Effects of Soil Solarization on *Macrophomina phaseolina* and *Sclerotium rolfsii*

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ABSTRACT

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Effects of soil solarization on natural and/or artificially established populations of *Macrophomina phaseolina* and *Sclerotium rolfsii* were examined using 51-μm clear polyethylene tarp for 2, 4, or 6 wk during spring, summer, and fall trials. In no case was tarping effective in reducing either natural *M. phaseolina* populations or buried inocula to undetectable levels. Complete control of buried, precounted sclerotia of *S. rolfsii* was achieved to 15-cm depths in the summer but only to 1 cm in the fall.

Additional key words: charcoal rot, *Euphorbia lathyris*, solar pasteurization

Soil solarization (solar pasteurization) involves covering moist soil with clear polyethylene tarp to increase soil temperatures to levels lethal to soilborne pests. The pioneering work with this method by Katan and co-workers in Israel (7,8) demonstrated control of *Verticillium dahliae* Kleb. and *Fusarium oxysporum* Schlecht.: Fr. f. sp. *lycopersici* (Sacc.) Snyd. & Hans. by application of a 30-μm tarp for 2 wk. Control of *V. dahliae* persisted for 160 days. A treatment period of 31 days (6) was sufficient to control *V. dahliae* at depths of 30 cm, reduce *Pratylenchus thornei* Sher. & Allen populations by 80-100%, and control most weeds. Partial control of *Pyrenochaeta terrestris* (Hansen) Gorenz, Walker & Larsen (10) and *Sclerotium rolfsii* Sacc. (5) also occurred. Some of these workers further noted neutral to stimulatory effects of the solarization treatment on populations of the beneficial organisms *Rhizobium* sp. and *Trichoderma* sp. (4,5). Katan et al (9) reported the duration of the solarization effect as 3 yr for Fusarium and Verticillium wilts of cotton and 2 yr for pink root of onion.

Pullman and co-workers (15-17) in

California were able to effect an 83-100% reduction of populations of *V. dahliae, Rhizoctonia solani* Kühn, and *Thielaviopsis basicola* (Berk. & Br.) Ferraris to a depth of 30 cm in cotton fields by a 4-wk solarization treatment with 25 μm tarp. Further work in California by Ashworth and Gaona (1,2) demonstrated the efficacy of solarization with 150- and 100-μm tarps in established pistachio nut groves to control Verticillium wilt. Solarization has also been reported effective for control of *S. oryzae* Catt. (21).

Macrophomina phaseolina (Tassi) Goid., the causal agent of charcoal rot of sorghum, corn, bean, and other hosts (3), has been reported in both native and cultivated soils in Arizona (23). Recent studies in both Australia and California have indicated that soil solarization is not effective in controlling *M. phaseolina* in forest soils (11,13).

The objectives of this study were to determine soil temperature increases possible with solarization in the Sonoran desert region of Arizona and to assess the efficacy of solarization in reducing soil populations of *M. phaseolina* and *S. rolfsii* in Arizona. After solarization, *Euphorbia lathyris* L., a plant with hydrocarbon-rich latex (18) and one that is highly susceptible to *M. phaseolina* (24), was planted in treated and untreated plots to determine the differences in *M. phaseolina*-associated mortality.

MATERIALS AND METHODS

All solarization work was conducted at the University of Arizona's Campbell Avenue Farm at Tucson. Field soil was loam (51.9% sand, 33.0% silt, and 15.1% clay) with a pH of 7.25.

Thermal death range. The thermal death points in vitro of *M. phaseolina* and *S. rolfsii* were determined as follows. The fungi were grown on PDA (39 g/L Difco potato-dextrose agar, and 5 g/L Difco Bacto agar). In each test, three plates of the test fungus were placed in a controlled-temperature incubator at 40, 45, 50, or 55 C for a specific period of time. Subsequently, 10 6-mm plugs were aseptically removed from each plate and placed on PDA. Fungal survival after treatment was measured as the average percentage of plugs with emerging hyphae. All tests were repeated at least once.

Soil solarization. Five field trials of soil solarization were conducted between March 1981 and October 1982. Five plots (2.5 × 6.1 m) were used for each trial. Three solarized plots ("tarped") were preirrigated to saturation 1 day before placement; all edges of the 51-μm, clear polyethylene tarp were buried. A fourth area, a "wet control" was preirrigated in the same manner as the solarized plots but no tarp was applied. A fifth plot was neither preirrigated nor tarped ("dry control"). For each trial, one tarp was removed every 2 wk, giving treatment periods of 2, 4, or 6 wk.

