Short- and Long-Term Effects of Soil Solarization and Crop Sequence on Fusarium Wilt and Yield of Cotton in Israel

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This research was supported by grants from the Cotton Production and Marketing Board, Ltd.; the United States-Israel Binational Science Foundation (BSF), Jerusalem; and the United States-Israel Binational Agricultural Research and Development Fund (BARD), Israel.

The authors gratefully acknowledge the encouragement of Moshe Schor and H. Pachter and the cooperation and help of G. Saluss, Y. Epstein, Y. Halperin, D. Hacohen, and Y. Cohen in carrying out these experiments. We also thank Kibbutz Hefzi-bah, Beit Alpha, and Hamadiya for providing the field plots and for their cooperation.

Accepted for publication 16 March 1983.

ABSTRACT

Katan, J., Fishler, G., and Grinstein, A. 1983. Short- and long-term effects of soil solarization and crop sequence on Fusarium wilt and yield of cotton in Israel. Phytopathology 73:1215-1219.

Solarization (solar heating) of field soil by mulching with transparent polyethylene during the summer results in increased temperatures and pest control. In several fields naturally and heavily infested with *Fusarium oxysporum* f. sp. *vasinfectum*, soil solarization effectively reduced the pathogen population in the soil, decreased wilt incidence in cotton plants, and improved plant growth, weed control, and yield. Disease incidence in the untreated plots was significantly and negatively correlated with the yield. Soil solarization depressed Fusarium wilt and increased cotton yields for as long as 3 yr after treatment. Solarized and nonsolarized infested plots were planted to susceptible *Gossypium barbadense* 'Pima' and the resistant *G. hirsutum* 'Acala.' Plots planted to cultivar Pima in the second cropping year had lower disease incidence and the higher yield in plots where Acala had been grown the preceding year. The beneficial effect of solarization was prolonged by this crop sequence.

Additional key words: biological control, plastic mulch, soil disinfestation.

Cotton is usually grown in the same field for several consecutive years. This may result in the buildup of soilborne organisms such as *Fusarium oxysporum* f. sp. *vasinfectum*. Fusarium wilt incited by this organism is very important in many countries, causing heavy losses of both seedlings and mature plants (4). In Israel, where cotton has been a very important crop for 20 yr, Fusarium wilt was detected in 1974 (3). The pathogen, identified as belonging to race 3 (15), is pathogenic to long-staple, Pima-type cotton (*Gossypium barbadense*) plants but not to the upland Acala-type cotton (*G. hirsutum*).

Soil fumigation, although potentially effective for controlling many soilborne pathogens, is not economically feasible with cotton. Instead, breeding for resistant cultivars and improved cultural methods are continuously being tried (4). A new approach for controlling soilborne pathogens and weeds by using soil solarization (solar heating) was developed in Israel (10). This is carried out by mulching moistened soil with transparent polyethylene sheets during the summer, thereby increasing soil temperature, killing pests, and effectively controlling several soilborne pathogens including *Verticillium dahliae, Rhizoctonia solani, Sclerotium rolfsii, Pyrenochaeta terrestris,* and *Orobanche* spp. (5,6,8,10–12). Effective control of *V. dahliae* and other pathogens in cotton was obtained in the United States (16). In earlier experiments (10), the soil was kept moist during mulching by drip (trickle) irrigation, but the use of this irrigation method is very limited in cotton. The Fusarium-resistant cotton cultivar Acala might be alternated with the susceptible one, Pima. However, the significance of such a cropping sequence in disease control in Fusarium-infested soils is unknown.

In the present study, short-term (one growing season) and long-term (three growing seasons) effects of soil solarization and crop sequence on the pathogen, cotton plants, and the development of Fusarium wilt were investigated. Brief reports of some of the results reported herein have already been published (9,11).

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MATERIALS AND METHODS

Two main field experiments were carried out in the Bet-Shean Valley in the northern region of Israel, where cotton has been continuously grown for the last few years. Both fields were naturally infested with *Fusarium oxysporum* Schlect f. sp. *vasinfectum* (Atk.) Snyd. et Hans. Isolates of *Fusarium* obtained from diseased cotton plants were pathogenic to cultivar Pima S-5 (*G. barbadense* L.), but not to cultivar Acala SJ-2 (*G. hirsutum* L.).

