# Effects of Soil Solarization on Plant-Parasitic Nematodes and *Phytophthora cinnamomi* in South Africa

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**ABSTRACT**

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The effect of clear plastic mulch on the survival of plant-parasitic nematodes and *Phytophthora cinnamomi* was investigated. Populations of total plant-parasitic nematodes, *Pratylenchus pratensis, Rotylenchus incultus, Criconemella xenoplax*, and a mixed population of *Paratrichodorus lobatus* plus *P. minor* were reduced by between 37 and 100% of their original levels by soil solarization. Control of *Meloidogyne javanica* was inconsistent. Solarization for 3 wk eliminated *Phytophthora cinnamomi* from 91% of buried infested wheat grains, whereas solarization for 6 wk completely eradicated the fungus. Growth of grapevines (cultivar Jacquez) and tomatoes (cultivar Moneymaker) was enhanced in soil treated with solarization for 6 wk.

Soil solarization is a method of controlling soilborne pests and pathogens by raising the temperature of the soil through application of thin, transparent polyethylene plastic sheets to a moist soil surface. Since the development of solarization in Israel (9), it has been used successfully to reduce populations of plant-parasitic nematodes (5,10,14,17,19) and various plant-pathogenic fungi (7,8,11,13,15).

The South African nursery and agricultural industries require effective control measures for plant-parasitic nematodes and plant-pathogenic fungi. Root-knot nematodes (*Meloidogyne* Goeldi) and the fungus *Phytophthora cinnamomi* Rands account for most of the nursery material destroyed or placed under quarantine in the southwestern Cape Province. Because of the hot, dry summers in the region, solarization appeared to have potential for eliminating soilborne pathogens and nematodes from nursery soils.

Experiments were conducted over two summers to evaluate the effectiveness of solarization in reducing populations of plant-parasitic nematodes and *P. cinnamomi* under local conditions. Total fungi, total bacteria, total pythiaceous fungi, and posttreatment plant growth effects were also monitored.

## MATERIALS AND METHODS

Field trials were conducted in December 1983 through January 1984 and January through February 1985 (summer) in Stellenbosch, Cape Province. Sites were prepared by rotovating the soil to seedbed tilth, leveling, and irrigating sufficiently to wet the soil to a depth of 50 cm. Transparent polyethylene plastic sheets 50 or 150 $\mu$m thick were used for solarization treatments. In nematicide treatments, the fumigant ethylene

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dibromide (EDB, 450 g a.i./L) was injected by handgun into the soil to a depth of 20 cm on centers 30 × 30 cm (10 injection sites per square meter). Fumigated soil was sealed by mechanical compaction or, when combined with solarization, by plastic sheets. Plots measured 4 × 4 m. All tomatoes used were cultivar Moneymaker.

**Field trial 1 (20 December 1983 to 31 January 1984).** Six replicates of four treatments were laid out in a randomized block design in sandy soil (94% sand, 4% silt, and 2% clay) with a pH of 4. The site was planted to a potato/lupine rotation before the trial. Treatments were solarization for 3 and 6 wk with 50-$\mu$m-thick transparent plastic, fumigation with EDB at the recommended nursery rate of 6 m/30 × 30 cm (2) applied 3 wk after initiation of the trial, and fallow. Fallow plots were kept weedfree by hoeing twice during the 6-wk trial period. Soil temperatures were recorded in one solarized plot and one fallow plot at 5, 15, and 30 cm deep.

To determine nematode populations, soil samples were collected immediately before initiation of the experiment, 3 and 6 wk after initiation, and then monthly for 6 mo. Six cores (2 cm in diameter) were taken to a depth of 40 cm in each replicate, bulked in polyethylene bags, and processed upon return to the laboratory.