Temperatures (±1 C) were recorded every 2 hr at depths of 1, 15, and 30 cm in plots tarped 6 wk and the wet control and dry control plots. Temperature data were not obtained for trial 3 because of equipment failure. From these data, the duration of temperatures exceeding various arbitrarily chosen threshold temperatures (45 and 50 C) was calculated in degree hours (DH) with a polar compensating planimeter.

Pathogen population measurement. In trials 1-4, native populations of *M. phaseolina* were measured before and after solarization. Before tarping, five soil cores (3.2 × 30.5 cm) were taken on a diagonal transect from the combined tarped plots and each of the two control plots (15 cores total). In trials 3 and 4, each core was divided into two depth classes (0-15 cm and 16-30 cm). The five cores from each plot type and depth class

were bulked and five 25-g samples were assayed (12) for *M. phaseolina* from each of the composite samples. Each time a tarp was removed, five soil cores were collected on the diagonal in that plot and five each from the two control plots. The cores from each plot were composited and sampled as described.

In trials 2 and 4, the effect of solarization on buried *M. phaseolina* inoculum was determined. A field-soil isolate was used to produce sclerotia by the method of Short and Wyllie (19), modified by growing the sclerotial mats 8 days instead of 2–3 wk. Sclerotia were mixed with air-dry field soil and five 1-g samples of the mixture were assayed for *M. phaseolina* to establish the initial populations. Samples of 25 ml of the soil mixture were wrapped in weighing paper (10 × 10 cm), then in small swatches of nylon hosiery. Five such packets were wrapped together in nylon windowscreen bags to aid recovery. One pit was dug in each of three tarped plots; three pits were dug in each control plot. One bag, containing five packets, was buried at depths of 1, 15, and 30 cm in each of the nine pits. Every 2 wk, after one of the tarps was removed, the three nylon bags from one pit in each plot type were recovered. A single 1-g sample from each of the five packets in each bag was assayed for *M. phaseolina*.

The effect of solarization on buried sclerotia of *S. rolfsii* also was determined in trials 4 and 5. Groups of 30 sclerotia produced on PDA were wrapped in small swatches of nylon hosiery; five packets with sclerotia were then wrapped in nylon windowscreen. This inoculum was buried as described for *M. phaseolina*. After retrieval, the number of sclerotia in each packet was noted. After surface-sterilization (1–2 min in 0.525% NaClO), 15 sclerotia from each packet were placed on PDA amended with streptomycin sulfate (200 μg a.i./ml final concentration) after autoclaving. Plates were incubated 4 days at 29 C and the percentage of germination was recorded.

Planting after solarization. Because of its susceptibility to *M. phaseolina* (24), *E. lathyris* was planted after solarization in trials 1–3 to determine the influence of solarization on emergence and on infection by *M. phaseolina*. Five 2.5-m rows (60 cm apart) were planted with 100 seeds 8–10 cm deep in each of five plot types (three tarped and two control). All plots were flood-irrigated immediately after planting and every 2–3 wk as needed. Because *E. lathyris* seedlings were more easily established in the fall than during the summer, trial 2 was not planted until October 1981. Roots of all dead plants were examined microscopically for sclerotia of *M. phaseolina*. Where sclerotia were absent, root sections (3–5 mm), surface-sterilized 2 min in 0.525% NaClO, were placed on selective medium (12) and incubated 6

days at 32–34 C to determine the presence of *M. phaseolina*. After harvest, soils from all five plots were assayed again for the pathogen as described.

RESULTS

Thermal death range. *M. phaseolina* sclerotia survived more than 72 hr at 45 C but were killed in 48 hr at 50 C or 24 hr at 55 C. *S. rolfsii* sclerotia survived 12 hr at 45 C but were killed in 4–6 hr at 50 C or 3 hr at 55 C.

Soil solarization. The five field trials of soil solarization were conducted in April, June, and September 1981 and in June and September 1982. The soil temperature maxima and the average daily maximum are shown in Table 1. Temperature maxima were highest during the two June studies (trials 2 and 4). Temperature

maxima in early fall (trial 5) were generally slightly lower than in the summer trials, whereas those during the spring test (trial 1) were much lower than in the other trials.

