J. Turk. Phytopath., Vol. 41 No. 1-3, 27-35, 2012 ISSN 0378 - 8024

Control of Verticillium Wilt of Olive by Soil Solarization in Aegean Region

Lalehan YOLAGELDI* Cahit TUNC Ersin ONOGUR***

* Department of Plant Protection, Faculty of Agriculture, University of Ege, 35100 Bornova Izmir -Turkey
** Olive and Olive Oil Agricultural Sales Cooperatives Union, 35620, Çiğli Izmir -Turkey
lalehan.yolageldi@ege.edu.tr

Accepted for publication October 10, 2013

ABSTRACT

A soil solarization experiment was carried out in a seven years old commercial olive orchard naturally infected with *Verticillium dahliae* in western Anatolia. Solarization was applied to individual trees for either one or two successive years. The maximum temperature was recorded in solarized soil were 42.9 and 44.4 ºC in the first and second year's application respectively. Solarization slightly reduced the mean severity of wilting in both years without a statistical significance between treated and control trees. In one-year solarization, the percentage of recovery exceeded the natural recovery in control trees while double-solarization couldn't supply a significant additive effect in improving the health of olive trees.

Keywords: *Verticillium dahliae, Olea europaea,* solarization

INTRODUCTION

Verticillium wilt, caused by *Verticillium dahliae* Kleb. has become the main phytopathological problem threatening olive trees in western Anatolia. The disease was first observed in this region of Turkey in 1970 (Saydam and Copçu, 1972) and then became prominent, especially in young, well-tended groves in the last decade. During a two-year survey conducted in western Anatolia, the disease prevalence was found as 49 % and 60 % in 1998 and 1999, respectively. Also, the incidence was 0.8 % in 1998 and 1.0 % in 1999 in the olive groves where disease symptoms were observed. Furthermore, Verticillium wilt was determined to be most prevalent (84 %) in young olive groves established by grafted nursery trees (Yolageldi et al., 2003).

Verticillium wilt of olive is a hardly controlled disease. Since fungicides are unable to control the pathogen successfully or protect the trees from the infection, the wide spreading of the disease and also infection of the trees can only be prevented by integrated management based primarily on cultural methods (Tjamos, 1993;Himenez-Diaz et al., 2012).

The causal agent, *V. dahliae,* produces microsclerotia that can survive in soil for more than 10 years (Harris, 1998). Because of their persistence in soil and their primary role in root infection, the microsclerotia are regarded as targets for control measurements.

A phenomenon called 'natural recovery' has been reported by several researchers in some countries (Wilhelm and Taylor, 1965; Thanassoulopoulos et al., 1979; Cirulli, 1981; Blanco Lopez et al., 1984; Levin et al. 2003; Lopez Escudero and Blanco Lopez, 2005) which exhibits itself as an absence of symptoms for an undeterminable period of time after a few years of symptom expression in infected trees. This may be attributed to the inactivation of the pathogen in the xylem as a result of the pathogen inability to infect the new annual ring (Tjamos, 1993). Thus, if new root infections don't occur, the symptom development may be ceased. Consequently, any techniques applied to reduce the inoculum level of *V. dahliae* in the soil could contribute to the recovery of diseased olive trees.

Soil solarization is an effective technique to inactivate the soil pathogens and therefore disinfest the soil by solar heating (Katan, 1981; Stapleton, 2000). The inoculum density of *V. dahliae* in soil can be reduced and Verticillium wilt can be controlled in herbaceous crops by pre-planting application of this technique (Katan, 1980; Pullman et al., 1981b; Malero-Vara et al, 1995; Bourbos and Skoudriakis, 1996). Post-planting application of soil solarization is also possible to woody hosts affected by *V. dahliae* and was shown to be effective in leading recovery in pistachio (Ashworth and Gaona, 1982), apricot, almond (Stapleton et al., 1993) and olive (Tjamos et al., 1991; Lopez-Escudero and Blanco-Lopez, 2001) trees.

The present work was designed to evaluate the efficacy of soil solarization of individual trees in controlling Verticillium wilt of olive trees over a 3-year period. The study involved the determination of the effectiveness of a single (one year) or double (two consecutive years) soil solarization treatments for control of Verticillium wilt in a seven years old olive orchard situated in the western Anatolia, in an area intensively contaminated by the disease.