Nematodes were extracted from a 250-$cm^3$ subsample of soil from each replicate by Oostenbrink's elutriation method (18), and the resulting suspensions were cleared in a modified Baermann funnel for 48 hr. The plant-parasitic nematodes in two 1-ml aliquots were counted, identified, and their population densities estimated from the average number of nematodes in the two aliquots from each replicate. Data were transformed to ln ($Yx/Yo$), where $Yx$ represented the number of nematodes per 250 $cm^3$ soil at sampling time $x$ and $Yo$ represented the initial nematode population density per 250 $cm^3$ of soil.

The effects of solarization on the survival of *P. cinnamomi* were also tested. Wheat grains infested with two isolates of *P. cinnamomi* (C37 and C121) were buried at depths of 5, 15, and 30 cm in the centers of plots, which were then solarized or left fallow for 3 and 6 wk. The infested wheat grains were prepared as described previously (21). Ten wheat grains each were placed in bags 3 × 3 cm made of nylon net with 5-$\mu$m pores. The bags were sewn with different colors of thread to mark the two isolates and three depths for each burial site (total of six bags per plot). After both 3 and 6 wk, bags were retrieved from all six replicates of both solarized and fallow plots. The wheat grains were removed from the net bags and assayed as described previously (21), except surface disinfestation was not used.

**Field trial 2 (8 January to 19 February 1985).** Six replicates of six treatments were laid out in a randomized block design in sandy soil (92% sand, 6% silt, and 2% clay) with a pH of 5.5. The site was planted to potatoes before the field trial. Soil temperatures were recorded at depths of 10 and 30 cm in one replicate each of solarization with 50- and 150-$\mu$m plastic and fallow. Treatments were solarization for 6 wk with 50- or 150-$\mu$m-thick plastic, fumigation with EDB at 2 ml/30 × 30 cm immediately followed by the application of 50- or 150-$\mu$m plastic for 3 wk, EDB at 4 ml/30 × 30 cm applied during the third week of the trial, and fallow.

Soil samples for nematodes were collected as in trial 1 immediately before the experiment, after 3 and 6 wk, then monthly for 4 mo. The plant-parasitic nematodes were extracted, identified, and counted as in trial 1.

To test the effects of the treatments on the survival and infectivity of the root-knot nematode (*M. javanica* (Trueb) Chitwood), egg masses of *M. javanica* were placed in cages and buried at a depth of 30 cm in each replicate of all treatments. The cages were made from 5-cm lengths of 4.5-cm-diameter PVC pipe. A covering of 10-$\mu$m-pore nylon net was held over each end of the pipe by a 1.5-cm ring of PVC pipe of a slightly larger diameter than the cage pipe. Each cage was filled with moist, microwaved (4) field soil containing five egg masses of *M. javanica* from a greenhouse culture of tomatoes. The cages were retrieved after 3 or 6 wk of treatment. Three-week-old tomato seedlings were planted in 15-cm-diameter pots containing soil from the cages and grown in a glasshouse at 25 ± 5 C. After 8 wk, the roots of the indicator plants were washed and rated for infection by *M. javanica* by Taylor and Sasser's (20) rating method modified so that 0 = no galls or egg masses, 1 = 1–2 egg masses, 2 = 3–10 egg masses, 3 = 11–25 egg masses, 4 = 26–50 egg masses, and 5 = more than 50 egg masses.

The effects of solarization using 50- and 150-$\mu$m plastic on the survival of *P. cinnamomi* were evaluated. Wheat grains infested with two isolates of *P. cinnamomi* (C37 and C121) were buried in three replicates of the 50-$\mu$m plastic solarized, 150-$\mu$m plastic solarized, and fallow plots. The wheat grains were prepared and buried as in trial 1, except plastic photographic slide mounts were used to enclose the wheat grains in the nylon net and wheat grains were buried at 10 and 30 cm. The wheat grains were removed after 3 and 6 wk and assayed for survival as in trial 1.

Soil samples were taken with a boring soil sampler to a depth of 30 cm from each of the plots in which wheat grains were buried at the beginning of the trial and after 3 and 6 wk. These soil samples were assayed by soil dilution plating for total fungi (6), total bacteria (12), and total pythiaceous fungi (22).

