Use of Soil Solarization to Control Fusarium Wilt of Watermelon

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ABSTRACT

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Soil solarization for either 30 or 60 days was effective in delaying the onset of wilt symptoms as well as in reducing total disease incidence in a *Fusarium*-susceptible watermelon cultivar, Sugarbaby, but complete disease control was not achieved. These effects lasted over two growing seasons; however, best control was obtained during the first year. Temperature maxima during 17–19 July 1984 in solarized soil were 60, 50, 42, and 37 C at depths of 2, 10, 20, and 30 cm, respectively. The population of *Fusarium oxysporum* f. sp. *niveum* was reduced dramatically throughout the soil profile after 30 days of solarization compared with a similarly infested, nonsolarized treatment. Further decline in *F. o.* f. sp. *niveum* was achieved in the top 10 cm of soil after the 60-day solarization. Populations of saprophytic *Fusarium* spp. were twofold higher at 15–20 cm deep and eightfold higher at 30–35 cm deep after 30 days of solarized than in nonsolarized soil.

Watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) production in the United States approached 185,000 harvested acres in 1984 and generated almost $150 million gross market value. Texas production was about 30% of the national total. Fusarium wilt of watermelon, caused by *Fusarium oxysporum* Schlecht. f. sp. *niveum* (*F. o.* f. sp. *niveum*) (E. F. Sm.) Snyd. & Hans., is perhaps the most economically important disease of watermelon worldwide. Once the pathogen has been introduced into a field, it may survive for 10 yr or more. When wilt-susceptible cultivars are grown, losses can exceed 75% of the potential crop. In many instances, Fusarium wilt is a limiting factor in production.

Chemical control of Fusarium wilt is erratic and expensive, thus control has generally been restricted to the use of wilt-resistant cultivars, long-term rotations (5–7 yr), and virgin-land plantings. Although sometimes successful, these control methods are not always acceptable or practical to the grower. In many instances, the widely used commercial cultivars are highly susceptible to Fusarium wilt and long-term rotations or fallow periods are not economically feasible. Likewise, the use of virgin land is becoming increasingly more difficult and costly.

Soil solarization (pasteurization) involves the use of a clear, polyethylene tarp placed over moist soil during a summer fallow period to trap radiation and build up enough heat to reduce populations of soilborne pests (10). This technique has provided control of a number of diseases caused by soilborne pathogens, including Fusarium wilt of tomato (10,16), damping-off caused by *Rhizoctonia solani* (4,10,19) and *Pythium* spp. (7,17), Verticillium wilt (1,18,19), club root of cabbage (17), white rot of onions (17), soft rot of lettuce (17), and certain nematode-induced diseases (16). Additionally, several studies have demonstrated that soil solarization has the added benefit of reducing weed populations (3,9,20).

Major watermelon production areas in Texas (Lower Rio Grande Valley and Winter Garden area) have a climate suitable for soil solarization (e.g., clear hot summer days). This study was initiated to evaluate soil solarization as an economical means of reducing losses caused by Fusarium wilt. A preliminary report of the first year's results has been published (13).

MATERIALS AND METHODS

The experiments were conducted in microplots established at the USDA Subtropical Research Center in Weslaco, TX. Concrete cylinders (84 cm i.d.) were sunk into the ground to a depth of 1 m and the native soil was replaced with methyl bromide-treated sandy loam. Each cylinder constituted an individual microplot.

To infest the soil uniformly with the wilt pathogen, 1 L of a sand/cornmeal inoculum mix was incorporated into the top 45 cm of 15 microplots. The inoculum was prepared by growing a culture of *F. o.* f. sp. *niveum* (ATCC 18476) in a modified liquid broth (FLC) (5) on a rotary shaker with indirect fluorescent light at room temperature (22 C). After 3 days, the contents of the flask were filtered through eight layers of sterile cheesecloth. One hundred milliliters of the filtrate, which was predominantly microcondia, was mixed with 4 L of a twice-autoclaved sand/cornmeal (4:1, v/v) mixture. The mixture was incubated 8 wk at room temperature to allow the fungus to colonize the medium extensively. To verify that *F. o.* f. sp. *niveum* had been established successfully, microplots were planted with seeds of the wilt-susceptible watermelon cultivar Sugarbaby. After 1 mo, a high percentage of wilt had occurred in all infested plots while no wilt occurred in uninfested plots. The remaining aboveground plant material was cut off at the soil line and removed.

