Soil Solarization in Established Avocado Trees for Control of *Dematophora necatrix*

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ABSTRACT

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Four field experiments on the control of *Dematophora necatrix* in avocado orchards affected by white root rot were conducted in the Mediterranean coastal area of southern Spain during 1991 to 1994. In the unshaded locations of solarized plots, the maximal temperatures were 35 to 42°C, depending upon the year and soil depth (15 to 60 cm). Temperature increases attributable to soil solarization ranged between 4 and 8°C in unshaded areas, whereas for shaded areas they were approximately 4°C. Inoculum recovery was decreased in root samples buried at 15 to 30 cm in unshaded locations of both solarized and unsolarized plots after 3 to 5 weeks, whereas 4 to 8 weeks of solarization were required for the elimination of the pathogen buried at depths of 45 to 60 cm. In contrast, inoculum recovery ranged from 30 to 60% for samples in shaded locations of unsolarized plots. *D. necatrix* was not recovered from roots of infected trees in solarized plots sampled 9 months after solarization, whereas recovery from roots in unsolarized plots was similar to levels before solarization. Soil solarization in established orchards was successful in reducing viability of inoculum buried in soil and eliminated inoculum in infected roots of live trees.

Additional keywords: *Persea americana*, soilborne pathogen, thermal inactivation

Rosellinia necatrix Prill. (anamorph: *Dematophora necatrix* Hartig), the causal agent of white root rot in avocado and many other crops, has a very wide host range (i.e., 170 plant species or varieties in 63 genera and 30 families of dicotyledonous angiosperms) (9). This fungal pathogen is destructive to many fruit tree crops (2,8,20), including tropical and subtropical species such as avocado (*Persea americana* Mill.) and mango (*Mangifera indica* L.), which are particularly susceptible (9,18,20,24).

Disease development in infected trees is usually rapid, killing trees within a few weeks of the first foliar symptoms. Significant losses of avocado trees in 15- to 20-year-old orchards in the coastal area of southern Spain have been observed since the first report of the disease in 1986 (11). The pathogen is capable of surviving many years on residue of crops susceptible to *D. necatrix*, such as olive (*Olea europaea* L.), grapevine (*Vitis vinifera* L.), and almond (*Prunus amygdalis* Batsch.), which were common in the region prior to the introduction of avocado. The high susceptibility of Topa-Topa (14), the rootstock most frequently used in avocado orchards in the area, may have favored the disease increase.

Systemic fungicides, such as the benzimidazoles, phosphorous acid, and PCNB, were effective against the pathogen in tests in vitro and when used as soil drenches on apple (3,5,16,17,22) and avocado plants (12,13). Soil fumigants have also been effective in eradicating the pathogen from fallow soil (10,21).

Soil solarization has been successfully used to control soilborne fungal pathogens such as *R. necatrix* in apple and *Verticillium dahliae* in established pistachio, avocado, almond, and olive orchards (1,4,6,7,15,19,23).

Thermal sensitivity of different inoculum types of *D. necatrix* has been studied (9), and the use of soil solarization to eradicate this pathogen in infested bare soil has been effective when avocado seedlings were planted in solarized soil (19). However, reduction of the pathogen in established avocado orchards has not been studied. Therefore, the aim of this work was to determine the effect of soil solarization on the viability of *D. necatrix* in established avocado orchards on the southern coast of Spain.

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MATERIALS AND METHODS

Four field experiments (I to IV) were conducted in four avocado orchards (A to D) affected by white root rot. The experiments in orchards A and B were established in 1991 and those in orchards C and D in 1993 and 1994, respectively.