**Effect of soil solarization on plant growth.** The effect of solarization on vine and tomato growth was determined as follows. Six weeks after initiation of trial 1, all plastic was removed and 20 grapevines (cultivar Jacquez) were planted in each replicate to determine treatment effect of vine growth. After 6 mo, the vines were removed and fresh total, cane, and root mass; cane length; and dry cane mass were measured.

Six weeks after the initiation of trial 2, soil from each replicate was brought to the greenhouse to determine treatment effect on tomato germination and growth. One 15-cm-diameter pot per replicate was filled with treated field soil, sown with 10 tomato seeds, and placed in a greenhouse at 25 C. Germination was recorded twice a week for 3 wk. The seedlings were then thinned to two per pot, and height was measured twice a week until the seedlings were 6 wk old. The tomato plants were removed, air-dried for 2 wk, and weighed.

**Thermal inactivation studies.** The effect of constant and fluctuating temperature on the survival and infectivity of *M. javanica* was tested in the laboratory. Ninety-nine polyacrylate centrifuge tubes were filled with 40 $cm^3$ of moist autoclaved potting mix. Five egg masses of *M. javanica* from a glasshouse tomato culture were placed in each of 90 soil-filled tubes. Nine tubes served as an uninoculated check. Each tube was covered with a 70-$\mu$m layer of transparent plastic and secured with a rubber band. The tubes were divided into nine groups of 11, consisting of 10 inoculated tubes plus one uninoculated check tube. Each group was treated in an environmental growth chamber at 80% relative humidity for 4 wk with one of the following treatments: constant temperature of 20, 30, or 40 C; holding 22 hr at 20 C fluctuating to 30, 35, or 40 C for 2 hr per day for five consecutive days per week; or holding temperature of 30 C fluctuating to 40, 45, or 50 C for 2 hr per day for five consecutive days per week.

After 4 wk, the soil from the tubes was used in a bioassay with 3-wk-old tomatoes as an indicator of *M. javanica* survival and infectivity. After 8 wk, the roots were rated for infection as previously described.

The effect of temperature on the inactivation of chlamydospores of *P. cinnamomi* was studied in the laboratory. Chlamydospores of two isolates (C113 and C141) were produced axenically by the method of Darling (16). Mycelium with chlamydospores was macerated in the culture medium in a Waring Blendor for 2 min at low speed and the resultant slurry filtered through four layers of cheesecloth. Chlamydospores were resuspended to 100 ml with sterile distilled water, and 5-ml aliquots of this

suspension were placed in McCartney bottles and held at 4 C until tested. The bottles were placed in a water bath for 0, 5, 10, 15, 20, and 30 min at each of three temperatures: 44, 41, and 38 C. Treatments were terminated by removing bottles from the bath, immediately placing them in an ice bath, and then plating four 1-ml aliquots of chlamydospores each onto a plate containing HMI medium (21).

## RESULTS

**Field trial 1.** In solarized plots, maximum soil temperatures of 51.8, 46, and 41.6 C at depths of 5, 15, and 30 cm, respectively, were attained during the third week of the trial (Table 1). The plastic disintegrated after the third week and was replaced.

Total plant-parasitic nematodes increased by 25.4% in fallow treatment and decreased by 67.5, 88.2, and 99.1% in 3-wk solarization, 6-wk solarization, and EDB fumigation treatments, respectively. Immediately after the trial, free-living nematodes, *Pratylenchus pratensis* Filipjev, *Rotylenchus incultus* Sher, *Criconemella xenoplax* (Raski) Luc & Raski, and a combined population of *Paratrichodorus minor* (Colbran) Siddiqi plus *P. lobatus* (Colbran) were decreased by 77.2–95.3% of their initial population level after 6 wk of solarization. Populations of *M. javanica* were reduced 95.5% after 3 wk of solarization but increased by 42.8% after 6 wk of solarization (Table 2). During the 6 mo following the field trial, total plant-parasitic nematode population levels were generally lower in EDB-treated plots than in other treatments. However, 6-wk solarization resulted in the greatest long-term reduction of *P. pratensis*.

