarized plots were covered continuously (7), above the ridges using two transparent polyethylene sheets (450cm wide and 0.04 mm thick) (Ginegar Plastic Products, Israel) containing ultra violet absorbent. Solarization started usually in mid July and lasted 5-10 weeks. Soil temperatures were measured by a distance thermograph (Lambrecht, Germany). Typical maximal temperatures of nonsolarized soil, recorded in August 1983 at Giza and Fayed at a depth of 20 cm, were 33-34C, while temperatures of the solarized soil were usually 7-8C higher. Parameters used to evaluate the effectiveness of solarization, includes soilborne pest counts, disease rating, assessement of plant development at various stages and yield component measurements.

After harvest, some experimental plots were replanted in order to assess the prolonged effects of soil solarization.

Nematode counts. Recovery of nematodes from soil samples was carried out by the sieve technique (2). The resulting suspension was left for 49 hrs in Baermann pan for extraction before counting.

Salinity measurements. For the Fayed loamy sand soil, a saturated paste was prepared and extracted and then electrical conductivity (EC), anions and cations were determined (17). SO_4^{2-} was calculated from the difference between the sums of cations ($Ca^{2+}+Mg^{2+}+Na^{2+}+K^{+}$) and the anions ($HCO_3^{-}+Cl^{-}$) concentrations. For the Youth Farms-Sinai sandy soil, a 1:1 paste was prepared and EC was determined in the extract. Data were then corrected for saturation (26% w/w) by multiplication.

Demonstration plots. Selected farmers' plots were solarized manually to assess and demonstrate its effectiveness under semi commercial conditions. There were two to three replicates (1000-4000 m^2 each) of either solarized or nonsolarized treatments in each site. Plants were sampled periodically to assess growth and yield.

RESULTS

Effect of soil solarization on weeds, pathogens and crops. The first soil solarization experiment in Egypt was carried out at the Giza Experiment Station (ARC) in 1981-2. A pronounced reduction in weed populations, was observed soon after removal of the polyethylene sheets and remained significant throughout the growing period (Table 1). *Amaranthus*,

Chaenopodium, Plantago, Portulaca and Solanum nigrum were controlled, while Mellilotus and Cyperus rotundus were not. A similar weed control was evident in all solarization experiments. Broadbean plants were stunted during the first stages of growth in the solarized soil, but recovered later in the season (Table 1). The stunted plants had significantly less Rhizobium nodules. Broomrape (Orobanche crenata), first detected 3 mo after planting, was eradicated by solarization. Yield was increased by 25%.

The effects of solarization, with or without Rhizobium inoculation of seeds, was examined in a second experiment at Giza (Table 2). In this experiment, plant growth was not adversely affected by solarization. The effect of inoculation with Rhizobium on the yield was very pronounced in nonsolarized plots (241 % yield increase) but not in solarized ones. Solarization increased the yield by 66-432%. As in the previous experiment, broomrape was completely controlled by solarization. Rate of broomrape infection in nonsolarized plots was not affected by Rhizobium inoculation.

The above two Giza experiments were carried out in a clay loam soil. Two other experiments were carried out in sandy loam or sandy soils in the Ismailia region. In the solarized plots, the improved growth of onion plants was visible shortly after planting and throughout the growth period, and was expressed in the various parameters of plant growth (Fig. 1). Few plants with the pink root disease were detected only in the nontreated plots.

Solarization improved stand and growth of tomato plants (Table 3). Stand reduction in the nonsolarized plots resulted mainly from mortality due to

Phytophthora parasitica and plant uprooting occuring during manual weeding. Solarization effectively controlled root knot disease. In addition, disease severity of the few diseased plants in the solarized plots was lower than that of plants in the nontreated plots. Corky root disease was detected only in the nonsolarized plots. Solarization positively affected all yield components.

Effect on nematodes. Nematode counts were made in experimental and other nonsolarized and solarized plots. Rotylenchulus reniformis populations were significantly reduced by 93-95% in the first two soil samplings at the first Giza experiment but later the differences diminished (Fig. 2). Population of this nematode was significantly reduced also in the second Giza experiment (Table 4). Populations of five other nematode genera were significantly reduced by 69-100% in experiments carried out in different sites (Table 4).

Prolonged effects of solarization. The first three described experimental plots were replanted to examine the long term effect of solarization extending during the following growing seasons. Plots in the 1981-2 and 1983-4 Giza experiments (referred to in Tables 1 and 2) planted with corn and sunflower , respectively, were harvested, cultivated and both replanted with broadbeans, as a third crop after solarization. In both experiments, significant (P=0.05) long term broomrape control was evident. Broomrape populations (per m^2) in nonsolarized and solarized plots numbered 6.9 and 0.6 in the 1981-2 Giza experiment, and 5.1 and 0 in the 1983-4 one, respectively.