Because of the time required to kill both fungi in the laboratory, the duration of temperatures in the field exceeding arbitrary levels (thresholds) of 45 and 50 C were determined (Table 2). For each plot and depth, the range of DH is reported for the 15 days of the 42-day treatment that had the maximum DH. One DH is defined as the maintenance of a temperature 1 degree higher than the threshold temperature for 1 hr. (Thus, a measurement of 4 DH could be 1 hr at a temperature 4 degrees higher than the threshold or 4 hr at a temperature 1 degree higher than the threshold.) Temperatures were generally highest and

Table 1. Soil temperatures and rainfall during soil solarization

Plot	Depth (cm)	Maximum daily soil temperatures (avg. daily max.) (C)			
		Trial 1[a]	Trial 2	Trial 4	Trial 5
Tarped	1	53 (45.8)	63 (50.5)	58 (53.7)	54 (41.2)
	15	42 (34.1)	49 (44.5)	50 (42.4)	45 (36.1)
	30	37 (29.2)	46 (40.3)	45 (37.8)	40 (32.8)
Wet control	1	44 (36.1)	63 (56.6)	50 (43.8)	53 (43.2)
	15	32 (25.4)	41 (37.0)	43 (34.6)	41 (33.4)
	30	28 (22.0)	38 (33.8)	40 (31.2)	38 (31.3)
Dry control	1	⋯	⋯	59 (52.3)	44 (36.1)
	15	30 (22.8)	42 (38.5)	45 (36.9)	42 (33.1)
	30	⋯	⋯	37 (31.8)	39 (30.3)
Air temperature (C)[b]		34 (27.3)	42 (37.6)	41 (35.8)	40 (33.8)
Rainfall (mm)		21[b]	22[c]	8[c]	86[c]

[a] Trial 1 = 21 March through 1 May 1981, trial 2 = 28 May through 8 July 1981, trial 4 = 28 May through 9 July 1982, and trial 5 = 23 August through 4 October 1982.
[b] Climatic measurements as recorded by the National Oceanic and Atmospheric Administration, Tucson International Airport.
[c] Rainfall measurements made at the field location.

Table 2. Degree hours (DH) exceeding threshold temperatures during soil solarization

Plot	Depth (cm)	Trial 1[b]	Trial 2	Trial 4	Trial 5
		DH exceeding 45 C[a]			
Tarped	1	4–32	40–60	46–80	0–38
	15	0	4–20	0–5	0–1
	30	0	0	0	0
Wet control	1	0	72–136	2–24	0–26
	15	0	0	0	0
	30	0	0	0	0
Dry control	1	⋯	⋯	32–72	0
	15	0	0	0	0
	30	⋯	⋯	0	0
		DH exceeding 50 C[a]			
Tarped	1	0–8	8–22	14–40	0–10
	15	0	0	0	0
	30	0	0	0	0
Wet control	1	0	32–82	0–2	0–4
	15	0	0	0	0
	30	0	0	0	0
Dry control	1	⋯	⋯	6–32	0
	15	0	0	0	0
	30	⋯	⋯	0	0

[a] Each range includes the 15 of the 42-day duration of the tests that the maximum DH exceeded the threshold temperature.
[b] Trial 1 = 21 March through 1 May 1981, trial 2 = 28 May through 8 July 1981, trial 4 = 28 May through 9 July 1982, and trial 5 = 23 August through 4 October 1982.

DH exceeding thresholds greatest in the early summer treatments (trials 2 and 4) at every depth.

The effect of solarization on the naturally established population of *M. phaseolina* was examined in field trials 1–4 (Table 3). In no case was the population of *M. phaseolina* reduced to undetectable levels as a result of tarp application. Because the natural population of *M. phaseolina* in the field was low, field soil artificially infested with high sclerotial populations was also subjected to the solarization treatment during June to more accurately assess treatment effects on population dynamics. In both June trials, populations of *M. phaseolina* were never reduced to undetectable levels as a result of tarping. During trial 2, the initial population of 147 sclerotia per gram was reduced to fewer than 20 sclerotia per gram in the tarped and wet control plots and to 80–115 sclerotia per gram in the dry control plot at the end of 6 wk. During trial 4, the initial population of 254 sclerotia per gram was reduced to 130–136 sclerotia per gram in all plots and at all depths at the end of 6 wk.