All treatments increased the population of *P. minor* plus *P. lobatus* to higher than initial levels within 2 mo of treatment. After 6 mo, *M. javanica* and *C. xenoplax* showed an increase from their initial level in all treatments except EDB fumigation.

*P. cinnamomi* was eradicated from all colonized wheat grains buried in 3- and 6-wk solarized plots. Fallow treatment eliminated 84 and 99% of the *P. cinnamomi* after 3 and 6 wk, respectively (Table 3).

**Field trial 2.** Average daily maximum soil temperatures attained at 10 and 30 cm under 150-μm plastic were 39.8 and 32.4 C; under 50-μm plastic, 38.9 and 33.1 C; and in fallow plots, 32.8 and 27.7 C, respectively (Table 1). The 50-μm plastic disintegrated after 3 wk, but the 150-μm plastic remained undamaged for the duration of the trial. As a precaution, all plastic was replaced 3 wk after initiation of the trial.

Initial populations of plant-parasitic nematodes were low (Table 2). *P. pratensis* and *P. minor* were the only plant-parasitic nematodes present in sufficient numbers for statistical analysis. Other plant-parasitic nematodes occurring infrequently or sporadically in samples were *M. javanica, C. xenoplax, R. incultus, Paratylenchus* sp., and *Heterodera* sp.

EDB fumigation at 3 ml/30 × 30 cm and EDB fumigation at 2 ml/30 × 30 cm combined with 3-wk solarization with 50- or 150-μm plastic were the most effective treatments for reducing free-living nematodes (95–99.2% reduction), total plant-parasitic nematodes (85.7–100% reduction), and *P. minor* (100% reduction) 1 day after treatment. EDB combined with solarization was more effective than EDB alone in reducing all nematode populations 1 day after treatment. There was no significant difference in effect on nematode populations between solarization with 50- or 150-μm plastic.

Percent infection and average gall index of indicator plants grown in soil taken from *M. javanica*-inoculated cages buried in the field and removed after treatment are shown in Table 4. *M. javanica* was eradicated by EDB, EDB combined with 3-wk solarization with 50- or 150-μm plastic, and 6-wk solarization with 50-μm plastic treatments. *M. javanica* survived fallow and solarization with 150-μm plastic treatments.

*P. cinnamomi* was eradicated from all colonized wheat grains buried in the 6-wk solarized plots and survived in only 9% of the wheat grains buried in 3-wk solarized plots (Table 3). No significant differences between isolates or depths were found. *P. cinnamomi* survived in 45 and 15% of the wheat grains buried in fallow plots after 3 and 6 wk, respectively.

The total numbers of fungi and bacteria per cubic centimeter of soil from solarized and fallow plots did not differ significantly from each other throughout the study. Initial total numbers of pythiaceous fungi were too low to ascertain treatment effects.

**Effects of soil solarization on plant growth.** After 6 mo, total, root, and cane mass of grapevines planted at trial site 1 were numerically, but not significantly, greater in the 6-wk solarized soil than in other treatments. Cane length was significantly greatest in 6-wk solarized soil.

Tomato germination in treated soil from trial 2 was greatest in soil treated by EDB fumigation combined with solarization with 150-μm plastic for 3 wk. Growth rate and dry weight of tomatoes were greatest in soil treated by 6-wk solarization with 150-μm plastic and in EDB fumigation combined with 3-wk solarization with 50-μm plastic. Tomatoes grown in fallow soil had the slowest growth rate.

**Thermal inactivation studies.** Eggs and larvae of *M. javanica* were able to survive 4 wk of exposure to constant temperatures of 20 and 30 C but not 40 C. *M. javanica* also survived daily 2-hr temperature fluctuations between 20 and 30, 35, or 40 C and between 30 and 40 C but not fluctuations between 30 and 45 C or between 30 and 50 C.