The soil solarization field experiment (field 1). This was carried out in six replicates in a randomized block design in a heavily infested field divided into 7 × 18-m plots. The soil texture was clay. Mulching with polyethylene was carried out essentially as previously described (6,10). To increase the thermal sensitivity of pathogen resting structures and improve heat conduction, soil was irrigated by one of two methods: single irrigation—the field was sprinkler-irrigated to a depth of 80 cm 4 days prior to mulching and no additional water was applied during mulching; drip irrigation—the soil was sprinkler irrigated, as described above, and in addition, a drip irrigation system was laid out before mulching. This system (consisting of perforated plastic tubing from which water is delivered at a constant flow rate) enabled supplemental irrigation of 50–100 m^3/ha every 10–14 days during mulching, without removing the polyethylene sheets. This procedure was followed for the untreated plots as well.

The soil was mulched with transparent polyethylene sheets (40 μm thick) on 17 July 1977. The polyethylene remained intact for 7 wk. Maximum soil temperatures, recorded with a soil thermograph, were 46–53 C and 41–44 C at depths of 5 and 20 cm, respectively, in mulched soils, and 9–15 C lower in the untreated plots. The field plots remained undisturbed and weed-free until planting, except for herbicide treatments.

On 4 April 1978, the field was sown with cotton—two thirds of each plot with the Pima cultivar (susceptible to *Fusarium*) and the remaining third with resistant Acala. The spaces between rows were 96 cm. The field was irrigated by sprinklers. After harvest in October 1978, the soil was ploughed to the depth of 30 cm, to incorporate the plant residues. In April 1979, the entire field was sown with the susceptible cultivar Pima. This enabled examination of the long-term effect of soil solarization on Fusarium control as well as the effect of a crop sequence, namely, the alternation of susceptible and resistant cotton cultivars. The same procedure, using the Pima cultivar for the entire field, was repeated in the third year (1979–1980).

An additional soil solarization experiment was carried out in another cotton field (75 × 200 m) designated field 2, which also was naturally infested with the Fusarium pathogen. Disease incidence was especially high in a 12 × 120 m strip, diminishing at both edges. The entire field was mulched with polyethylene in July 1979 as described earlier. Two small strips (2 × 30 m each), perpendicular to the highly infested one, were left unmulched for comparison. The field was sown with cotton (cultivar Pima) in April 1980. Diseased and surviving plants were periodically recorded throughout the season.

Some other experiments with solar heating, carried out essentially as described above using the single irrigation method, during 1978–1980 in various locations in the same region, will be referred to in the text.

The crop sequence field experiment. This was carried out in four replicates, 8 × 50-m plots in a clay loam soil. In March 1978, the field was sown with cotton, either the susceptible Pima cultivar or the resistant Acala. After harvest, the field was ploughed and in April 1979 the entire field was sown to cultivar Pima to evaluate the effect of the preceding crop on Fusarium incidence in a susceptible cultivar in large plots.

Other procedures. All field experiments were monitored throughout the growth period for disease symptoms caused by *Fusarium*. Counts were made for both diseased and healthy surviving plants. In addition, 20 randomly selected plants were removed from each plot at the indicated time and checked for root xylem discoloration on a scale of 0 to 3, in which 0 = no discoloration and 3 = intense (brown to black) discoloration.

Stem and root pieces of cotton plants heavily infected with *F. oxysporum* f. sp. *vasinfectum* were incorporated in the soil before polyethylene mulching, removed 38 days later, and plated on a Fusarium-selective agar medium for determining the viability of the pathogen. These plant tissues represent one type of a natural inoculum that is normally added to soil. Ten segments of roots or stems were incorporated in each replicate plot at depths of 5 and 30 cm.

The presence of *Fusarium* or other pathogens in roots and stems of either randomly selected plants (5–10 plants per plot) or those suspected of being diseased was verified by plating plant tissues (surface disinfested with 1% sodium hypochlorite for 2 min) on potato-dextrose agar (PDA) or PCNB-peptone, a Fusarium-selective medium (7). Pathogenicity tests of the isolates of *Fusarium* were carried out in the greenhouse by using the root-dip method (7) with cotton plants of both the Pima and Acala cultivars.