Experiment I. Orchard A consisted of 10-year-old trees (at 4 × 4 m spacing) with a canopy diameter of approximately 3 m. They were cv. Fuerte grafted to Topa-Topa seedling rootstock established in a sandy loam soil (pH = 7.3, organic matter 0.9%). The two treatments, i.e., solarized and unsolarized, had four completely randomized plots, each of 12 × 7 m. Soil was rototilled (15 cm) and irrigated to field capacity in the upper 60-cm layer. One nylon net containing five pieces of freshly cut avocado roots (5 cm long, 0.5 to 1 cm thick) naturally infected by *D. necatrix* was buried at 30-cm depth in the soil at each of two locations (shaded and unshaded) in each of the plots at least 1.5 m from the tarp edge. Simultaneously with root sample burial, thermistors were placed in one plot per treatment at 30-cm depth. For shaded locations, root samples and thermistors were buried close to tree trunks and to the north, whereas unshaded locations were equidistant from two contiguous rows of trees. Thermistors were connected to a data logger to record hourly temperatures calculated as the average of temperatures every 5 min. After placement of samples and thermistors, the area between tree rows was tarped from the trunk base with 3.5-m-wide, 75-µm-thick transparent polyethylene. Soil solarization was conducted for 5 weeks starting 25 July 1991, and maximum daily air temperature was obtained from the nearest (1 km) meteorological station. At the end of solarization, root samples were removed from the soil, surface-disinfested by dipping in 1% aqueous NaClO solution for 3 min, and plated onto potato dextrose agar (PDA) acidified with 10 ml of a 25% (vol/vol) aqueous lactic acid per liter. Viability of the mycelium of *D. necatrix* in these samples was assessed after 3 days of incubation at 24°C in the dark, and percent root segments yielding *D. necatrix* was determined.

Experiment II. Orchard B consisted of 20-year-old trees (8 × 4 m spacing) in a sandy soil (pH = 7.6, organic matter 0.7%) with a canopy diameter of approximately 6

m of cv. Hass grafted to Topa-Topa seedling rootstock, had three completely randomized replicated plots, each of 10 × 5 m. After angular transformation of the percent recovery of *D. necatrix* on PDA, analysis of variance was conducted to determine significant differences among treatments. Similarly, soil preparation and soil temperature recording were performed as in experiment I, except that root samples and thermistors were placed at 20-cm depth. Solarization was conducted from 25 July to 19 August 1991.

Experiment III. Orchard C consisted of 18-year-old trees of cv. Hass (8 × 4 m spacing) with a canopy diameter of approximately 6 m, grafted to Topa-Topa seedling rootstock established in a sandy loam soil (pH = 7.8, organic matter 1.1%). Three plots, each 8 × 8 m, including one tree affected by white rot and one contiguous asymptomatic tree, were established as previously described. Procedures were as in experiments I and II, but a double set of infected root samples (10 root segments, 5 cm long, 0.5 cm thick, per set) was buried for each treatment and location at depths of 15, 30, and 45 cm to allow sampling at 4 and 8 weeks after tarping. Assessments of the viability of *D. necatrix* on root samples were evaluated as in 1991. Analysis of variance was performed with angular-transformed data on inoculum recovery, using a split-split-plot design, with the soil treatment being the main plots.

Prior to tarping, trees were laterally pruned in the preceding spring to achieve a higher proportion of solar-radiated soil surface. After having been tarped with 75-µm-thick polyethylene, soil was irrigated every 5 days with microsprinklers located underneath the plastic. Soil solarization lasted for 8 weeks starting in mid-July 1993.

Trees in solarized and nonsolarized plots in orchard C were sampled for root infection upon the initiation and the end of the solarization period, and yearly until February 1997. Ten segments from 1- to 3-cm-thick roots sampled at 15- to 30-cm soil depth of infected trees were plated, after surface disinfestation, onto acidified PDA and incubated at 24°C for 2 to 3 days or incubated for 7 days at 22 to 24°C in moist chambers. Thereafter, mycelial growth of *D. necatrix* was evaluated under a microscope.

Experiment IV. Trees in orchard D, soil characteristics, experimental design, and procedures were as in experiment III, but trees were not pruned. Similarly, there was one plot per treatment (solarized and unsolarized), each of 500 m^2 containing seven infected trees. Soil temperature was continuously recorded at 15-, 30-, 45-, and 60-cm depth, but there was no record at 15 cm in solarized unshaded plots. Maximum daily air temperature was obtained from the farm meteorological station. In each plot, three subplots were used for each