Chlamydospores of *P. cinnamomi* were completely inactivated by exposure to 38 and 41 C for 30 min and to 44 C for 10 min (Table 5).

## DISCUSSION

Our results showed that no significant differences in thermal or biological effects resulted from the thickness of plastic used for solarization. Other workers (7,15) have reported that thinner plastic is more effective in transmitting heat energy to the soil than thicker plastic. In our trials, 150-μm plastic had the advantage of remaining intact for the duration of the experiment, whereas 50-μm plastic disintegrated in the third week of both field trials and needed to be replaced.

In general, solarization for 6 wk greatly reduced the population of plant-parasitic nematodes (sometimes to undetectable levels) immediately after treatment but did not eradicate them. Free-living nematodes were less affected by solarization than plant-parasitic nematodes. Stapleton and DeVay (19) found that nematode populations continued to decrease during the months following solarization, but we found this effect only with *P. pratensis* in trial 1. In

**Table 1.** Soil temperatures during solarization field trials in South Africa

| | | Soil temperature (C) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 50-μm Plastic | | | 150-μm Plastic | | | No plastic | | |
| Year | Depth (cm) | Max. | Av. max. | Av. min. | Max. | Av. max. | Av. min. | Max. | Av. max. | Av. min. |
| 1983/1984 | 5 | 51.87 | 46.04 | 27.16 | ... | ... | ... | 41.16 | 37.06 | 21.44 |
| | 15 | 46.09 | 40.95 | 28.85 | ... | ... | ... | 36.95 | 33.28 | 23.03 |
| | 30 | 41.15 | 37.11 | 30.01 | ... | ... | ... | 31.78 | 29.11 | 25.00 |
| 1985 | 10 | 44.00 | 38.98 | 26.44 | 47.78 | 39.88 | 25.90 | 36.44 | 32.80 | 22.19 |
| | 30 | 35.78 | 33.12 | 28.08 | 35.78 | 32.46 | 27.61 | 30.00 | 27.78 | 24.06 |

trial 2, *P. pratensis* remained undetected 2 mo after treatment in EDB at 4 and 2 ml/30 × 30 cm combined with solarization with 150-μm plastic. Other workers have shown long-term reduction of *Pratylenchus* spp. (5,19); however, poor control of *Pratylenchus* spp. by solarization has also been observed (14,19).

Natural soil populations of *M. javanica* were most effectively reduced by EDB at 6 ml/30 × 30 cm. *M. javanica* buried in cages were eradicated by EDB at 2 ml/30 × 30 cm combined with 3-wk solarization, EDB at 4 ml/30 × 30 cm and 6-wk solarization with 50-μm plastic. In laboratory experiments, *M. javanica* survived periodic exposure to 40 but not 45 C. In both field trials, average daily maximum temperatures at 10 cm and deeper never exceeded 40 C. Bird (1) reported that sublethal thermal stress to *M. javanica* eggs delays hatching by suspending development until after the stress is removed, then development proceeds. Maximum temperatures at 30 cm and deeper in solarized plots were probably not sufficient to kill *M. javanica* directly, especially since the maximum temperatures were not constant but occurred in 1- to 2-hr peaks. However, temperatures attained may have been able to cause sufficient stress to delay development.