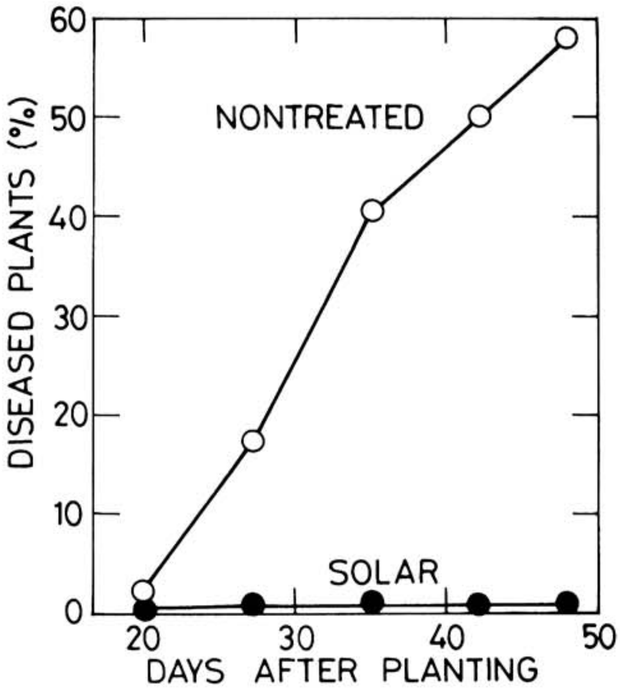

Fig. 1. Effect of soil solarization (using either drip or a single irrigation) on the incidence of disease caused by *Fusarium oxysporum* f. sp. *vasinfectum* in cotton (Pima cultivar). Field experiment in a naturally infested field.

Fig. 2. Effect of soil solarization on Fusarium wilt in a cotton field (1978 experiment). Forefield, an untreated plot; midfield, a solar-heated plot.

RESULTS

Effect of soil solarization on incidence of disease caused by *Fusarium* and on cotton plants. In the soil solarization experiment (field 1) both Pima and Acala cotton cultivars were planted. Shortly after emergence, diseased plants of the susceptible cultivar Pima were observed in the untreated control plots. Seedlings affected at the early stages of growth quickly collapsed, became desiccated, and were difficult to find. Plants affected at a later stage showed wilt symptoms, yellowing of the cotyledonary veins (typical of *G. barbadense*) (4), and xylem discoloration. Survivors also showed various degrees of stunting. While disease incidence in the untreated plots increased rapidly during the first 50 days after planting, it was less than 1% in both solarized plots (Figs. 1 and 2). The percentage of disease incidence at a given period does not necessarily represent the total number of diseased plants, since some may have died and disappeared, which happens especially when air temperatures are high. The corresponding figures for surviving plants show a similar pattern relative to the effectiveness of the two soil solarization treatments (Fig. 3). Diseased or desiccated plants, collected randomly from the various plots, yielded cultures of *Fusarium oxysporum* pathogenic to Pima, but not Acala, seedlings. Acala plants, in both treated and untreated plots, showed no Fusarium disease symptoms; those in the solarized plots were somewhat better developed, indicating an increased growth response phenomenon, similar to that described elsewhere (2). One hundred days after planting, 90% of the plants lifted from the untreated plots showed root xylem discoloration, compared to 5% in both solarized plots. At harvest, the xylem discoloration index of plants from solarized plots was significantly lower than that of plants from untreated plots (Table 1). The difference between the affected plants in the untreated plots and the healthy plants in the solarized plot could easily be seen in color infrared aerial photographs.

Plant height in the untreated plots was reduced by the disease, especially at the early stages of plant growth (Table 1). Soil solarization treatments resulted in yield increase of 40–69% (Table 1).

Plant roots and soil samples from both untreated and treated plots were examined at the Nematology Division of the Volcani Center and found to be free of phytopathogenic nematodes.

The correlation between percentage of diseased or surviving plants of cultivar Pima and yield in the untreated plots was calculated. Throughout the season, starting from 27 days after planting, a high and significant ($P = 0.05 - 0.001$) correlation was obtained between the yield at harvest and the percentage of diseased ($r = -0.76$ to -0.80) or surviving plants ($r = 0.71$ to 0.83), determined at each recording date. At an earlier sampling date the results were variable and not always significant. Yield was also correlated with plant height determined 75–107 days after planting ($r = 0.63$ to 0.66). Similar results were obtained by correlating the yield and the percentage of diseased or surviving plants in the untreated plots of the other experiments described below. Such an analysis could not be made for the solarized plots since the percentage of diseased plants there was too low to reduce the yield.