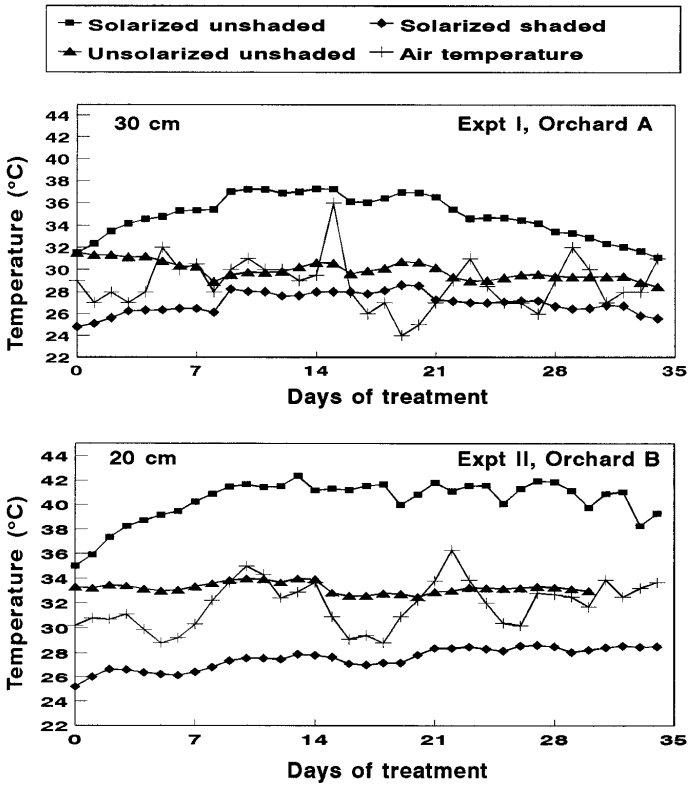

Fig. 1. Maximum air temperatures, and soil temperatures at 30 cm (orchard A, experiment I) and at 20 cm (orchard B, experiment II) soil depth in different treatments and locations (unshaded, shaded) during the solarization period 25 July to 29 August 1991.

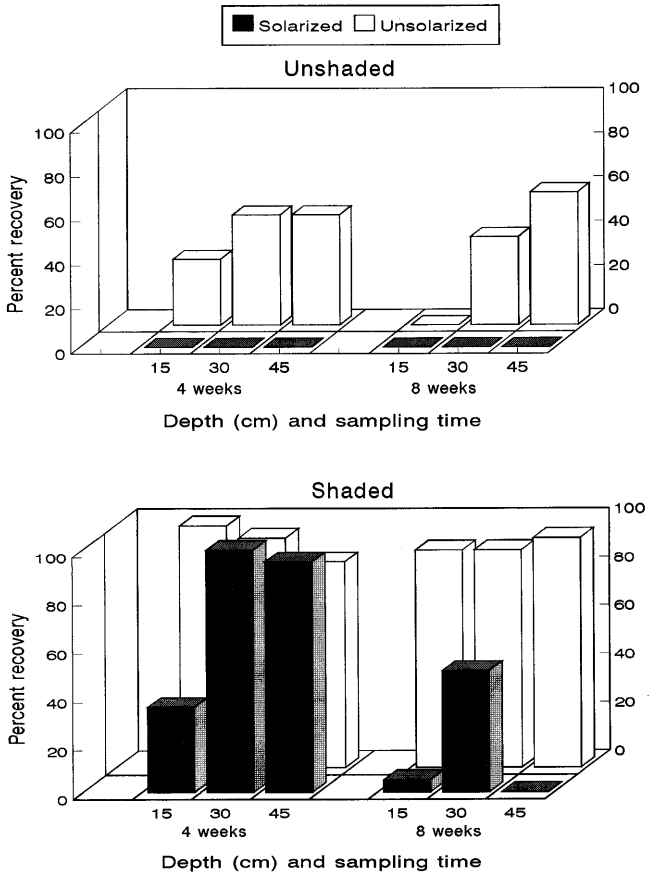

Fig. 2. Percent recovery of *Dematophora necatrix* after 4 and 8 weeks of solarization in unshaded and shaded locations at different soil depths (orchard C, experiment III, 14 July to 19 September 1993).

location and depth, and two sets of infected root samples similar to those of experiment III were buried for sampling at 3 and 8 weeks after tarping. Solarization started in mid-July 1994 after irrigating to field capacity. In contrast with the previous experiment, there was no additional irrigation during the solarization period, which lasted for 8 weeks. After angular transformation of percent recovery of *D. necatrix* from buried root samples, analysis of variance was performed using a split-split-plot design. Assessments of root infection in trees were conducted as in experiment III, but samplings were performed only until 9 months after solarization.