In solarization treatments where buried *M. javanica* were eradicated,

**Table 2.** Effect of soil solarization, EDB, and fallow on nematode populations in South Africa

| Year / Nematode | Treatment | Initial nematode population per 250 cm³ soil | Nematode population per 250 cm³ soil after treatment[z] (% change from initial population) | | |
|---|---|---|---|---|---|
| | | | 1 Day | 2 Mo | 6 Mo |
| 1983/1984 | | | | | |
| Free-living | Fallow | 1,438 | 1,125 (−21.7) a | 733 (−49) a | 830 (−42.3) |
| | Solarized (3 wk) | 1,324 | 298 (−77.5) ab | 348 (−73.7) a | 745 (−43.7) |
| | Solarized (6 wk) | 2,060 | 126 (−93.8) b | 393 (−80.9) b | 835 (−59.5) |
| | EDB (6 ml) | 1,318 | 21 (−98.4) ab | 353 (−73.2) a | 726 (−44.9) |
| Total Plant-parasitic | Fallow | 735 | 922 (+25.4) a | 1,068 (+45.3) | 650 (−11.5) |
| | Solarized (3 wk) | 816 | 265 (−67.5) ab | 251 (−69.2) | 548 (−32.8) |
| | Solarized (6 wk) | 1,015 | 120 (−88.2) ab | 166 (−83.6) | 426 (−58) |
| | EDB (6 ml) | 1,446 | 12 (−99.1) b | 171 (−88.2) | 156 (−89.2) |
| *Meloidogyne javanica* | Fallow | 24 | 20 (−16.6) a | 16 (−33.3) | 70 (+191.6) |
| | Solarized (3 wk) | 22 | 1 (−95.5) a | 15 (−31.8) | 31 (+40.9) |
| | Solarized (6 wk) | 7 | 10 (+42.8) a | 6 (−14.3) | 21 (+200) |
| | EDB (6 ml) | 42 | 1 (−97.6) b | 0 (−100) | 8 (−92.2) |
| *Pratylenchus pratensis* | Fallow | 60 | 80 (+33.3) | 46 (−23.3) | 50 (−16.7) |
| | Solarized (3 wk) | 47 | 24 (−48.9) | 10 (−78.7) | 3 (−93.6) |
| | Solarized (6 wk) | 165 | 9 (−94.5) | 10 (−93.9) | 0 (−100) |
| | EDB (6 ml) | 90 | 3 (−96.7) | 3 (−96.7) | 30 (−66.7) |
| *Rotylenchus incultus* | Fallow | 563 | 764 (+35.7) a | 856 (+52) a | 211 (−62.5) a |
| | Solarized (3 wk) | 572 | 204 (−64.3) a | 113 (−80.2) a | 200 (−65) a |
| | Solarized (6 wk) | 642 | 70 (−89.1) a | 21 (−96.7) a | 75 (−88.3) a |
| | EDB (6 ml) | 1,120 | 3 (−99.7) b | 13 (−98.8) b | 16 (−98.5) b |
| *Criconemella xenoplax* | Fallow | 39 | 15 (−61.5) | 5 (−87.2) | 251 (+543.5) a |
| | Solarized (3 wk) | 100 | 11 (−89) | 6 (−94) | 150 (+50) ab |
| | Solarized (6 wk) | 110 | 25 (−77.2) | 1 (−99.1) | 183 (+66.3) ab |
| | EDB (6 ml) | 75 | 0 (−100) | 1 (−98.6) | 0 (−100) b |
| *Paratrichodorus minor* + *P. lobatus* | Fallow | 50 | 80 (+60) a | 143 (+186) | 61 (+22) |
| | Solarized (3 wk) | 74 | 22 (−70.3) ab | 106 (+43.2) | 163 (+120.2) |
| | Solarized (6 wk) | 86 | 4 (−95.3) bc | 126 (+46.5) | 146 (+69.7) |
| | EDB (6 ml) | 116 | 3 (−97.4) c | 151 (+30.2) | 101 (−12.9) |
| 1985 | | | | | |
| Free-living | Fallow | 878 | 608 (−30.7) a | 495 (−43.6) a | ... |
| | EDB (4 ml) | 668 | 33 (−95) abc | 216 (−67.6) ab | ... |
| | Solarized (150 μm) | 710 | 193 (−72.8) ab | 253 (−64.3) a | ... |
| | Solarized (50 μm) | 865 | 191 (−77.9) ab | 266 (−69.2) a | ... |
| | EDB (2 ml) + 150 μm | 665 | 10 (−98.5) bc | 75 (−88.7) ab | ... |
| | EDB (2 ml) + 50 μm | 1,301 | 11 (−99.2) c | 66 (−94.9) b | ... |
| Total plant-parasitic | Fallow | 53 | 35 (−33.9) a | 87 (+64.1) | ... |
| | EDB (4 ml) | 21 | 3 (−85.7) a | 6 (−71.4) | ... |
| | Solarized (150 μm) | 90 | 25 (−72.2) a | 15 (−83.3) | ... |
| | Solarized (50 μm) | 73 | 16 (−78.1) a | 38 (−47.9) | ... |
| | EDB (2 ml) + 150 μm | 76 | 0 (−100) b | 16 (−78.9) | ... |
| | EDB (2 ml) + 50 μm | 50 | 0 (−100) b | 15 (−70) | ... |
| *Pratylenchus pratensis* | Fallow | 8 | 0 (−100) | 11 (+37.5) a | ... |
| | EDB (4 ml) | 1 | 3 (+200) | 0 (−100) a | ... |
| | Solarized (150 μm) | 8 | 5 (−37.5) | 6 (−25) a | ... |
| | Solarized (50 μm) | 11 | 0 (−100) | 3 (−72.7) a | ... |
| | EDB (2 ml) + 150 μm | 11 | 0 (−100) | 0 (−100) b | ... |
| | EDB (2 ml) + 50 μm | 6 | 0 (−100) | 1 (−83.3) b | ... |
| *Paratrichodorus minor* | Fallow | 45 | 33 (−26.6) a | 33 (−26.6) | ... |
| | EDB (4 ml) | 15 | 0 (−100) a | 6 (−60) | ... |
| | Solarized (150 μm) | 80 | 13 (−83.7) ab | 11 (−86.3) | ... |
| | Solarized (50 μm) | 60 | 11 (−81.6) a | 35 (−41.6) | ... |
| | EDB (2 ml) + 150 μm | 33 | 0 (−100) a | 16 (−51.5) | ... |
| | EDB (2 ml) + 50 μm | 41 | 0 (−100) b | 15 (−63.4) | ... |