The onion plot at Ismailia (referred to in Fig. 1) was replanted with tomatoes. Results (Table 5) show a long term effect of solarization

regarding plant growth, increased yield and control of the corky root disease but not of root knot nematodes.

In another experiment carried out in Fayed (1983-4), solarization significantly increased height and yield of tomato plants (the first crop) by 27.3 and 172%, respectively. Clover was planted as a second crop in fall 1984. The total yield (two harvests) was 6.7 and 10.0 kg/m^2, in nonsolarized and solarized plots respectively (49% increase).

Effects on soil salinity. Soil samples were collected from the experimental site at Fayed (described above) 4 mo after planting tomatoes (from the upper 15cm layer) and were analyzed. Data for the solarized soil were: EC=17.6 d Sim/m, total cations or total anions = 179.8 meq/l. For the nonsolarized soil: EC=29.7 d Sim/m, total cations or total anions 384 meq/l. Such high salt concentrations in loamy sand soil (saturated paste, 30-32%) resulted in a distinct white film of dried salts on the soil surface in the nonsolarized soil.

The effect of solarization on salts distribution in the soil was demonstrated in another experiment in the sandy soil at the Youth Farms-Sinai. Two mo after the termination of solarization, soil was sampled to a depth of 50 cm at 10 cm increments before planting. Results (Table 6) show that EC values were lower in four of the solarized samples, as compared to the nonsolarized ones.

Observation and demonstration plots. Solarization of farmers plots, under semi-commercial conditions, was examined at three different sites. Tomato (Sarabium 1983-4) stand, yield per plant and yield per unit area were significantly (P=0.05) increased by 24, 211 and 287%, respectively by solarization. In a second tomato plot (Youth Farms-Sinai, 1984-5), solarization increased yield per unit area by 71% and extended the harvest period (eight pickings compared to five in the nonsolarized plot). Strawberry (Kalyubya 1983-4) yield per plant and per unit area were significantly (P=0.05) increased by 52 and 75%, respectively, by solarization. In all cases, there were distinct visible differences in plant development between solarized and nonsolarized plots.

DISCUSSION

Soil solarization is effective in controlling soilborne pests and improving plant growth and yield in a variety of Egyptian soils and crops, under furrow irrigation. This is in agreement with other studies regarding effective control of broomrape, corky root disease, various nematodes, *Rhizoctonia solani* and weeds (7,8,10,15,16,20,21). Control of broomrape and the corky root disease, as well as yield increase, lasted for two or three successive seasons, as was also shown with several diseases in other countries, with crops under sprinkler or drip irrigation (10,12,13). The long term effect found in this study, takes place in spite of the fact that, due to furrow irrigation and the continuous cultivation of successive crops, certain levels of recontamination cannot be avoided. The two prerequisites for a long term effect by solarization (or any disinfestation

method), a drastic reduction of pathogen inocula to considerable soil depths and the induction of soil suppressiveness to retard reinfestation from various sources, were demonstrated with solarization in several cases (5,9,10,18). It is possible that these mechanisms operate in Egyptian soils as well, resulting in the prolonged effect of solarization. This long term effect, can possibly, be improved by various means such as solarizing larger plots, using filtered water or applying sanitation measures. The reproducibility of results, a major prerequisite for introducing a new method of control, was shown, during six years under various conditions, including farmers plots.

Improved plant growth that has frequently been shown in disinfested soils in the absence of known pathogens, was attributed to a variety of chemical, physical and biological factors (1,10,22). An additional chemical mechanism by solarization, demonstrated here for the first time, is the decreased salt concentrations in the upper soil layers in soils maintaining shallow ground water. These changes in the distribution of salts in the soil profile propably result from the fact that the plastic mulch prevents evaporation thereby slowing down the upward movement of salts from relatively shallow (60-80cm), possibly salty, ground water. Excess salinity may cause great damage to crops in certain soils. This beneficial side-effect of solarization should be taken into consideration whenever applicable. A detailed simulation and field work on this specific subject is presently performed.

Integrating solarization with other means of control or crop menagement should be investigated. For example, combining solarization with Rhizobium inoculation is a potential means for counteracting the adverse effect of solarization on this bacterium. Combination with adequate herbicides (20), possibly at reduced dosages, may effectively control weeds, which escape solarization. Combining solarization with biological or chemicals means of control improved results (3,4). In the present studies, the yields were frequently increased by solarization to high levels. This might be attributed, among other factors, to the long history of cropping of these soils, resulting in an accumulation of abiotic and biotic detrimental factors (11) including unidentified pests. Hence, soil disinfestation may also be used as a tool for identifying the causes for yield decline.