On 28 June 1984, each microplot was watered to field capacity and 10 plots were covered with an ultraviolet-stabilized, 1.5-mil, clear, polyethylene film (Visqueen Film Products, LaGrange, GA). The plastic was removed from five plots after 30 days and from the remaining plots after 60 days. Minimum and maximum temperatures were recorded continuously in solarized and nonsolarized plots at depths of 2, 10, 20, and 30 cm with thermistors linked to a Campbell CR7 data logger during 17–19 July 1984. Three thermocouples were wired in parallel for each depth and each treatment. Temperatures reported are an average of three thermocouple readings.

To monitor soil populations of *Fusarium* spp., three core samples (2 cm in diameter × 35 cm deep) were collected from each microplot after 30 and 60 days and divided into depth segments of 5–10, 15–20, and 30–35 cm. Segments at similar depths within each microplot were bulked, placed in a paper bag, and immediately transported in a Styrofoam container to College Station, TX, where all samples were refrigerated (7 C) until analyzed 3 days later. Soil dilution plates (10^{-1}, 10^{-2}, and 10^{-3}) were made on Komada's *Fusarium*-selective medium (11) from each treatment and depth. Duplicate soil plates were made for each sample. The plates were incubated 10 days without light at 22 C. Soil samples from each depth and treatment were also analyzed for pH.

Fusarium colonies that grew on the Komada's medium were identified as either *F. oxysporum* or "other *Fusarium*

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spp." on the basis of cultural and morphological characteristics. About 10% of the *F. oxysporum* colonies and 1% of the other *Fusarium* spp. colonies were arbitrarily selected and transferred to FLC broth and tested for pathogenicity to watermelon. Microconidia from each culture were adjusted to 1×10^6 per milliliter and used to root-dip inoculate 10 2-wk-old Sugarbaby watermelon seedlings. The seedlings were transplanted into 15-cm plastic pots filled with pasteurized soil and placed in the greenhouse. Final wilt percentage was recorded after 3 wk, and the results were used to adjust the soil population counts of pathogenic *F. oxysporum* recovered on the soil-dilution plates.

To determine efficacy of the solarization treatment, 20 seeds of Sugarbaby watermelon were planted in each microplot on 7 September 1984. Stand establishment counts were recorded after 2 wk. Percentages of seedlings with symptoms of *F. o.* f. sp. *niveum* infection (wilting) were determined weekly.

To evaluate long-term effects of solarization on disease control, the microplots were left fallow for the remainder of the year and replanted in February 1985. Before planting, soil samples were collected from each treatment as before and assayed for *F. o.* f. sp. *niveum* and other *Fusarium* spp. These samples represented an elasped time of 240 days from the original date of infestation and spanned a summer, fall, and winter season. The microplots were then replanted with two cultivars: wilt-susceptible Sugarbaby and moderately wilt-resistant Charleston Gray. The microplots were divided in half, and 12 seeds of each cultivar were planted on one side or the other. The percentage of seedlings that developed wilt was recorded weekly for 4 wk.

RESULTS

Solarization had a pronounced effect on most parameters measured. Good seedling establishment occurred in the nonsolarized plots each year; however, better stand production was achieved with solarization although no clear statistical separation was established (Table 1). Increases of 3–7% in seedling establishment were recorded between the solarized and nonsolarized, infested plots. In addition, seeds planted in the solarized plots had a more uniform stand establishment rate among replicates than did seeds in the nonsolarized plots.

Solarization also delayed the onset of wilt development during 1984 and reduced total disease incidence (Fig. 1A). Wilt first appeared in nonsolarized, infested control plots within 1 wk of germination and increased rapidly over the next 2 wk. Solarization delayed the initial appearance of wilt by 1 wk. It also reduced the amount of wilt at 2 wk from 31% in nonsolarized soils to 3.4 and 1% in 30- and 60-day solarized soil, respectively. By 3 wk, wilt in the 30-day treatment approached that of the nonsolarized soils. However, even after 4 wk, wilt incidence in the 60-day treatment was only one-half that in the nonsolarized soils (46 vs. 93%).