[z] Values followed by different letters are different ($P \leq 0.05$) according to Tukey's test for significant difference.

factors such as enhanced susceptibility of the stressed nematodes to antagonism may have played a role. In natural soil, nematodes surviving deeper in the soil may have recolonized the area through weed and host roots after the plastic was removed. Where natural soil populations of *M. javanica* increased after solarization, heat-intolerant antagonists may have declined, leading to the eventual increase of *M. javanica*. Mihail and Alcorn (11) hypothesized this effect when *Macrophomina phaseolina* increased in solarized soil.

In most instances, nematode population levels did not increase to greater than original levels after solarization; however, the combined population of *P. minor* plus *P. lobatus* and *C. xenoplax* increased in the months following all treatments except EDB at 6 ml/30 × 30 cm. Stapleton and DeVay (19) reported similar effects with *Paratylenchus* sp.

The marked reduction and elimination of *P. cinnamomi* from buried wheat grains by 3- and 6-wk solarization is probably due to the direct effect of increased soil temperatures on the fungus. *P. cinnamomi* does not survive well at 35 C or higher (23). Soil temperatures reached at least 35 C in all solarization treatments (Table 1). The fungus was previously shown to be rapidly inactivated in infested wheat grains at 40 C (21). Our study shows that chlamydospores are inactivated by short exposures to 38 C and higher. Temperatures and exposure times in solarized plots were therefore sufficient to account for elimination of *P. cinnamomi*. However, fallow alone considerably reduced survival, especially in trial 1, where soil moisture levels were low. These data suggest that factors other than thermal inactivation may also be involved.

In these trials, fungi and nematodes were probably not limiting factors to plant growth; however, grapevine and tomato growth were enhanced by solarization. This supports other work where enhanced growth was found after solarization even in the absence of known plant pathogens (3) and where pathogens were not a growth-limiting factor (7,19).