Recovery of *Fusarium* from stem and root pieces (derived from diseased cotton plants), which were incorporated into the untreated plots and removed 38 days later, were 75 and 85% at depths of 5 and 30 cm, respectively. Seventy percent of the isolates were pathogenic to Pima cotton seedlings. In the solarized plots, however, no cultures of *Fusarium* could be isolated from the plant pieces incorporated at a depth of 5 cm, and in those incorporated at a depth of 30 cm the average colonization was 21%, but only 13% of these isolates were pathogenic.

The effectiveness of soil solarization was examined in greater detail in field 2. A typical distribution pattern of the disease (expressed in percentage of surviving plants) from one reading taken for 30 rows and representing a cross section of one untreated strip, as well as the yield from each row, are depicted in Fig.4. As expected, the lowest number of surviving plants were in the middle rows where a high disease incidence was recorded in the previous year. This was well correlated with the yield, thus confirming the correlation analysis described earlier. Data were also obtained for the respective 30 rows in the adjacent solarized area, but for simplicity only data for five rows are given (Fig. 4). In these rows 1% or less of the plants were diseased and the yield was comparable to disease-free plots.

Soil solarization experiments were carried out in other Fusarium infested fields as well in 1978–1980, and the fields were planted with cotton (cultivar Pima) the next spring. Disease control (70–95% disease reduction) was significant and visible even where the polyethylene mulching lasted for only 3 wk.

In all soil solarization experiments weed control was evident until the end of the season, more than a year after mulching. Population reduction (60–100%) was recorded in many weeds, such as *Avena, Chenopodium, Fumaria*, and *Sorghum halepense*.

Long-term effects of soil solarization. The entire field plot in which the 1977–1978 experiment was carried out (field 1) was replanted to cultivar Pima in 1979 to examine the effect of soil solarization on disease control, growth, and yield in cotton in the second growing season after treatment. Disease progress and pattern in the untreated plots were similar to those described for the 1978 experiment. Results (Fig. 5) show that disease incidence in the solarized plots (single irrigation) was lower than in the untreated plots, though it was higher than that recorded in 1978 (Figs. 1–3). Disease severity of individual plants in the untreated plots was much greater than in the solar-heated ones (not expressed in Fig. 5). Disease incidence was affected by the crop sequence too. Where cotton cultivar Acala was the previous crop, disease incidence was lower in both treated and untreated plots (Fig. 5). The corresponding figures for surviving plants (Fig. 6) show a similar trend. Similar results were obtained with the other solar heating treatment (drip). Xylem discoloration index (determined on harvesting day) was lower, and plant height (determined 115 days after planting) greater in plots that had received the solar treatments than in the untreated ones (Table 2). A pronounced increase in the yield (by 87–120%) was also recorded for the solarized plots (Table 2). The greatly increased disease severity in the untreated plants, as compared to the previous year, was also expressed by a further yield reduction. In the third year after solarization (1980) disease severity increased in all plots, but the

TABLE 1. Effect of soil solarization on growth of cotton plants (cultivar Pima), root discoloration index, and crop yield. Field experiment in soil naturally infested with *Fusarium oxysporum* f. sp. *vasinfectum*

	Plant height (cm) after				Yield, seed cotton	
Treatment	75 days	89 days	107 days	Discoloration index[x]	Kg/ha	Percent of control
Untreated	44.2 b[y]	64.8 b	79.3 b	2.85 a	2,463 c	100.0
Solar, drip[z]	63.8 a	77.7 a	88.7 a	1.03 b	3,461 b	140.5
Solar, SI[z]	65.6 a	77.0 a	83.0 b	0.96 b	4,167 a	169.2

[x]Scale 0–3; 0 = no root xylem discoloration; 3 = intense xylem discoloration (brown to black).

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

[z]Drip = soil was sprinkler-irrigated before polyethylene mulching; additional irrigations were applied during mulching by a drip-irrigation system. SI = single irrigation (soil was irrigated before mulching as above and no additional irrigations were given).

