

Soil Solarization for the Control of Verticillium Wilt of Greenhouse Tomato

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Verticillium dahliae, the causal agent of Verticillium wilt of tomato, causes serious damage to crops grown in unheated greenhouses. To control this disease, growers are obliged to employ strong soil disinfectants. The possibility of controlling *V. dahliae* by using soil solarization during the months of June – August was examined. The soil was covered with transparent polyethylene sheets for 10 weeks. The pathogen could not be isolated from the solarized soil, whereas the inoculum level in the nonsolarized soil remained high (1379–1806 propagules/g soil). The yield from the solarized soil was increased by 112.4% in comparison with the control, and no infected plants were observed. The percentage of infected roots was very low (0.3–0.4%) in relation to the nonsolarized soil (66.7–67.1%). From these results it was concluded that solarization can effectively control Verticillium wilt of greenhouse-grown tomato under the summer conditions in Crete.

KEY WORDS: Soil solarization; *Verticillium dahliae*; tomato.

INTRODUCTION

Three species of *Verticillium*, *V. dahliae* Kleb., *V. albo-atrum* Reinke & Berthold and *V. tricorpus* Isaac, have been found responsible for Verticillium wilt of tomato (7). The disease has caused serious damage to greenhouse tomato crops in Greece in recent years (12). This may be attributed to tolerance which has developed in *V. dahliae* to the commonly used soil disinfectant methyl bromide in the greenhouses (5), as well as to the breakdown of resistance in many hybrids under high inoculum pressure of the pathogen or the establishment of some nematodes which facilitate the infection of these hybrids by the pathogen (1).

Soil solarization with the aid of transparent polyethylene (PE) sheets has been used by many workers for the control of *V. dahliae* on tomato (2,6,9,12). In the present research, the effect of soil solarization of greenhouse tomato for the control of *V. dahliae* was studied.

MATERIALS AND METHODS

Trials were conducted in a plastic house covered with a PE film (Plastica of Crete S.A., Heraklio, Crete), which is changed every 3 years. The soil was a sandy clay which was heavily infested with *V. dahliae* and had been planted with a susceptible tomato variety (cv. 'Early Pack 7') in previous years.

Soil solarization was carried out during the summer months of 1993 and 1994 in the same plastic house and in different experimental plots each year, and lasted for 10 weeks

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(June–August). Transparent PE sheets (Plastica of Crete S.A., Heraklio, Crete), 0.05 mm thick, were used to cover the soil, which first was plowed, leveled and irrigated to field capacity. The plastic covering was buried along the edges in a 20-cm-deep furrow. The irrigation pipes remained under the PE sheets to enable irrigation every 20 days. The temperatures which developed in the solarized and nonsolarized soils were measured with the aid of soil thermographs (SIAP s.p.a., Bologna, Italy). The plastic house remained closed during the weeks of soil solarization.

Tomato plants with three true leaves were transplanted one month after the removal of the PE sheets (September), in both years of the trial. Tomato cv. 'Early Pack 7' was used. The seeds were obtained from FMC Corporation, California, USA. The planting distances were 0.8 m along the rows and 1 m between rows. Each experimental plot was 5×5 m and included 30 plants. The greenhouse experiments were laid out in a randomized block design consisting of 16 replications of both solarized and nonsolarized treatments.

The effect of solarization on populations of the pathogen in the soil was determined by soil assays carried out before and soon after the lifting of the PE sheets. For this purpose, five 1-kg soil samples from the 0–40-cm-depth were taken from each experimental plot with a soil auger. These five samples were mixed aseptically and a representative sample of every experimental plot was taken for analysis. Until the analyses were conducted, the samples were passed through a 5-mm sieve and kept at 15% relative humidity and a temperature of 7°C (4).

Quantitative estimation of the presence of the pathogen in the soil was made with a dilution–suspension technique and expressed in propagules/g of the tested soil. Dilutions 10^{-2} , 10^{-3} , 10^{-4} and 10^{-5} were made from 1 g of each representative soil sample diluted in 100 ml of distilled and sterilized water. Ten 9-cm-diameter petri dishes were used for each dilution, with 16 replications. One ml of dilution was placed in each petri dish containing 15 g of solidified culture medium. The counting of the colonies was based on the 10^{-3} dilution, which had *ca* 15–50 colonies per petri dish. The culture medium contained (per liter): 200 g of potatoes, 15 g of sucrose, 20 g of agar and 100 mg of tetracycline (8). Incubation lasted 2 weeks, at 23°C.