The effect of soil solarization on the viability of buried, precounted *S. rolfsii* sclerotia was examined during field trials 4 and 5 (Table 4). Some sclerotia apparently disintegrated but recovery was generally between 83 and 100%, with a few exceptions. These exceptions occurred in trial 4 in the 6-wk tarped plot at 15 cm (48%) and 30 cm (37%), the 2-wk wet control plot at 15 cm (67%) and 30 cm (0%), and the 6-wk wet control plot at 30 cm (51%). One exception occurred in trial 5 in the 6-wk tarped plot at 1 cm (77%). Application of the tarp during early summer (trial 4) resulted in complete loss of sclerotial viability at 1 and 15 cm by 6 wk. Although recovery of sclerotia in the tarped plot was reduced at 30 cm by 6 wk, many sclerotia recovered were still viable. Application of the tarp during early fall (trial 5) resulted in complete loss of sclerotial viability only at 1-cm depth.

Planting after solarization. After trial 1, there was a marked increase in emergence of *E. lathyris* seedlings in the 4-wk tarped plot (44%) compared with the other plots (19–27%). In the planting

after trial 1, *M. phaseolina*-associated mortality was similar for all plots regardless of solarization treatment. In the trial 2 planting, *M. phaseolina* was associated with 92–97% of the dead plants from three solarized plots and 98% of the dead plants from the wet control plot but only 42% of the dead plants from the dry control plot. In the trial 3 planting, *M. phaseolina* was associated with 89–97% of the dead plants from three tarped plots and 86% of the dead plants from the dry control plot but only 70% of the dead plants from the wet control plot. (These percentages are the average of five rows per plot.) Thus, *M. phaseolina*-associated mortality was at least as high as that in control plots.

DISCUSSION

Early-summer solarization treatments were the most effective for raising soil temperature under the climatic conditions in southern Arizona. Solarization in the fall (trial 5) was nearly as efficient in raising soil temperatures as summer treatments (trials 2 and 4), whereas early-spring trial temperatures were substantially lower (Table 1). Maximum soil temperatures achieved in summer trials 2 and 4 under tarp were nearly the same as those reported in Israel (4–6,10), 9–14 C higher than those reported in Pakistan (21) and Australia (13), and 2–4 C lower than those reported in California (17). Grinstein et al (5) demonstrated control of *S. rolfsii* to a depth of 20 cm while achieving temperature maxima similar to those in this report. Data in Table 4, indicating eradication of *S. rolfsii* at 15 cm but not at 30 cm, corroborate the findings of previous investigators.

In all experiments, tarping was ineffective in controlling *M. phaseolina* in agricultural soil (Table 3). These data agree with previously published reports (11,13) that solarization did not control *M. phaseolina* in forest soils. The low natural population of *M. phaseolina* did not vary in any consistent way with respect to time, depth, or treatment and residual populations were always sufficient to cause a 15–99% loss in *E. lathyris* plantings. For artificially established *M. phaseolina* populations, decreases in sclerotial populations in tarped and control plots were observed in trials 2 and 4 at all depths. Despite the reductions, the residual artificial populations in tarped plots (1.4–16.8 and 132.2–159.3 sclerotia per gram in trials 2 and 4, respectively) were within the range reported for agricultural soil wherein susceptible plants became infected (14,20,22–24).

Laboratory tests indicated that 4–6 hr were required to kill *S. rolfsii* at 50 C. In field trials 4 and 5, this temperature duration was achieved only at 1-cm depths in the tarped plots, the dry control plot of trial 4, and in the wet control plot of trial 5 (Table 2). *S. rolfsii* was eliminated only in the tarped plots at 1-

Table 3. Effects of soil solarization on naturally established populations of *Macrophomina phaseolina* at various depths

| Plot | Weeks tarped (no.) | *M. phaseolina* population (sclerotia/g soil)[a] | | | | | |
| | | Trial 1[b] (0–30 cm) | Trial 2 (0–30 cm) | Trial 3 | | Trial 4 | |
				0–15 cm	16–30 cm	0–15 cm	16–30 cm
Tarped	0[c]	0.16 (0.06)	0.27 (0.11)	ND[d]	0.12 (0.03)	0.08 (0.08)	0.05 (0.03)
	2	0.36 (0.16)	0.28 (0.27)	0.23 (0.10)	0.20 (0.07)	0.19 (0.06)	0.21 (0.09)
	4	0.18 (0.06)	0.10 (0.08)	0.17 (0.06)	0.06 (0.03)	0.38 (0.18)	0.23 (0.08)
	6	0.17 (0.07)	0.02 (0.03)	0.30 (0.19)	0.19 (0.08)	0.19 (0.09)	0.16 (0.04)
Wet control	0	0.28 (0.14)	0.34 (0.10)	0.22 (0.05)	0.26 (0.13)	0.18 (0.07)	0.07(0.06)
	2	0.54 (0.76)	0.20 (0.07)	0.23 (0.13)	0.10 (0.06)	0.18 (0.05)	0.27 (0.10)
	4	0.13 (0.05)	ND	0.38 (0.13)	0.22 (0.06)	0.18 (0.15)	0.17 (0.14)
	6	0.22 (0.09)	0.08 (0.07)	0.37 (0.13)	0.17 (0.06)	0.29 (0.01)	0.19 (0.09)
Dry control	0	1.03 (1.60)	0.24 (0.07)	0.16 (0.10)	0.13 (0.07)	0.10 (0.10)	0.08 (0.08)
	2	0.17 (0.08)	0.25 (0.11)	0.14 (0.09)	0.10 (0.07)	0.24 (0.06)	0.17 (0.03)
	4	0.37 (0.23)	0.08 (0.04)	0.26 (0.05)	0.14 (0.08)	0.25 (0.12)	0.22 (0.07)
	6	0.30 (0.12)	0.01 (0.01)	0.39 (0.12)	0.18 (0.09)	0.19 (0.04)	0.28 (0.10)