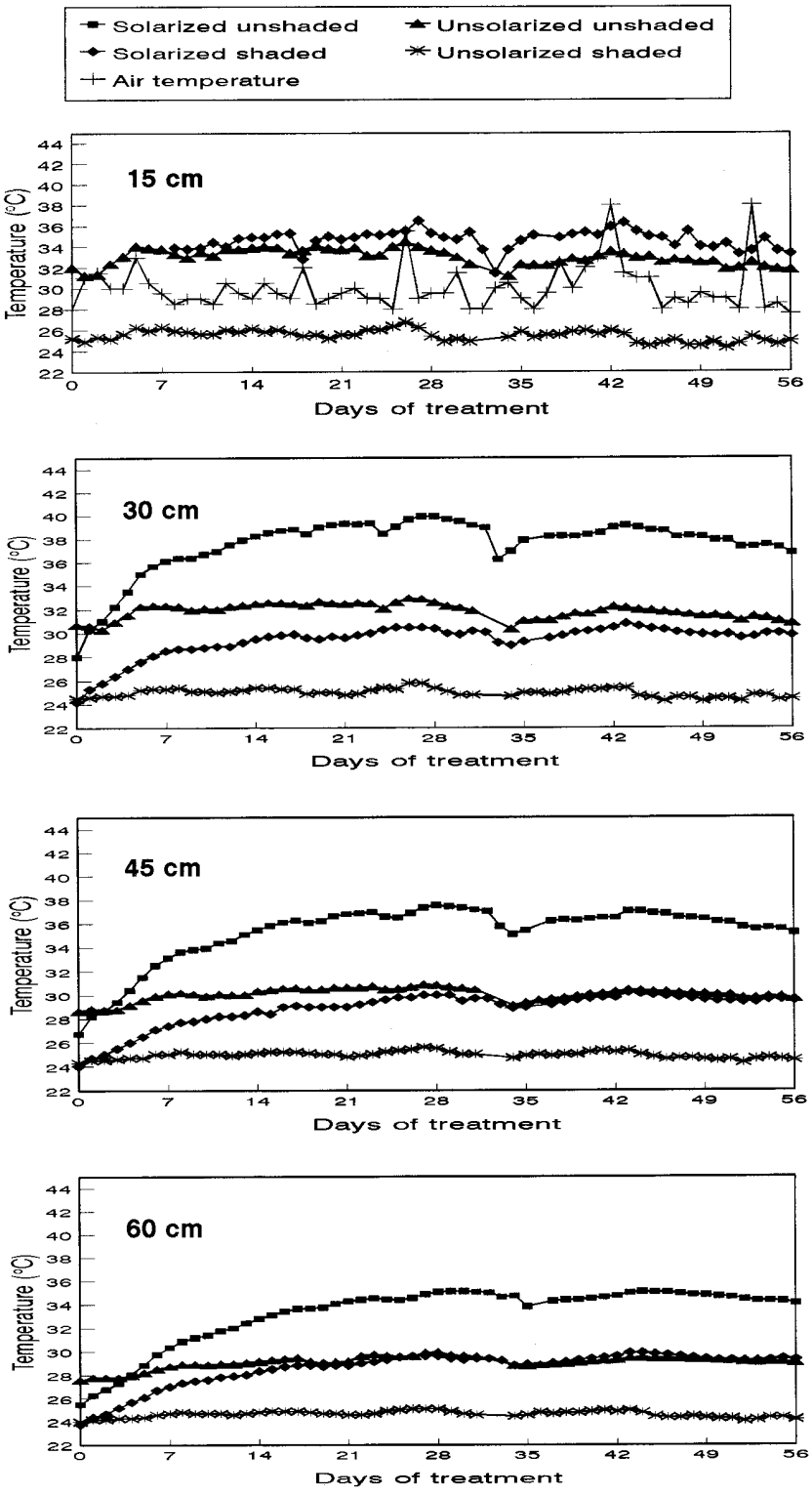

Fig. 3. Maximum air temperature, and soil temperature in different locations (unshaded, shaded) and depths (15 to 60 cm) during the solarization period 13 July to 14 September 1994 (orchard D, experiment IV).

RESULTS

Experiments I and II. The maximum temperature in unshaded areas of solarized plots reached 37.3°C at 30 cm (orchard A, Fig. 1A) and 42.3°C at 20 cm (orchard B, Fig. 1B) during the solarization period. The increases when compared with unsolarized plots were 5.8 and 8.3°C, respectively. Maximum temperatures in shaded areas of solarized plots were 28.6°C for the two depths considered. Maximum daily air temperature ranged from 24 to 36°C for the locations of orchards A and B (Fig. 1).