MATERIALS AND METHODS

Experimental site

The experiment was carried out during 2001 to 2004 in a commercial olive orchard in Akhisar county of Manisa province situated in Western Anatolia. Some characteristics of the orchard are presented in Table 1.

Table 1. Management history and soil type of the olive orchard.

Characteristics	
Planting date	1994
Cultivar	“Gemlik”
Soil texture	Loam
Number of trees da^{-1}	19
Average canopy height (m)	4
Planting material	Olive cuttings
Previous crops	Wheat and cotton
Intercrops	Cotton (1994-1997)
Border crops	Cotton, tomato, corn
Watering system	Furrow (twice a year)
Soil cultivation system	Cultivator, plough
Disease identified	1998 (Yolageldi et al., 2003)
Disease incidence	% 10

Application of soil solarization

At the initiation of the experiment in 2001, trees exhibited symptoms of Verticillium wilt were determined and the presence of the pathogen was affirmed by isolations from olive twigs.

Soil solarization was initiated on 15 July, 2001 in 31 trees having disease severity rating from 1 to 3 with a mean index of 1.68 (14 trees graded 1, 13 graded 2, and 4 graded 3). Another group of 31 diseased trees with the same mean index were used as untreated controls. To facilitate assessment of symptom remission, diseased branches or twigs were excised after the initial determination of the disease index in all of the trees selected to use in the experiment just before the application of soil solarization.

Before the solarization, the soil surface just under the tree canopy were mechanically cleared of weeds and stones in order to avoid damaging plastic sheets and the upper 5 cm of the soil was drawn to the periphery of the canopy projection to form a pond with an area of 4x4 meter for the uniform irrigation. All the trees were irrigated at a rate of 1000 litre per tree so that a depth of at least 25 cm of soil was saturated with water. After irrigation polyethylene sheets were placed over the pond at the same day and their edges were tighten firmly with soil to avoid evaporation. Mechanical weed destruction, removing of the top soil and irrigation was also applied to the control trees.

The second solarization was applied on 16 July 2002 following the same basis to all of the trees showing disease symptoms and to half of the trees showing no symptom that had been solarized the year before. The control trees of previous year and the trees which were not solarized second time were used as controls. Solarization lasted for about two months both years until the sheets began to disintegrate and then they were removed from orchard.

Recording of the soil temperature

The recording of the soil temperature was achieved by means of two data loggers at depths of 10 and 20 cm which were placed under a treated and a control tree. Those devices were adjusted to measure temperature with one-hour intervals between 27 July and 13 September in 2001 and between 25 July and 21 September in 2002.

Treatments after solarization

During the whole period of this study, from 15 July 2001 to 4 July 2003, no weed control was applied mechanically or chemically to the soil of mulched and untreated trees and to their close surrounds. These trees were also exempted from cultural practices such as crop pruning, soil cultivation except usual insecticide applications. No irrigation, following onset of the experiment was done during three years.

Assessment of disease progress

The disease severity was evaluated on a scale of 0-4 developed by the authors where; 0-No symptoms, 1-Wilt symptoms on one main branch, 2-Wilting affected 1/2 of the tree canopy, 3-Wilting affected 2/3 of the tree canopy, 4-Total wilting, dead plant.

The effectiveness of soil solarization in symptom remission was evaluated by assessing disease incidence and severity of solarized and control trees on the 0-4 scale on 22 April, 14 June, and 8 July 2002 after the first solarization application and on 21 September, 1 March, 1 May, and 4 July 2003 after the second one.

RESULTS

Effect of Solarization on Soil Temperature

Soil temperatures were recorded at one hour intervals under one solarized and one control tree at depths of 10 and 20 cm in both 2001 and 2002. Solarization increased soil temperature as compared with the control in both years, but the degree of increase varied with year. The higher values were observed mostly in the beginning of August and soil temperature tended to drop down as from September (Fig. 1 and 2). The difference in temperatures between maximum values recorded in solarized soil and the corresponding values in control soil, at the same recording time, changed from 4.7 to 11.8 °C (Table 2). Maximum soil temperature in solarized soil was recorded as 44.4 °C at depth of 10 cm in 2002. That value could be attained only once and it lasted for approximately two hours. In the first year the highest soil temperature was 42.9 °C at the same depth and it occurred seven times during the solarization process and also it remained steady for one to two hours each time.