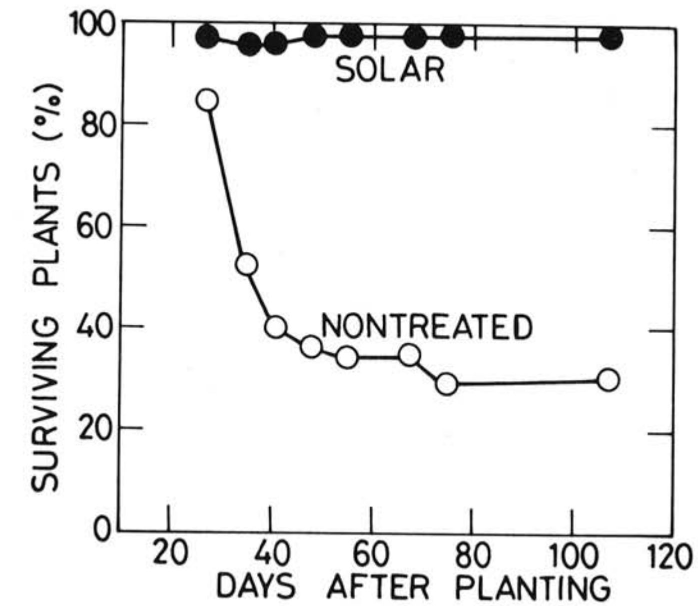

Fig. 3. Effect of soil solarization (using either drip or a single irrigation) on the percentage of surviving cotton plants in a field naturally infested with *Fusarium oxysporum* f. sp. *vasinfectum*.

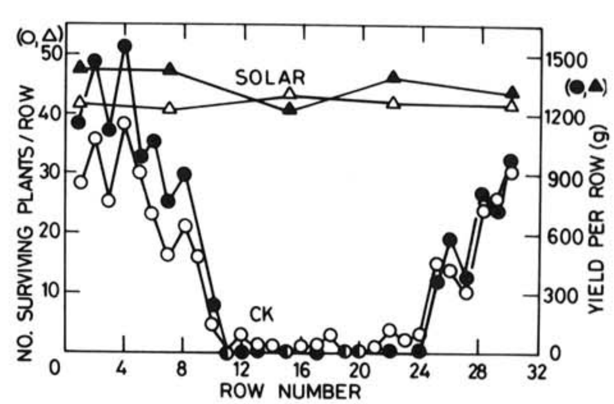

Fig. 4. Effect of soil solarization on the number of surviving cotton plants (40 days after planting) and on the yield in a field naturally infested with *Fusarium oxysporum* f. sp. *vasinfectum* (field 2). Data were taken for 2 m for each row. CK = untreated plot.

effect of soil solarization or crop sequence or both was still evident and the differences were similar to those observed the previous year. Thus, where cultivar Pima was the preceding crop, the yield was 490, 2,030, and 1,290 kg/ha for the untreated and solarized drip-irrigated and single-irrigation treatments, respectively. The corresponding figures for plots where Acala was the preceding crop were 805, 2,770, and 2,420 kg/ha. Control of certain weeds (eg, *S. halepense*) was still noticeable even in the third year after solarization.

The long-term effect of soil solarization on disease control and

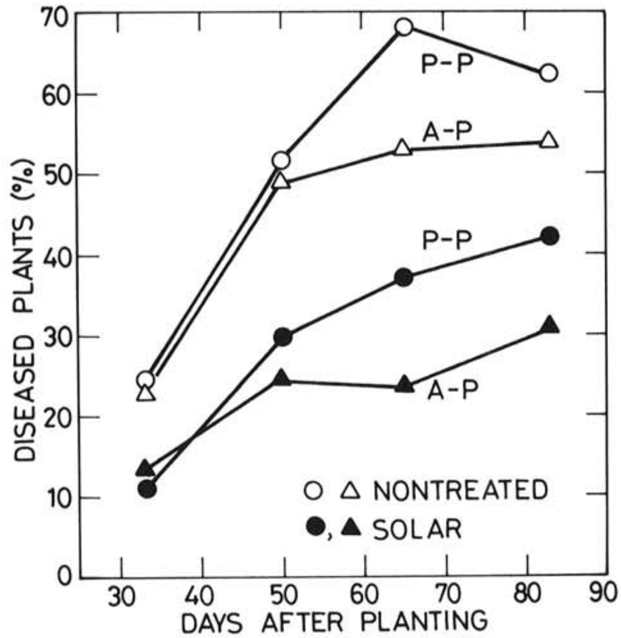

Fig. 5. Incidence of disease caused by *Fusarium oxysporum* f. sp. *vasinfectum* in cotton plants (Pima) planted in either untreated or solar heated soil (single irrigation) as a second crop (second year) after soil treatment. The preceding crop was either Pima (P-P) or Acala cotton (A-P).