After 5 weeks, viability of *D. necatrix* in infected root segments buried at 30- and 20-cm depth (orchards A and B, respectively) was nil in unshaded locations of both solarized and unsolarized plots. With regard to shaded locations, a large reduction in the recovery of *D. necatrix* was noticed in orchard A when unsolarized and solarized plots were compared (90 and 18% recovery, respectively). Likewise, the recovery of the pathogen in orchard B was 68% from root segments buried in unsolarized plots, which contrasts ($P = 0.0001$) with the complete elimination of inoculum observed in solarized plots.

Experiment III. Viability of *D. necatrix* from infected root segments was zero at all soil depths 4 weeks after solarization in unshaded areas and at 15 cm in unshaded areas of the unsolarized plots after 8 weeks. The high variability in inoculum viability showed significant differences ($P = 0.0004$ and $P = 0.0121$ for 4 and 8 weeks of solarization, respectively) only between shaded and unshaded areas regardless of the treatment and depth of sampling (Fig. 2).

The pathogen was recovered from diseased root samples taken from the trees before initiation of the experiment, with an average of 85 and 70% for solarized and unsolarized plots, respectively. After removal of the tarp in September 1993, viability of *D. necatrix* in roots sampled from trees in solarized plots was zero, while viability was unaffected in the unsolarized plots. Examinations of roots 3 years after tarping resulted in remission of white root rot symptoms and lack of recovery of *D. necatrix*, whereas symptomatic trees in unsolarized plots died 2 months after tarp removal.

Experiment IV. Average maximum temperatures during the solarization period in the unshaded solarized areas ranged from 37.4°C (at 30-cm depth) to 33.2°C (at 60-cm depth); whereas in shaded solarized areas, temperatures were 29.4 and 28.6°C, respectively (Fig. 3). Depending on soil depth, temperature increases attributable to soil solarization were 5.7 to 4.0°C in unshaded areas and 4.5 to 4.0°C in shaded areas. Maximum daily air temperatures ranged from 28 to 38°C (Fig. 3).

After 3 weeks of solarization, a significant (P = 0.030) reduction of mycelium viability from root segments infected by *D. necatrix* was observed regardless of soil depth. Significant differences (P < 0.001) between shaded and unshaded locations were also found. The interaction (P < 0.005) between treatment and location indicated a higher reduction of mycelium viability due to solarization in the shaded than in the unshaded areas of the solarized plots. The pathogen was killed from all root samples solarized for 8 weeks and from most depths of the unshaded areas of unsolarized plots (Fig. 4).

Recovery of *D. necatrix* from infected roots sampled from diseased trees in orchard D prior to solarization was 90% in unsolarized plots and 40% in solarized plots. After 9 months, in the unsolarized plots, the level of fungal viability remained similar, whereas *D. necatrix* was completely killed in the solarized plots.

DISCUSSION

In established orchards of avocado in southern Spain, increases of 4 to 8.3°C were obtained in solarization plots, depending on soil depth and year, and as expected, temperatures decreased as soil depth increased. Maximum temperature in unshaded locations of unsolarized plots was higher than in shaded locations of solarized plots except at the 15-cm depth (Figs. 1 and 3). This is the result of the high degree of shading provided by unpruned large avocado trees. Based on a previous report (19), the temperature reached in solarized plots was high enough to kill the pathogen from avocado roots.

Variation in the effectiveness of soil solarization was evident from 1991 to 1994. Solarization for 4 weeks of 1993 in shaded locations partially reduced the viability of *D. necatrix* buried at 15 cm (Fig. 2), whereas viability was zero in samples buried at 20-cm depth in similar locations when solarization lasted for 5 weeks (orchard B, 1991), and even at 30-cm depth in the shaded areas of plots solarized for only 3 weeks in 1994 (Fig. 4). Solarization for 8 weeks in 1993 significantly reduced inoculum to a depth of 45 cm in shaded locations (Fig. 2), whereas 8 weeks of solarization in 1994 eliminated inoculum up to 60-cm depth in the shaded locations (Fig. 4). In contrast, only a partial reduction of inoculum viability after 8 weeks of solarization was observed in the shaded locations of an apple orchard in Israel (19). The unusually mild temperatures during the summer of 1993 (average maximum daily temperatures of 28.4°C) in contrast to 1994 (29.9°C) could account for the differences in effectiveness of solarization between these 2 years, emphasizing the need for solarization to be conducted during optimal periods. Irrigation underneath the polyethylene film during solarization in 1993 was used to favor normal tree development during solarization, so that high soil temperature would not impair tree growth and yield. Irrigation should therefore not be recommended unless extremely high temperatures are anticipated and solarization is expected to continue over 2 months.