Effect of Soil Solarization on Disease Progress

Application of solarization to individual trees reduced the mean severity of infections in both 2001 and 2002 compared with control (Table 3 and 4).

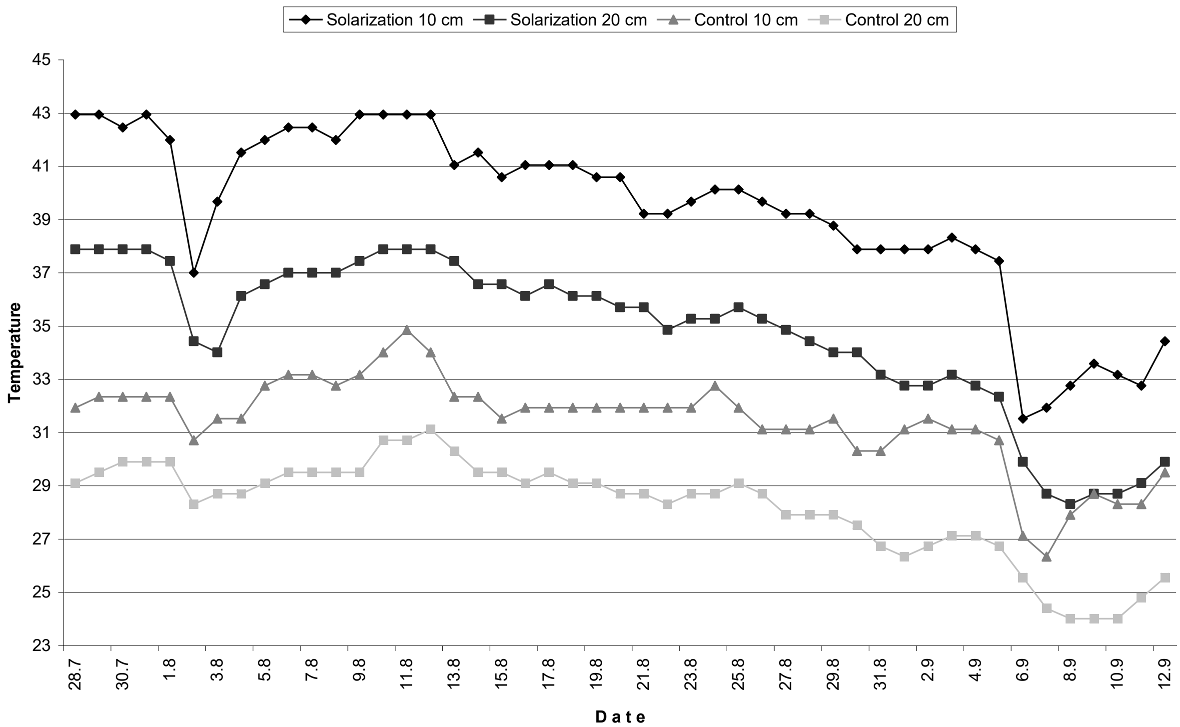

Fig. 1. Soil temperatures recorded during the first year's experiment (2001) at two different soil depths at 5 p.m.