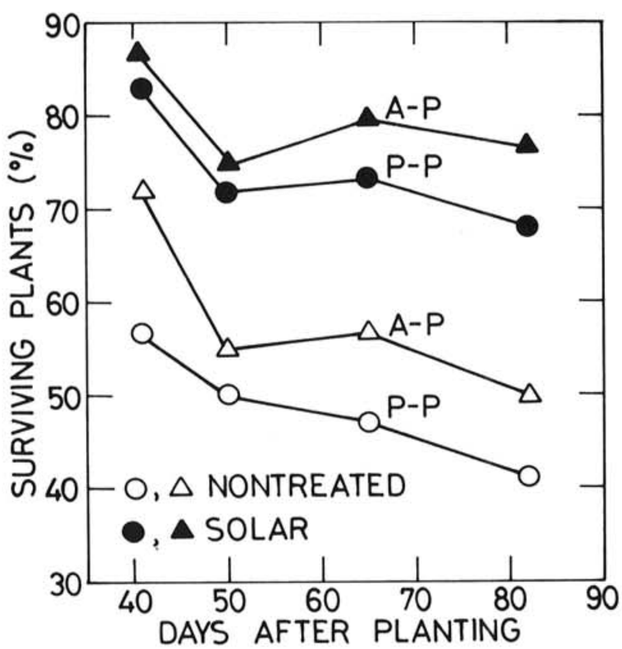

Fig. 6. Percentage of surviving cotton plants, as a second crop (second year) after soil treatment, in a field naturally infested with *Fusarium oxysporum* f. sp. *vasinfectum*. Plots were either untreated or solar heated (single irrigation). The preceding crop was either Pima (P-P) or Acala cotton (A-P).

yield increase was evident in field 2 as well. In the second year after solarization, a disease reduction of 60–90% was recorded. A quick buildup of the disease in the untreated plots, on the other hand, was very pronounced; more than 90% of the plants were destroyed. Consequently, the yield in these plots was close to zero.

Crop sequence. The effect of crop sequence on Fusarium wilt in cotton was examined following the approach described above, in an additional experiment using large plots in order to reduce contamination and reinfestation from adjacent plots. The results (Fig. 7), confirming those presented in Figs. 5 and 6, show that more cotton plants survived where Acala was the preceding crop. This was also reflected in disease incidence, eg, 20 days after planting; the disease incidences where cultivars Pima and Acala were planted the preceding year were 41 and 4%, respectively. The corresponding figures for the yield were 1,520 and 3,400 kg/ha.

DISCUSSION

Soil disinfestation for the control of soilborne diseases in cotton can be economically feasible only if an effective long-term control is achieved that will minimize the frequency with which soil treatments must be applied, significantly increase yield, and control

TABLE 2. Effect of soil solarization and crop sequence on the growth of cotton plants (cultivar Pima), root discoloration index, and crop yield in the second year after treatment of field soil naturally infested with *Fusarium oxysporum* f. sp. *vasinfectum*

				Yield, seed cotton	
Treatment	Previous crop[w]	Plant height (cm)	Discoloration index[x]	Kg/ha	Percent of control
Untreated	Pima	46 b[y]	2.9 a	1,310 b	100
Solar, drip[z]	Pima	59 a	2.1 b	2,830 a	216
Solar, SI[z]	Pima	56 a	2.5 ab	2,880 a	220
Untreated	Acala	···	2.9 A	1,660 B	100
Solar, drip[z]	Acala	···	1.8 B	3,100 A	187
Solar, SI[z]	Acala	···	2.0 B	3,230 A	195

[w]The cotton cultivar grown in the first year after soil solarization. Pima and Acala are cultivars susceptible and resistant to *Fusarium*, respectively.
[x]Scale 0–3; 0 = no root xylem discoloration; 3 = intense xylem discoloration (brown to black).
[y]Numbers in each column followed by the same letter are not significantly different ($P = 0.05$). Analyses were made separately for each previous crop.
[z]Drip = soil was sprinkler-irrigated before polyethylene mulching and additional irrigations were applied by a drip-irrigation system. SI = single irrigation (soil was irrigated before mulching as above and no additional irrigations were given).