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Legends to Figures

Fig.1. Effect of soil solarization on onion (cv Giza 6) growth, at various periods after planting in sandy soil (Ismailia 1983-4). In all cases, the solarized treatment was significantly higher (P=0.05) than its respective nonsolarized one.

Fig.2. Effect of soil solarization on *Rotylenchulus reniformis* populations at various periods after the termination of solarization on Oct. 1, 1981 (Giza 1981-2). Arrow indicates broadbean planting time. Numbers followed by the same letter, at the same sampling date, are not significantly different (P=0.05).

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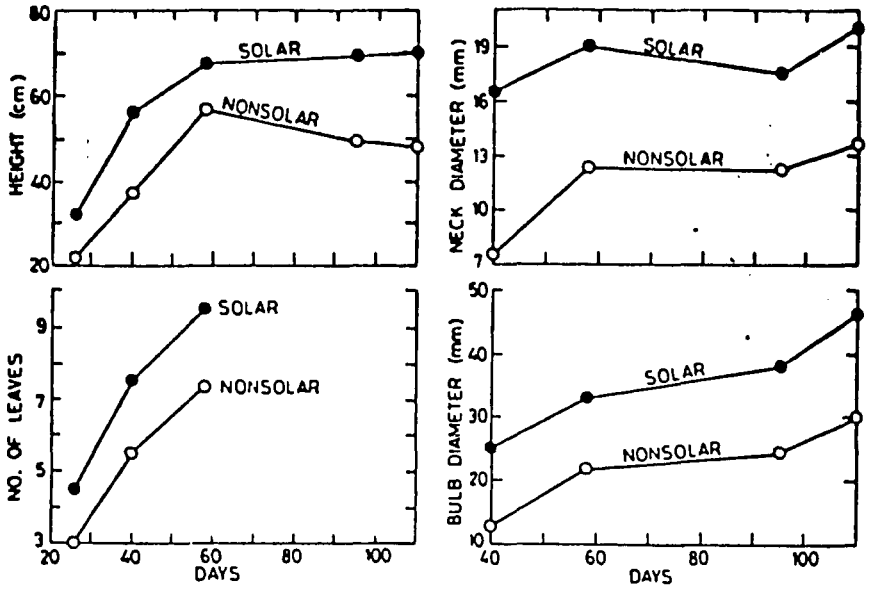

Fig 2

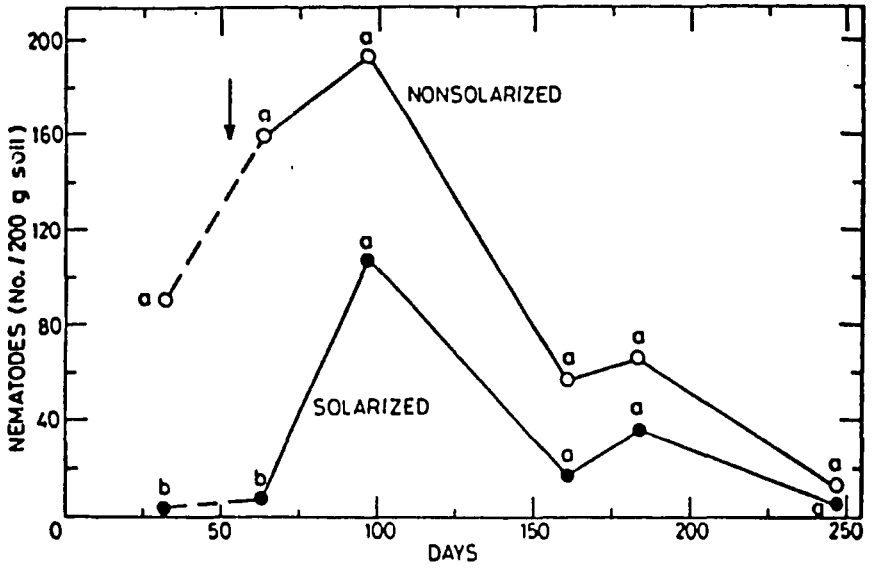

Fig 1.

Table 1. Effect of soil solarization on broomrape and weed populations, broadbean growth, nodulation, and yield (Giza 1981-2[w]).

Soil Treatment	No. weeds/m^2[x] Without Mellilotus	No. weeds/m^2[x] Mellilotus	Broomrape[x] (No/m^2)	Plant height (cm) 12Feb.	Plant height (cm) 27March	Nodules[y] (No/ plant)	Yield (Kg/ha)
Nonsolarized	109a[z]	22a	1.3a	64a	126a	88a	2384b
Solarized	33b	33a	0 b	52b	114a	20b	2992a

[w] Broadbeans (cv Giza 2) were planted on Nov. 19, 1981 and harvested in May 1982.