The increase in seedling establishment and decrease in wilt appear to be related to the increased temperatures in solarized soils that adversely impacted the pathogen population. As expected, soil temperatures in the plastic-covered microplots were considerably higher than in the uncovered soils (Fig. 2). Maximum temperature at 2 cm in the nonsolarized soil was 44.7 C, only 5 C higher than the maximum ambient air temperature. The temperature at 2 cm in the solarized soils was almost 60 C, or 20 C higher than the maximum ambient air temperature. The difference between solarized and nonsolarized soil temperatures decreased with increasing depth; however, the solarized soils still maintained temperatures 4–11 C higher than nonsolarized soils at all depths. The minimum temperatures of solarized and nonsolarized soil differed less and fluctuated less than did maximum temperatures. The minimum temperature at 30 cm in solarized soil was the same as the maximum temperature in nonsolarized soil at the same depth (32.6 C).

After 30 days, *F. o.* f. sp. *niveum* populations in nonsolarized soil were extremely high, ranging from 6,400 propagules per gram of soil in the top 10 cm to 3,200 propagules per gram of soil at 30–35 cm (Fig. 3). Solarization for 30 days reduced *F. o.* f. sp. *niveum* to 200 propagules per gram within the top 10 cm. At the deepest level (30–35 cm), *F. o.* f. sp. *niveum* propagules were reduced to 330 per gram.

F. o. f. sp. *niveum* declined in nonsolarized soil over the 60-day test period at each soil depth tested. However.

Table 1. Seedling establishment of Sugarbaby and Charleston Gray watermelon in solarized and nonsolarized soils

	Percent seedling establishment[z]		
Treatment	1984 Sugarbaby	1985 Sugarbaby	1985 Charleston Gray
Infested check	90 ab	88 ab	90 a
Uninfested check	86 b	80 b	90 a
30-Day solarization	97 a	93 a	97 a
60-Day solarization	95 ab	85 ab	92 a

[z] Percent values are the mean of five replicates. Numbers followed by the same letter are not significantly different at $P = 0.05$ according to Duncan's multiple range test.

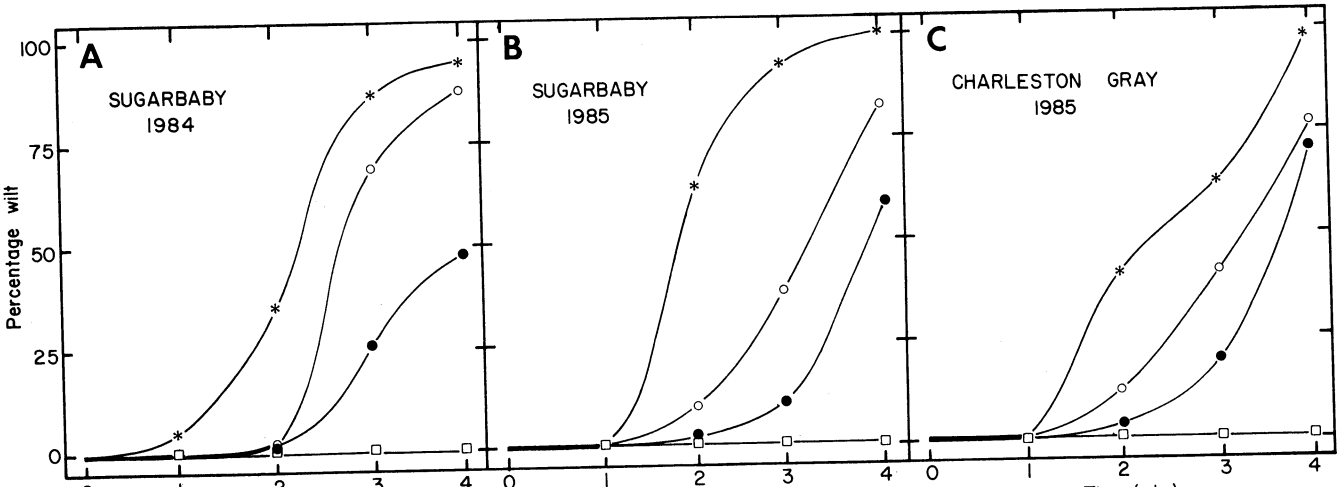

Fig. 1. Incidence of Fusarium wilt in 1984 and 1985 in solarized and nonsolarized soils: * = infested, nonsolarized soil; o = infested, 30-day solarized soil; ● = infested, 60-day solarized soil; and ☐ = noninfested, nonsolarized soil.

solarization for 60 days further reduced *F. o.* f. sp. *niveum* in the top 10 cm from 200 propagules per gram in the 30-day treatment to 40 propagules per gram. The amount of *F. o.* f. sp. *niveum* appeared to increase below 15 cm in the 60-day treatment compared with the 30-day treatment.