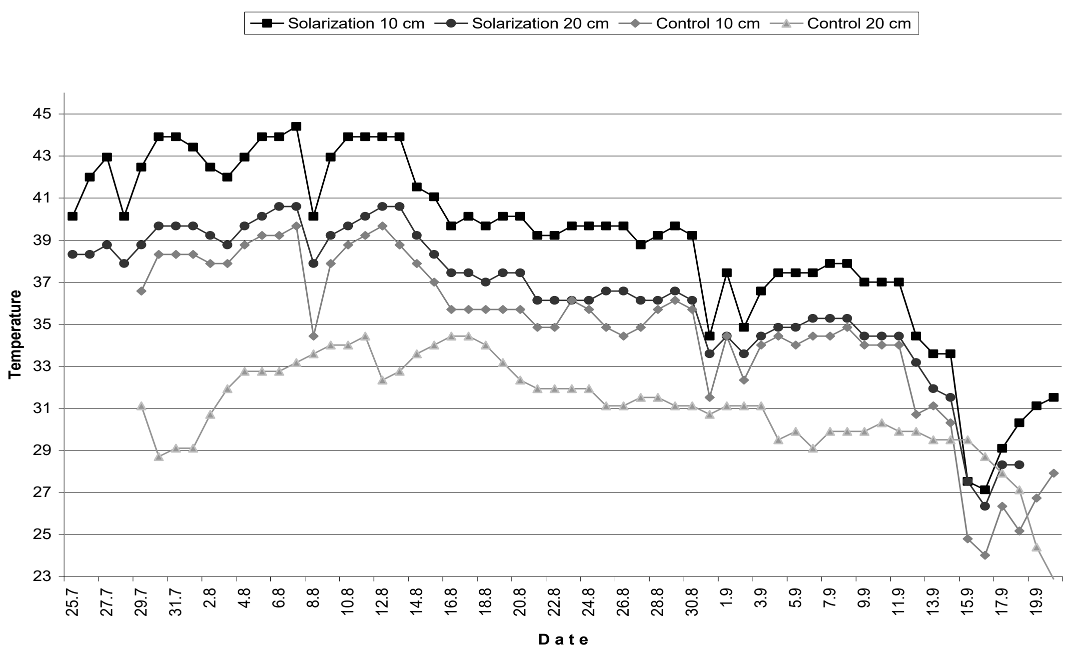

Fig. 2 Soil temperatures recorded during the second year's experiment (2002) at two different soil depths at 5 p.m.

Table 2. Effect of soil solarization treatments on soil temperatures at different soil depths in 2001 and 2002.

Temperature Recording Period	Treatments	Recording Depth (cm)	Maximum Temperature* (ºC)	Date and Time of Recording	Difference of Temperatures **	Minimum Temperature *(ºC)	Date and Time of Recording	Difference of Temperatures **
8 Jul-13 Sep 2001	Solarization I	10	42.9	28 Jul, 16^{00}	11.8	24.0	09 Sep, 08^{00}	4.6
		20	39.2	11 Aug, 19^{00}	7.3	26.3	09 Sep, 10^{00}	4.6
	Control	10	35.2	11 Aug, 18^{00}	7.2	11.8	13 Sep, 12^{00}	5.0
		20	31.9	11 Aug, 19^{00}	7.3	21.7	08 Sep , 09^{00}	5.4
25 Jul-24 Sep 2002	Solarization II	10	44.4	07 Aug, 17^{20}	4.7	21.0	19 Sep, 08^{20}	5.3
		20	41.0	07 Aug, 18^{20}	6.2	22.1	19 Sep, 09^{20}	3.4
	Control	10	39.7	07 Aug, 17^{20}	4.7	16.0	19 Sep, 07^{20}	5.3
		20	35.3	12 Aug, 19^{20}	5.3	18.7	19 Sep, 09^{20}	3.4

* Temperatures (ºC) are maximum and minimum values recorded in solarized and non-solarized soils during first and second solarizations.
** Values are differences (ºC) between temperatures in solarized soil and the corresponding values in non-solarized soil or vice versa at the same depth and recording time.

Table 3. The effect of first soil solarization in 2001 on disease severity in the following year

Treatment	**Mean of disease index recording at different dates***		
	22.4.2002	**14.6.2002**	**8.7.2002**
Solarization	0.23	0.58	0.65**a****
Control	0.35	0.87	0.97**a**

*Soil solarization was performed with two groups of **31** diseased trees having the equal mean initial disease index of **1.68**. Diseased branches were removed within each group before the application of the solarization to facilitate the assessment of symptom remission. **Values followed by the same letter are not significantly different at *P*= 0.05 according to t test.

The effectiveness of the first application of soil solarization in recovery of Verticillium affected olive trees was evaluated by assessing disease severity of treated and untreated control trees in April, June and July 2002 (Table 3). The mean index values obtained during the observation period showed that the disease progressed in both solarized and control trees but the rate of progress in control trees was faster than treated ones. According to final values obtained in July, mean disease severity was slightly but not statistically reduced with single solarization and the rate of reduction could reach 33 %.

Table 4. The effect of second soil solarization in 2002 on disease severity in the following year.

Treatment	**Mean of disease index recording at different dates ***		
	1.3.2003	**1.5.2003**	**4.7.2003**
Solarization	0.32	0.55	0.59**a****
Control	0.50	0.68	0.77**a**

* The experiment was performed with two groups of **22** diseased trees having the equal mean initial disease index of **0.91**. Diseased branches were removed within each group before the application of the solarization to facilitate the assessment of symptom remission.
** Values followed by the same letter are not significantly different at *P*= 0.05 according to t test.