To estimate the disease severity, foliar and stem symptoms, percent of infected roots, and tomato yield of all the plants in each experimental plot, were determined. In particular, foliar symptoms were evaluated considering marginal and interveinal chlorosis on lower leaflets, leaflets with V-shaped lesions, unilateral leaflet wilting and general wilting. The estimation of stem symptoms was based on the vascular discoloration after longitudinal cut of the stem.

The extent of root colonization was determined using 20 1-cm-pieces of root chosen at random from the root system of the plants of each experimental plot. Ten of these pieces were placed, after superficial disinfection with 0.5% (v/v) NaOCl and thorough washing with sterile water, in petri dishes which contained the above-described solidified culture medium. After 3 weeks' incubation at 23°C, the percentage of root pieces in which the pathogen had developed, was calculated.

The fruit yield per plant in each experimental plot was weighed every 10 days. Data were analyzed statistically using Duncan's Multiple Range Test ($P=0.05$).

RESULTS

The mean maximal daily temperature in the solarized soil fluctuated from 43.5–44.2°C at the 40-cm depth to 57.5–58.3°C at the 10-cm depth. By comparison, temperatures ranged from 36.7 to 37.4°C at 40 cm, and from 48.0 to 49.1°C at 10 cm in the nonsolarized soil (Table 1).

TABLE 1. Variations in the mean maximal daily soil temperature (°C) during solarization

Soil treatment	Depth (cm)							
	10		20		30		40	
	1993	1994	1993	1994	1993	1994	1993	1994
None	49.1	48.0	40.9	41.6	38.1	37.7	36.7	37.4
Solarization	58.3	57.5	52.8	53.5	47.5	47.1	43.5	44.2

Ten weeks after covering the soil with PE, the pathogen could not be isolated to a depth of 40 cm in the solarized soil. A quantitative increase of up to 30.3% in the nonsolarized soil, was observed (Table 2). The percentage of plants expressing foliar and stem symptoms of the disease was zero in the solarized soil vs 56.3% in the nonsolarized soil (Table 2). The root systems of plants in solarized soil had a low level of infection (0.3–0.4%), whereas in the nonsolarized soil the level of infection was 66.7–67.1% (Table 2). Yields showed a significant increase (112.4%) associated with control of *Verticillium* wilt in solarized soil (Table 2).

TABLE 2. Effect of soil solarization on *Verticillium dahliae* inoculum density, foliar and stem wilt symptoms, root colonization and fruit yield of tomato plants (*Lycopersicon esculentum* cv. Early Pack 7)

Treatment	Year	Propagules/g soil × 10		Foliar and stem symptoms (% of plants)	Infected roots (%)	Yield (kg/plant)
		Before solarization, June	After solarization, August			
None	1993	137.9 a*	179.7 a	55.8 a	67.1 a	2.850 a
Solarization	1993	138.9 a	0.0 b	0.0 b	0.4 b	7.125 b
None	1994	138.7 a	180.6 a	56.3 a	66.7 a	3.126 a
Solarization	1994	139.3 a	0.0 b	0.0 b	0.3 b	7.569 b

*Within years and within columns, numbers followed by the same letter do not differ significantly ($P=0.05$).

DISCUSSION

Under our experimental conditions, elevated temperatures were detrimental to the survival of the pathogen. Populations of *V. dahliae* were greatly reduced by solarization. No infected plants were observed following solarization, and yields were significantly increased in relation to the control. Pathogen control extended to a depth of 40 cm, which

is greater than that achieved using chemical disinfestation with broad-spectrum biocides (5,10).

If we take into consideration: (a) the relatively low application cost of soil solarization (13), (b) the 'soil tiredness' caused by a lack of crop rotation, and by continual use of broad-spectrum soil disinfestants and fertilizers (3), (c) the control by solarization of other soilborne diseases and weeds, and (d) the increased growth response, soil fertility, and crop production and quality (11), we conclude that solarization, at least in locations with extended periods of solar radiation and high light intensity, can play a useful role in crop protection programmes for the control of *Verticillium* wilt, as well as other soilborne diseases, at low cost and without causing imbalances to the soil ecosystem.

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