Population densities of the nonpathogenic *Fusarium* spp. were also affected by solarization (Fig. 4). After 30 days, there was little difference in saprophytic *Fusarium* spp. populations at the shallow depths in solarized (1,070 propagules per gram) and nonsolarized soils (1,010 propagules per gram). However, saprophytic species increased greatly at the deeper levels in solarized soils. At 30–35 cm, the saprophytic *Fusarium* population in 30-day solarized soil was eight times that of the nonsolarized soil (2,510 vs. 310 propagules per gram). After 60 days, saprophytic *Fusarium* spp. declined in both solarized and nonsolarized soils; however, there were still 3.5 times as many saprophytic *Fusarium* propagules per gram in solarized soil as in nonsolarized soil (360 vs. 100 propagules per gram) at 30–35 cm.

Solarization had a minimal effect on the pH of the soil. The pH range (7.9–8.1) did not vary by more than 0.1 unit among replicate plots or treatments.

By February 1985 (240 days), populations of both *F. o.* f. sp. *niveum* and the other *Fusarium* spp. appeared to stabilize (Table 2). With the exception of the depth of 5–10 cm in both 30- and 60-day solarized soils, populations of *F. o.* f. sp. *niveum* were similar: each had declined to about one-half of the population of nonsolarized, infested soils at the same depth. Likewise, the populations of other *Fusarium* spp. were very similar for like depths.

Wilt percentages from the second year's planting did not vary greatly from

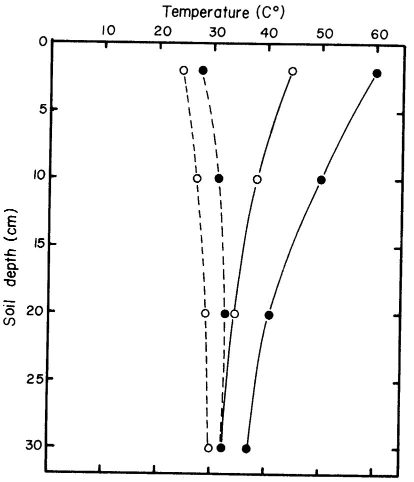

Fig. 2. Maximum and minimum temperature profiles in solarized and nonsolarized soil for 17–19 July 1984. Temperature values are the mean of three replicates. Dashed line = minimum temperature and solid line = maximum temperature; o = nonsolarized soil and ● = solarized soil.