[a] The first number is the mean of five replicates from a composite of five samples; the parenthetical value is the standard deviation.
[b] Trial 1 = 21 March through 1 May 1981, trial 2 = 28 May through 8 July 1981, trial 3 = 30 August through 11 October 1981, and trial 4 = 28 May through 9 July 1982.
[c] Week 0 = initial population before treatment.
[d] ND = not detectable.

Table 4. Viability of *Sclerotium rolfsii* sclerotia subjected to soil solarization

| Plot | Weeks tarped (no.) | Percent viability[a] | | | | |
| | | Trial 4[b] | | | Trial 5 | |
		1 cm	15 cm	30 cm	1 cm	15 cm
Tarped	2	0 (0)	68 (26.8)	19 (18.1)	0 (0)	99 (2.7)
	4	0 (0)	0 (0)	17 (15.6)	0 (0)	99 (2.7)
	6	0 (0)	0 (0)	61 (16.4)	0 (0)	100 (0)
Wet control	2	100 (0)	58 (29.6)	···	100 (0)	100 (0)
	4	83 (21.3)	31 (17.2)	17 (22.2)	97 (5.3)	97 (5.3)
	6	36 (26.2)	64 (28.5)	58 (27.0)	95 (5.0)	56 (36.7)
Dry control	2	96 (5.3)	96 (5.3)	65 (27.8)	100 (0)	100 (0)
	4	100 (0)	20 (24.6)	60 (25.7)	93 (7.3)	99 (2.7)
	6	99 (2.7)	71 (19.6)	95 (7.8)	100 (0)	85 (29.3)

[a] The first number is the percentage of 15 sclerotia that germinated. Each value is the mean of five replicates; the parenthetical value is the standard deviation. ··· = No viability data available because no sclerotia were recovered.
[b] Trial 4 = 28 May through 9 July 1982 and trial 5 = 23 August through 4 October 1982.

and 15-cm depths in trial 4 and at 1 cm in trial 5 (Table 4). Although temperature was clearly a factor in control, other factor(s) presumably contributed to the death of *S. rolfsii* at 15 cm in trial 4. Similar comparisons between laboratory temperature studies and field temperature durations can be made for *M. phaseolina*. The 48 hr at 50 C required in the laboratory for death of *M. phaseolina* was never attained in any tarped plot at any depth. This duration was attained only during trial 2 at 1-cm depth in the wet control; even so, the fungus was not eradicated. These comparisons again indicate that reduction in population achieved by soil solarization is more than just a function of temperature.

Apart from cost factors, the practicality of soil solarization is dependent on the heat tolerance of the target organisms and whether or not remaining inoculum levels are sufficient to cause disease. Under Arizona climatic conditions, solarization is further limited by disintegration of the polyethylene tarp after 6 wk. Incidence of *M. phaseolina*-associated plant mortality in tarped plots was always at least as high as in any control plot. This indicates that under certain soil conditions, soil solarization could eliminate a sufficient proportion of the soil microflora antagonistic to or competitive with *M. phaseolina* to result in a significant increase in disease incidence. Thus, successful application of solarization also requires full exploration of the area to be treated for nontarget temperature-tolerant pathogens such as *M. phaseolina*, whose development or

survival could be enhanced by this treatment.