D. necatrix can be found throughout the soil wherever 1- to 3-cm-thick roots are present. In order to control avocado white root rot, solarization must be effective at the deeper soil layers. Evaluations of the pathogen viability from roots in 1993 and 1994 showed it to have been completely killed at a depth of 10 to 15 cm after 8 weeks of solarization. It is recommended that large areas around affected trees be solarized in order to prevent the infection of roots of surrounding trees. Once symptoms develop, little chance for tree recovery can be expected.

In this work, the effectiveness of solarization to control white root rot in established avocado orchards has been demonstrated and eradication of *D. necatrix* by this method can be achieved down to 60-cm depth. Sequential sampling of infected roots from solarized plots indicates that soil remains pathogen-free for at least 3 years after solarization. This suggests a very slow spread of the pathogen from deep soil layers where solarization is ineffective, to the upper layers where the pathogen had been eradicated. Thus, and in concordance with the previous results obtained in apple orchards (4), solarization would seem to have a long-term effect on this pathosystem.

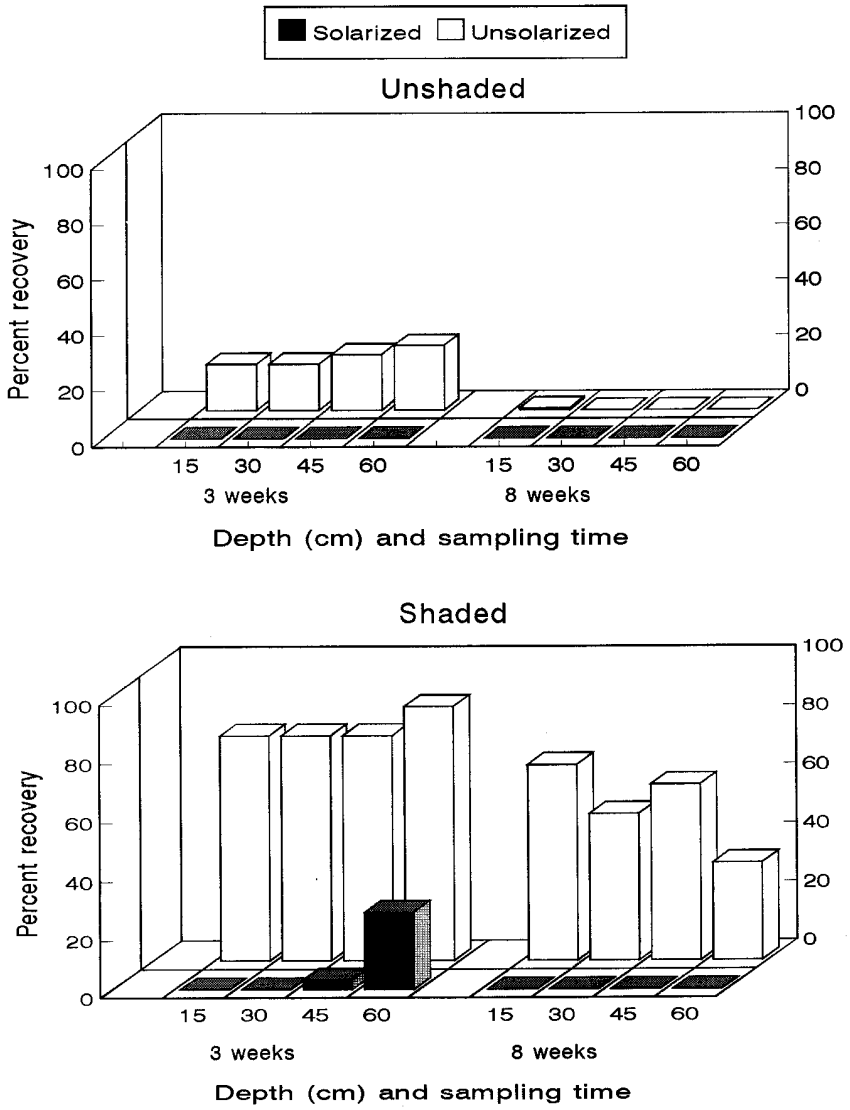

Fig. 4. Percent recovery of *Dematophora necatrix* after 3 and 8 weeks of solarization in unshaded and shaded locations at different soil depths (orchard D, experiment IV, 13 July to 14 September 1994).

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