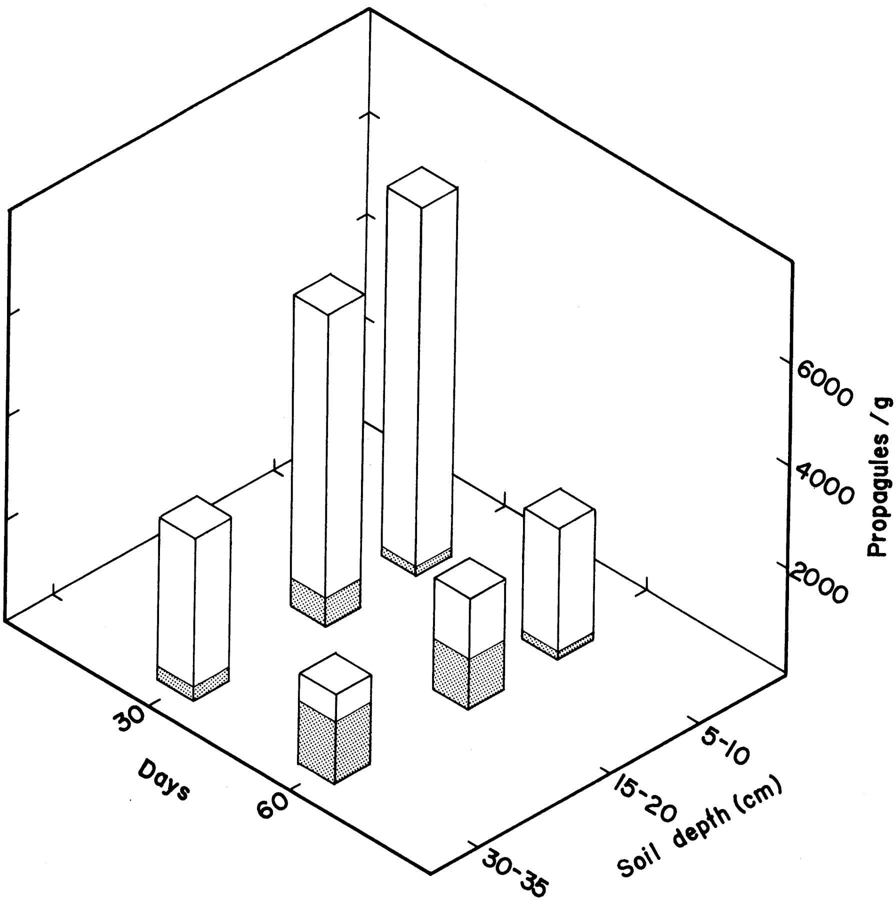

Fig. 3. Inoculum density (propagules per gram of soil) of *Fusarium oxysporum* f. sp. *niveum* for 1984 in 30- and 60-day solarized (shaded) and nonsolarized (clear) soils with soil depth. Propagule counts have been adjusted on the basis of results of random sampling and testing for pathogenicity.

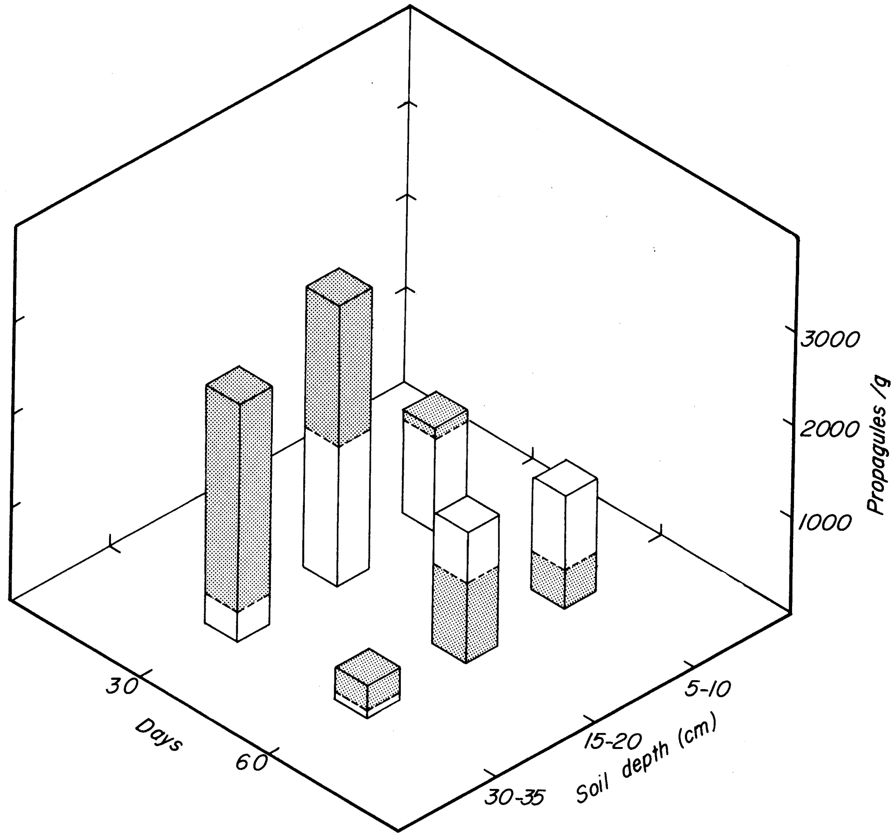

Fig. 4. Inoculum density (propagules per gram of soil) of *Fusarium* spp., excluding *F. oxysporum* f. sp. *niveum*, for 1984 in 30- and 60-day solarized (shaded) and nonsolarized (clear) soils with soil depth.

those of the first, with the exception of the nonsolarized, infested check (Fig. 1A-C). Although the final percentage of wilt in Sugarbaby was similar for both years (93 and 100%), the percentage of wilt at 2 wk was much greater the second year (62%) than the first (31%). Similarly, there was no major difference in percentage of wilt between the two cultivars except for the nonsolarized, infested checks. Charleston Gray performed better than Sugarbaby within the first 2–3 wk, but the final percentage of wilt was similar for both cultivars at 4 wk (96 and 100%, respectively).