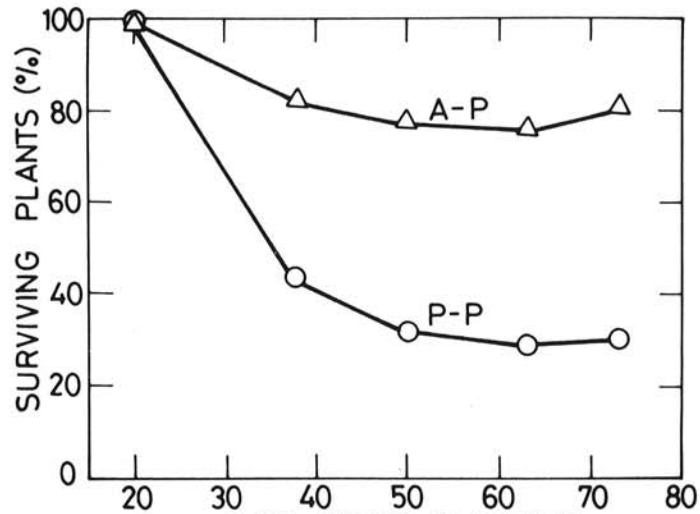

Fig. 7. Effect of crop sequence on incidence of disease, caused by *Fusarium oxysporum* f. sp. *vasinfectum*, in cotton (Pima). The preceding crop was either Pima (P-P) or Acala (A-P) cotton.

a broad spectrum of pathogens. Both disease control and the yield increase by solarization lasted for 3 yr even in a highly infested field and under severe conditions of reinfestation. Solar heating is effective against additional potential pathogens of cotton [eg, *R. solani, S. rolfsii, V. dahliae, Thielaviopsis basicola*, and *Pythium* spp. (5,6,10,11,16)] and weeds, and is cheaper than most other methods. An effective and lasting control of Verticillium wilt and a yield increase in cotton was demonstrated in California (16). This method involves certain limitations (eg, polyethylene disposal) and is limited to certain geographical regions. However, in the right circumstances, and especially if the frequency of application is reduced, soil solarization may provide an economic, simple, and safe method for disease control in cotton.

Alternating Acala and Pima cultivars reduced incidence of Fusarium wilt in the susceptible cultivar in the following 2 yr and increased the duration of the effect of solarization. A similar case regarding the effect of crop alternation on disease buildup was shown with mint where the increase in both the population of *V. dahliae* and the incidence of wilt caused by this pathogen was proportional to the susceptibility of the mint, which served as the preceding crop (14). It is still unknown whether disease reduction following the Acala crop is due to reduction of inoculum density (or potential) through biological control incited by the decomposition of the plant tissues, or to the lower frequency of incorporating infected tissues into the soil, thus slowing down inoculum buildup (1,13). Biological control, if induced by the nonsusceptible Acala crop, may also operate during the plant growth, as shown with *F. solani* f. *phaseoli*, which population in the rhizosphere of certain nonsusceptible plants decreased because chlamydospores of this pathogen germinated and died without producing additional resting structures (17).

Pathogen populations were followed during soil solarization, using naturally infected plant segments incorporated into the soil. Solar heating drastically reduced pathogen population in the soil and, moreover, most of the fusaria that survived the solar heating were saprophytic. Elimination of the pathogen from the infected tissues incorporated into the solarized soil was well correlated with disease control in the same plots. Thus, this technique can serve as a simple and reliable tool for evaluating and predicting disease control. These results also emphasize that in such a case, the determination of pathogenicity of isolates of *Fusarium*, though a very tedious procedure, is essential for obtaining reliable results.

Achieving a long-term disease control requires a reduction in inoculum density and a shift in the biological equilibrium in favor of the antagonists that will retard soil reinfestation. Pathogenic populations of *Fusarium* were markedly reduced in the solarized soil concomitantly with their replacement by nonpathogenic populations; a similar effect was reported in California (19). The long-term effect of soil solarization was also shown in controlling four other soilborne diseases, including *Verticillium* in peanuts (11), and *Fusarium* in melons (*unpublished*). This indicates that the long-term effect of soil solarization is not effective solely against the cotton pathogen. Populations of *Fusarium* decline more rapidly in a soil previously heated to 45–50 C (10), and chlamydospore formation by *Fusarium* was suppressed in some solarized soils (A. Yogev, *unpublished*). It will be interesting to compare the mechanisms that suppress *Fusarium* in the solarized soils to those naturally occurring in suppressive soils (18).