[x] Counts made on March 6, 1982.

[y] Counts made on Feb. 12, 1982.

[z] Numbers in each column followed by the same letter are not significantly different (P=0.05).

Table 2. Effect of soil solarization and *Rhizobium* (R) inoculation on broomrape population, and on broadbean growth and yield (Giza 1983-4[w]).

Treatment	R	Broomrape[x] (No./m^2)	Plant height[y] (cm)	Branches[y] (No./plant)	Yield (Kg/ha)	Yield (%)
Nonsolarized	+	30.2a[z]	86.2a	5.7b	1,480b	314
Nonsolarized	-	30.0a	80.2a	6.0b	472c	100
Solarized	+	0 b	98.2a	8.1a	2,456a	520
Solarized	-	0 b	89.6a	7.7a	2,512a	532

[w] Broadbeans (cv Giza 4) were planted on Oct. 30, 1983 and harvested on May, 1984.

[x] Counts made on May 23, 1984.

[y] Counts made on Feb. 2, 1984.

[z] Numbers in each column followed by the same letter are not significantly different (P=0.05).

Table 3. Effect of soil solarization on root diseases, growth and yield of tomatoes (El Menayef, 1985-6)[y].

Soil Treatment	Plant Stand (No/m)	Plant fresh wt (g)	Root knot (%)	Corky root (%)	No. fruits/plant	Av. fruit wt (g)	Yield g/plant	Yield Kg/ha
Nonsolarized	1.5b[z]	266b	48a	6a	31.7a	26.6b	844b	15,832b
Solarized	3.0a	484a	6b	0a	37.8a	38.2a	1,443a	54,142a

[y] Tomatoes (cv Peto 6) were transplanted on Sept 21,1985. Measurements were made on Feb. 10, 1986, with 50 individual plants for each treatment.

[z] Numbers in each column followed by the same letter are not significantly different (P=0.05).

Table 4. Nematode populations in nonsolarized (NS) and solarized (S) soils at various sites in Egypt.

Treatment	Site	No. nematodes per 200g soil					
		Tylen.[v]	Long.[v]	Hpl.[v]	Hel.[v]	Prat.[v]	Rot.[v]
NS	Ismailia[w]	120a[x]	20a	40a	560a	-	-
S	Ismailia[w]	0b	0b	0b	0b	-	-
NS	Fayed[y]	440a	87a	61a	33a	-	-
S	Fayed[y]	100b	27b	13b	0b	-	-
NS	Giza[z]	-	-	-	-	-	53a
S	Giza[z]	-	-	-	-	-	27b
NS	Kalyubya[z]	-	-	-	53a	13a	-
S	Kalyubya[z]	-	-	-	13b	0b	-
NS	Kfar Hakeem[z]	80a	-	-	-	10a	-
S	Kfar Hakeem[z]	23b	-	-	-	0b	-

[v] Tyl. = *Tylenchorhynchus*, Long. = *Longidorus*, Hopl. = *Hoplolaimus*, Helic. = *Helicotylenchus*, Prat. = *Pratylenchus*, Rot. = *Rotylenchus*.

[w] Determined on Oct. 1981, shortly after polyethylene removal, before planting.

[x] At each site, numbers followed by the same letter are not significantly different (P=0.05).

[y] Determined on Dec. 1981, 2 mo after planting beans.

[z] Determined on Oct. 1983, shortly after polyethylene removal, before planting.

Table 5. Long term effect of soil solarization, on root diseases, growth and yield of tomatoes (Ismailia 1985)[y].

Treatment	Plant wt (g)	Corky root (%)	Root knot (%)	Fruits No/ plant	Av. fruit wt. (g)	Yield Kg/ha
Nonsolarized	175a[z]	60a	52a	24a	24.8b	24,103a
Solarized	498b	24b	56a	22a	38.3a	33,497b

[y] Soil was solarized in the summer of 1983, planted with onions and after harvesting, the soil was planted with tomatoes cv UC 82 on Nov. 15, 1984. Measurements and harvest were carried out on June 4, 1985.

[z] Numbers in each column followed by the same letter are not significantly different (P=0.05).

Table 6. Electrical conductivity determined in solarized and nonsolarized soils at Youth Farms-Sinai.

Soil depth (cm)	Electrical conductivity (dSim/m)	
	Solarized	Nonsolarized
0 - 10	5.40	7.84
10 - 20	6.72	9.28
20 - 30	8.80	9.80
30 - 40	8.08	7.16
40 - 50	6.64	8.10