An increase in percentage of wilt at 4 wk was observed in Sugarbaby in 60-day solarized plots between 1984 and 1985 (46 and 65%, respectively), whereas no difference in percentage of wilt occurred in the 30-day solarized plots (87 vs. 82%).

DISCUSSION

The vascular wilt fusaria are probable examples of monocyclic pathogens; i.e., those that complete only one cycle of pathogenesis in one cropping season. The qualifier "probable" is included because although the vascular wilt fusaria produce secondary inocula in the form of microconidia and macroconidia on decaying root and stem tissue, their involvement in secondary spread during a single season is most probably negligible. The amount of disease induced by a monocylic pathogen in a single season is a function of several interacting factors: size and distribution of the pathogen population, the inherent ability of the pathogen to induce disease, host factors, and environmental influences (6).

Diseases caused by monocyclic pathogens are managed most effectively by techniques that reduce initial inoculum. Soil solarization is an example of such a technique. Pullman et al (19) demonstrated a 90% reduction in *Verticillium dahliae* propagules at 37 C at 46 cm in moist field soil after solarization. Those data correlate well with ours from this study after solarization for 30 days. *F. o.* f. sp. *niveum* propagules were reduced almost 90% (from 3,200 to 330 propagules per gram) at 30 cm, where the maximum temperature was 36.5 C.

The population of *F. o.* f. sp. *niveum* increased after 60 days of solarization at 15–20 and 30–35 cm compared with the 30-day treatment. This is inconsistent with the amount of wilt observed in these plots. This discrepancy is difficult to explain; however, soilborne pathogens often have a clumped distribution in soil (12), particularly around large pieces of organic matter, and this may have resulted in an excessively high propagule count in a soil-dilution plate. To avoid disturbing the soil profile, which would have resulted in mixing, the roots of the watermelon plants were left in the soil. Therefore, infected root pieces that may have been included in soil samples could have provided higher than expected plate counts.

Solarization was effective for at least two growing seasons in delaying the onset of wilt symptoms and reducing total disease incidence in susceptible Sugarbaby. Complete control, however, was not achieved in either year. Best disease control (final percentage of wilt at 4 wk) was obtained after 60-day solarization in the first growing season; however, there was also a decrease in the log phase of disease development during the second season. After 3 wk, there was only 10 and 37% wilt in Sugarbaby in the 30- and 60-day solarized plots, respectively, compared with 91% in the nonsolarized, infested check. This reduction in wilt during the young seedling stage is advantageous because tolerance to Fusarium wilt increases with plant age. Therefore, measures that tend to delay the onset of symptoms may reduce total disease incidence at the end of the season.

During the second growing season, two cultivars were planted. It was believed that a moderately wilt-resistant cultivar (Charleston Gray) would perform better than a susceptible cultivar in solarized soils where the inoculum level had been reduced (13). The results, however, did not support this hypothesis. There was very little difference in percentage of wilt between cultivars at 2, 3, or 4 wk in either the 30- or 60-day solarized plots. In fact, Sugarbaby actually showed slightly less wilt than Charleston Gray. We believe this is related to a difference in growth patterns of these two cultivars and to the type of *Fusarium* propagule in the soil. Sugarbaby is a small-seeded cultivar that produces a small plant relative to the much larger-seeded and larger plant of Charleston Gray. Consequently, root growth through the soil profile would be expected to be less rapid with Sugarbaby. Because the population of *F. o.* f. sp. *niveum* was reduced the greatest after solarization in the top 10–15 cm, there would be less inoculum coming in contact with Sugarbaby roots early on than with Charleston Gray roots, which would penetrate deeper into the soil profile in the same length of time where the inoculum density was higher. Martyn and McLaughlin (14) reported that at low inoculum levels of *F. o.* f. sp. *niveum*, moderately wilt-resistant cultivars showed few wilt symptoms; however, as inoculum density increased, any apparent resistance was lost and they became highly susceptible. Preliminary studies using rhizotrons support the contention of differing root-growth patterns between these two cultivars (*unpublished*).