Our results indicate that soil solarization has potential for use as a method of soil disinfestation in this region. Further investigations are needed to determine conditions and in which crop solarization is effective and practical. Populations of some plant-parasitic nematodes were greatly reduced, and *P. cinnamomi* was eradicated after solarization for 6 wk. Results obtained with some nematodes was poor or inconsistent, but where solarization was combined with a reduced rate of nematicide, control was effective. Fumigation plus solarization could be used as a method of soil disinfestation where nematodes are an economic problem and if a cost/benefit analysis justifies its use.

In the nursery industry, there is a zero tolerance for *Meloidogyne* spp. and *Pratylenchus* spp.; therefore, solarization cannot be recommended as a method of soil disinfestation where these two genera occur. However, solarization may be useful where *P. cinnamomi* occurs and nematodes are not an economic problem, where early plant growth in shallow-rooted annual crops would benefit by a temporary reduction of nematode and pathogen levels, or where the use of pesticides is not desirable.

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**Table 3.** Survival of *Phytophthora cinnamomi* on infested wheat grains buried in solarized and fallow plots

| Treatment | Percent survival[a] | |
|---|---|---|
| | Trial 1 | Trial 2 |
| 3-wk Fallow | 14 | 45 |
| 6-wk Fallow | 1 | 15 |
| 3-wk Solarization (50 μm) | 0 | 11 |
| 6-wk Solarization (50 μm) | 0 | 0 |
| 3-wk Solarization (150 μm) | – | 7 |
| 6-wk Solarization (150 μm) | – | 0 |

[a] Of 180 infested wheat grains per treatment in trial 1 and of 120 infested wheat grains per treatment in trial 2.

**Table 4.** Percent infection and average gall index of indicator plants grown in soil from *Meloidogyne javanica*-inoculated cages buried in field trial 2 and removed 3 or 6 wk after initiation of treatment

| Treatment | Plants infected (%)[a] | | Av. gall index[b] | |
|---|---|---|---|---|
| | 3 wk | 6 wk | 3 wk | 6 wk |
| Fallow | 100 | 80 | 2.8 | 2.2 |
| EDB (4 ml) | 0 | 0 | 0.0 | 0.0 |
| Solarized (150 μm) | 100 | 33 | 3.8 | 0.3 |
| Solarized (50 μm) | 83 | 0 | 1.6 | 0.0 |
| EDB (2 ml) + 150 μm | 0 | 0 | 0.0 | 0.0 |
| EDB (2 ml) + 50 μm | 0 | 0 | 0.0 | 0.0 |

[a] Six plants per treatment.
[b] Six plants per treatment. Gall index: 0 = no galls or egg masses, 1 = 1–2 egg masses, 2 = 3–10 egg masses, 3 = 11–25 egg masses, 4 = 26–50 egg masses, and 5 = more than 50 egg masses.

**Table 5.** Exposure times required to inactivate axenically produced chlamydospores of two isolates (C113 and C141) of *Phytophthora cinnamomi* at 38, 41, and 44 C

| Treatment Culture | No. colony-forming chlamydospores per cubic decimeter[a] (exposure time [min]) | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 5 | 10 | 15 | 20 | 30 |
| Control[b] | | | | | | |
| C113 | 11.5 | ... | ... | ... | ... | ... |
| C141 | 6.5 | ... | ... | ... | ... | ... |
| 38 C | | | | | | |
| C113 | ... | 12.0 | 7.3 | 2.3 | 1.8 | 0.0 |
| C141 | ... | 6.3 | 4.0 | 2.0 | 1.5 | 0.0 |
| 41 C | | | | | | |
| C113 | ... | 5.5 | 2.0 | 1.5 | 1.0 | 0.0 |
| C141 | ... | 5.8 | 2.8 | 1.8 | 1.0 | 0.0 |
| 44 C | | | | | | |
| C113 | ... | 2.8 | 1.5 | 0.0 | 0.0 | 0.0 |
| C141 | ... | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 |

[a] Average of four replicates.
[b] Counted immediately after plating at room temperature.

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