LITERATURE CITED

1. Ashworth, L. J. 1981. Use of polyethylene tarps for control of Verticillium wilt in a pistachio nut grove. (Abstr.) Phytopathology 71:200.
2. Ashworth, L. J., and Gaona, S. N. 1982. Evaluation of clear polyethylene mulch for controlling Verticillium wilt in pistachio nut groves. Phytopathology 72:243-246.
3. Dhingra, O. D., and Sinclair, J. B. 1978. Biology and Pathology of *Macrophomina phaseolina*. Universidade Federal de Viçosa, Brasil. 166 pp.
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. 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.
6. Grinstein, A., Orion, D., Greenberger, A., and Katan, J. 1979. Solar heating of the soil for the control of *Verticillium dahliae* and *Pratylenchus thornei* in potatoes. Pages 431-436 in: Soil-borne Plant Pathogens. B. Schippers and W. Gams, eds. Academic Press, New York.
7. Katan, J., Greenberger, A., Alon, H., and Grinstein, A. 1975. Increasing soil temperature by mulching for the control of soil borne diseases. Phytoparasitica 3:69-70.
8. 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.
9. Katan, J., Grinstein, A., Fishler, G., Frank, Z. R., Rabinowitch, H. D., Greenberger, A., Alon, H., and Zig, U. 1981. Long-term effects of solar heating of the soil. Phytoparasitica 9:236.
10. Katan, J., Rotem, I., Finkel, Y., and Daniel, J. 1980. Solar heating of the soil for the control of pink root and other soil-borne diseases of onions. Phytoparasitica 8:39-50.
11. McCain, A. H., Bega, R. V., and Jenkinson, J. L. 1982. Solar heating fails to control *Macrophomina phaseolina*. (Abstr.) Phytopathology 72:985.
12. Mihail, J. D., and Alcorn, S. M. 1982. Quantitative recovery of *Macrophomina phaseolina* sclerotia from soil. Plant Dis. 66:662-663.
13. Old, K. M. 1981. Solar heating of soil for the control of nursery pathogens of *Pinus radiata*. Aust. For. Res. 11:141-147.
14. Papavizas, G. C., and Klag, N. G. 1975. Isolation and quantitative determination of *Macrophomina phaseolina* from soil. Phytopathology 65:182-187.
15. Pullman, G. S. 1979. Effectiveness of soil solarization and soil flooding for control of soil-borne diseases of *Gossypium hirsutum* L. in relation to population dynamics of pathogens and mechanisms of propagule death. Ph.D. dissertation, Univ. Calif., Davis. 95 pp.
16. Pullman, G. S., DeVay, J. E., Garber, R. H., and Weinhold, A. R. 1979. Control of soil-borne fungal pathogens by plastic tarping of soil. Pages 439-446 in: Soil-borne Plant Pathogens. B. Schippers and W. Gams, eds. Academic Press, New York.
17. Pullman, G. S., DeVay, J. E., Garber, R. H., and Weinhold, A. R. 1981. Soil solarization: Effects on *Verticillium dahliae*, *Pythium* spp., *Rhizoctonia solani*, and *Thielaviopsis basicola*. Phytopathology 71:954-959.
18. Sachs, R. M., Low, C. B, MacDonald, J. D., Awad, A. R., and Sully, M. J. 1981. *Euphorbia lathyris*: A potential source of petroleum-like products. Calif. Agric. 35:29-32.
19. Short, G. E., and Wyllie, T. D. 1978. Inoculum potential of *Macrophomina phaseolina*. Phytopathology 68:742-746.
20. Short, G. E, Wyllie, T. D., and Bristow, P. R. 1980. Survival of *Macrophomina phaseolina* in soil and in residue of soybean. Phytopathology 70:13-17.
21. Usmani, S. M. H., and Ghaffar, A. 1982. Polyethylene mulching of soil to reduce viability of sclerotia of *Sclerotium oryzae*. Soil Biol. Biochem. 14:203-207.
22. Watanabe, T. 1972. *Macrophomina phaseoli* found in commercial kidney bean seed and in soil and pathogenicity to kidney bean seedlings. Ann. Phytopathol. Soc. Jpn. 38:100-105.
23. Young, D. J., and Alcorn, S. M. 1982. Soil populations of *Macrophomina phaseolina* in Arizona. (Abstr.) Phytopathology 72:993.
24. Young, D. J., and Alcorn, S. M. 1982. Soilborne pathogens of *Euphorbia lathyris*: *Macrophomina phaseolina*, *Pythium aphanidermatum*, and *Rhizoctonia solani*. Plant Dis. 66:236-238.