After 240 days, the concentration of *F. o.* f. sp. *niveum* was similar for both the 30- and 60-day solarized soils at depths of 15–20 and 30–35 cm, but each was twice as high as it was after 30 days. This may relate to the type of propagule present. Netzer (15) reported that in freshly infested soil (3 wk) there were no chlamydospores observed, whereas infested soil kept dry for 3 mo contained an abundance of chlamydospores. These same soils resulted in differences in wilt severity after planting. In freshly infested soil, a 100-fold higher population (6,500 propagules per gram) was required for extensive wilt than with the soil kept dry for 3 mo (400 propagules per gram). These figures are very similar to those we report here. In our studies, after 30 days, the concentration of *F. o.* f. sp. *niveum* in nonsolarized, infested soil at depths of 5–10 and 15–20 cm was 6,400 and 5,700 propagules per gram, respectively, and most probably made up of mycellia and conidia. This resulted in almost 100% death of the watermelon plants within 3–4 wk. This is analogous to the freshly infested soil reported by Netzer (15). After 240 days, the *F. o.* f. sp. *niveum* concentration in solarized soils was only one-half of that in nonsolarized, infested soil at each depth (Table 2) and was similar to those reported by Netzer (15) in stored soil. In this instance, the propagules were most likely to be chlamydospores and therefore would be a more efficient form of inoculum. Consequently, a high percentage of wilt occurred even in these soils the second year.

In fields previously cropped to watermelon, Netzer (15) reported a range of 400–1,800 *F. oxysporum* propagules per gram and a wilt severity in Sugarbaby of 95–100%. The propagule counts in our study at 240 days in nonsolarized, infested soil ranged from 1,290 to 1,320 propagules per gram and resulted in almost 100% wilt in both Sugarbaby and Charleston Gray. Solarization reduced the number of propagules to about one-half; however, they were still high enough to cause extensive wilt.

An additional benefit derived from soil

Table 2. Inoculum density (propagules per gram of soil) of *Fusarium oxysporum* f. sp. *niveum* (FON) and other *Fusarium* species (other) recovered after 240 days from solarized and nonsolarized, infested soils

	Soil depth (cm)					
	5–10		15–20		30–35	
Treatment	**FON**	**Other**	**FON**	**Other**	**FON**	**Other**
Uninfested, nonsolarized	0	410	0	610	0	430
Infested, nonsolarized	1,320	1,100	1,600	1,180	1,290	580
Infested, 30-day solarized	320	620	920	610	660	520
Infested, 60-day solarized	50	770	860	980	810	660

solarization is enhanced plant growth even in the absence of plant pathogens. Chen and Katan (2) reported increased concentrations of NO^{3-}, NH^{4-}, K^{+}, Ca^{++}, and Mg^{++} in solarized soils and showed greater growth of tomato plants on extracts from these soils. Stapleton and DeVay (21) reported increases in fresh weights of 42 and 58%, respectively, of peach and walnut seedlings grown in solarized soil. Similarly, Hartz et al (8) reported a 20% increase in marketable yield of bell peppers after solarization. Presumably, in each instance, some of this increased growth was related to increased activity of either directly or indirectly beneficial microflora in solarized soils. The results of our study support this contention. The population of saprophytic *Fusarium* spp. increased twofold at 15–20 cm deep after 30 days of solarization. At 30–35 cm deep, the saprophytic *Fusarium* spp. population increased eightfold (310 vs. 2,510 propagules per gram).

Although not specifically studied in this experiment, others have demonstrated excellent weed control with solarization. Ruben and Benjamin (20) obtained 90 and 95% control of bermudagrass and johnsongrass rhizomes, respectively, in soil heated to 40 C. At 50 C, total control of these two weeds was achieved. Egley (3) reported significantly reduced numbers of viable seed of seven weed species after solarization for 1–4 wk. Earlier studies by our laboratory (*unpublished*) demonstrated excellent control of bermudagrass for 1 yr in a watermelon field after solarization.