In many cases, the control of soilborne diseases by soil disinfestation is used only when disease incidence reaches high levels. At this late stage, the inoculum is high and the effectiveness of the control cannot be expected to last long. We should, therefore, consider the possibility of using soil disinfestation at earlier stages of inoculum buildup, possibly in combination with other methods, in order to achieve a better and longer-lasting disease control that may enable less frequent use of the control measures. This may also prevent future development of other diseases which, at this stage, are still minor.

LITERATURE CITED

1. Baker, K. F., and Cook, R. J. 1974. Biological Control of Plant Pathogens. W. H. Freeman, San Francisco. 433 pp.
2. Chen, Y., and Katan, J. 1980. Effect of solar heating of soils by transparent polyethylene mulching on their chemical properties. Soil Sci. 130:271-277.
3. Dishon, I., and Nevo, D. 1976. The appearance of Fusarium wilt in the Pima cotton cultivar. Hassadeh 56:2281-2283 (in Hebrew).
4. Ebbels, D. L. 1975. Fusarium wilt of cotton: A review, with special reference to Tanzania. Cotton Rev. 52:295-339.
5. Elad, Y., Katan, J., and Chet, I. 1980. Physical, biological, and chemical control integrated for soilborne diseases in potatoes. Phytopathology 70:418-422.
6. Grinstein, A., Katan, J., Abdul Razik, A., Zeydan, O., and Elad, Y. 1979. Control of *Sclerotium rolfsii* and weeds in peanuts by solar heating of the soil. Plant Dis. Rep. 63:1056-1059.
7. Katan, J. 1971. Symptomless carriers of the tomato Fusarium wilt pathogen. Phytopathology 61:1213-1217.
8. Katan, J. 1981. Solar heating (solarization) of the soil for control of soilborne pests. Annu. Rev. Phytopathol. 19:211-236.
9. Katan, J., Fishler, G., and Grinstein, A. 1980. Solar heating of the soil and other methods for the control of Fusarium, additional soil-borne pathogens and weeds in cotton. Pages 80–81 in: Proc. 5th Congr. Mediterr. Phytopathol. Union, Patras, Greece.
10. Katan, J., Greenberger, A., Alon, H., and Grinstein, A. 1976. Solar heating by polyethylene mulching for the control of diseases caused by soil-borne pathogens. Phytopathology 66:683-688.
11. Katan, J., Grinstein, A., Fishler, G., Frank, A. Z., Rabinowitch, H. D., Greenberger, A., Alon, H., and Zig, U. 1981. Long-term effects of solar heating of the soil. (Abstr.) Phytoparasitica 9:236.
12. Katan, J., Rotem, I., Finkel, Y., and Daniel, J. 1980. Solar heating of soil for the control of pink root and other soilborne diseases in onions. Phytoparasitica 8:39-50.
13. Katan, J., Sofer, S., and Lisker, N. 1976. Effect of incorporating plant tissue into soil on the increased incidence of root diseases and inoculum build-up. (Abstr.) Proc. Am. Phytopathol. Soc. 3:286-287.
14. Lacy, M. L., and Horner, C. E. 1965. Verticillium wilt of mint: Interactions of inoculum density and host resistance. Phytopathology 55:1176-1178.
15. Netzer, D., Reuveni, R., and Dishon, I. 1980. Race identification and distribution of Fusarium wilt of cotton in Israel. Hassedeh 61:31-32 (in Hebrew).
16. Pullman, G. S., DeVay, J. E., Garber, R. H., and Weinhold, A. R. 1981. Soil solarization: Effects on Verticillium wilt of cotton and soilborne populations of *Verticillium dahliae*, *Pythium* spp., *Rhizoctonia solani* and *Thielaviopsis basicola*. Phytopathology 71:954-959.
17. Schroth, M. N., and Hendrix, F. F., Jr. 1962. Influence of nonsusceptible plants on the survival of *Fusarium solani* f. *phaseoli* in soil. Phytopathology 52:906-909.
18. Smith, S. N. 1977. Comparison of germination of pathogenic *Fusarium oxysporum* chlamydospores in host rhizosphere soils conducive and suppressive to wilts. Phytopathology 67:502-510.
19. Smith, S. N., Pullman, G. S., and Garber, R. H. 1980. Effect of soil solarization on soil-borne populations of *Fusarium* species. Pages 17-18 in: Proc. Beltwide Cotton Prod. Res. Conf., January 1980, St. Louis, MO.