Ultimately, use of a particular disease control strategy by a grower depends upon the cost-benefit relationship. Currently, it costs about $222/ha to root plow virgin land and prepare it for watermelon production. The additional cost for adding solarization would be about $64/ha ($286/ha total). These figures are based on typical watermelon production on 12-ft (3.7-m) centers and stripping with plastic 4 ft (1.2 m) wide centered over each row. The probable benefits afforded by solarization over two growing seasons in the form of increased seed germination and stand establishment, increased plant growth, disease and weed control, and water conservation, coupled with the decreasing availability and increased cost of virgin land, might well outweigh the extra $64/ha cost. Additionally, it is possible to pigment the plastic after solarization and leave it in place, increasing its effectiveness in weed control the following year (8).

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LITERATURE CITED

1. Ashworth, L. G., Morgan, D. P., Gaona, S. A., and McCain, A. H. 1982. Polyethylene tarping controls Verticillium wilt in pistachios. Calif. Agric. 36 (5-6):17-18.
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. Egley, G. H. 1983. Weed seed and seedling reductions by soil solarization with transparent polyethylene sheets. Weed Sci. 31:404-409.
4. Elad, Y., Katan, J., and Chet, I. 1980. Physical, biological, and chemical control integrated for soilborne diseases in potatoes. Phytopathology 70:418-422.
5. Esposito, R., and Fletcher, A. A. 1961. The relationships of pteridine biosynthesis to the action of copper 8-hydroxyquinolate on fungal spores. Arch. Biochem. Biophys. 93:369-376.
6. Fry, W. E. 1982. Principles of Plant Disease Management. Academic Press, New York. 378 pp.
7. Greenhalgh, F. C., and Lucas, S. E. 1984. Effect of soil pasteurization on damping-off and root rot of subterranean clover caused by *Fusarium avenaceum* and *Pythium* spp. Soil Biol. Biochem. 16:87-88.
8. Hartz, T. K., Bogle, C. R., and Villalon, B. 1985. Response of pepper and muskmelon to row solarization. HortScience 20:699-701.
9. Horowitz, M., Regev, Y., and Herzlinzer, G. 1983. Solarization for weed control. Weed Sci. 31:170-179.
10. Katan, J. 1980. Solar pasteurization of soils for disease control: Status and prospects. Plant Dis. 64:450-454.
11. Komada, H. 1975. Development of a selective medium for quantitative isolation of *Fusarium oxysporum* from natural soil. Rev. Plant Prot. Res. 8:114-125.
12. Martin, S. B., Campbell, C. L., and Lucas, L. T. 1983. Horizontal distribution and characterization of *Rhizoctonia* spp. in tall fescue turf. Phytopathology 73:1064-1068.
13. Martyn, R. D., and Hartz, T. 1985. Soil solarization for the control of Fusarium wilt of watermelon. Tex. Agric. Exp. Stn. PR- 4302, College Station. 13 pp.
14. Martyn, R. D., and McLaughlin, R. J. 1983. Effects of inoculum concentration on the apparent resistance of watermelons to *Fusarium oxysporum* f. sp. *niveum*. Plant Dis. 67:493-495.
15. Netzer, D. 1976. Physiological races and soil population level of Fusarium wilt of watermelon. Phytoparasitiica 4:131-136.
16. Porter, I. J., and Merriman, P. R. 1983. Effects of solarization of soil on nematode and fungal pathogens at two sites in Victoria. Soil Biol. Biochem. 15:39-44.
17. Porter, I. J., and Merriman, P. R. 1985. Evaluation of soil solarization for control of root diseases of row crops in Victoria. Plant Pathol. 34:108-118.
18. Pullman, G. S., DeVay, J. E., and Garber, R. H. 1981. Soil solarization and thermal death: A logarithmic relationship between time and temperature for four soilborne plant pathogens. Phytopathology 71:959-964.
19. 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.
20. Rubin, B., and Benjamin, A. 1984. Solar heating of the soil: Involvement of environmental factors in the weed control process. Weed Sci. 32:138-142.
21. Stapleton, J. J., and DeVay, J. E. 1982. Effect of soil solarization on populations of selected soilborne microorganisms and growth of deciduous fruit tree seedlings. Phytopathology 72:323-326.