Disease index values determined after the second solarization treatment (Table 4) indicated that the mean disease severity was also reduced in the second year, but the rate of reduction was less significant compared to the first year's treatment and could hardly reach 23.4 %.

The effect of soil solarization on recovery of diseased olive trees was evaluated by determining the distribution of solarized and control trees into the disease indices before and after the solarization in both single and double treatments (Table 5 and 6).

In the first experiment, the percentage of recovery attributed to solarization exceeded natural recovery in trees with the initial disease indices of 2 and 3. Only, the rates of recovery of both solarized and control trees with the initial disease index of 1 were equal (57.1 %) (Table 5).

Disease progress in twiced-solarized trees showed that approximately 55 % of the diseased trees were recovered after two years of application whereas the rate of natural recovery was % 41 in control group (Table 6).

Table 5. Incidence of Verticillium wilt in olive trees within a year after a single application of soil solarization.

Treatments	Initial Disease Index	Distribution of Olive Trees to Different Disease Categories **									
		0		1		2		3		4	
		Number of Trees	Incidence (%)	Number of Trees	Incidence (%)	Number of Trees	Incidence (%)	Number of Trees	Incidence (%)	Number of Trees	Incidence (%)
Soil Solarization	1 (14)*	**8**	57.1	**5**	35.7	**1**	7.1	**0**	0.0	**0**	0.0
	2 (13)	**6**	46.2	**4**	30.8	**1**	7.7	**2**	15.4	**0**	0.0
	3 (4)	**3**	75.0	**1**	25.0	**0**	0.0	**0**	0.0	**0**	0.0
Control	1 (14)	**8**	57.1	**6**	42.9	**0**	0.0	**0**	0.0	**0**	0.0
	2 (13)	**1**	7.7	**9**	69.2	**2**	15.4	**1**	7.7	**0**	0.0
	3 (4)	**2**	50.0	**0**	0.0	**0**	50.0	**0**	0.0	**2**	50.0

* Numbers in brackets are the total number of treated or control trees per disease index
**Values were obtained in final record on 8 July 2002.

Table 6. Incidence of Verticillium wilt in olive trees within a year after the second application of soil solarization.

Treatments	Initial Disease Index	Distribution of Olive Trees to Different Disease Index Categories **									
		0		1		2		3		4	
		Number of Trees	Incidence (%)	Number of Trees	Incidence (%)	Number of Trees	Incidence (%)	Number of Trees	Incidence (%)	Number of Trees	Incidence (%)
Soil Solarization	0 (8)*	**7**	87.5	**1**	12.5	**0**	0.0	**0**	0.0	**0**	0.0
	1(10)	**3**	30.0	**6**	60.0	**0**	0.0	**0**	0.0	**1**	10.0
	2 (2)	**0**	0.0	**2**	100.0	**0**	0.0	**0**	0.0	**0**	0.0
	3 (2)	**2**	100.0	**0**	0.0	**0**	0.0	**0**	0.0	**0**	0.0
Control	0 (6)	**4**	66.7	**1**	16.7	**1**	16.7	**0**	0.0	**0**	0.0
	1 (13)	**5**	38.5	**6**	46.2	**2**	15.4	**0**	0.0	**0**	0.0
	2 (2)	**0**	0.0	**1**	50.0	**1**	50.0	**0**	0.0	**0**	0.0
	3 (1)	**0**	0.0	**1**	100.0	**0**	0.0	**0**	0.0	**0**	0.0

* Numbers in brackets are the total number of treated or untreated trees per disease index

**Values were obtained in final record on 4 July 2003

DISCUSSION

In the present study, the soil solarization was carried out during July to September, the warmest time of the year, and the increase on soil temperature was permanently compared to values obtained in the control parcel. The degree of increase in soil temperature varied with year and soil depth, and ranged from 4.7 to 11.8 °C.

The increase in soil temperatures due to solarization was comparable to what has been observed in a similar experiment done in Spain (Lopez-Escudero and Blanco-Lopez, 2001) but slightly different from those reported from Greece (Tjamos, 1991). Lopez-Escudero and Blanco-Lopez (2001) reported that, during a study carried out in commercial olive orchards in Southern Spain, maximum temperature attained at 15 cm soil depth was 45.0 °C and that was 12 °C higher than in the non-solarized soil. Tjamos (1991) also reported temperature increase of 9 to 12 °C in solarized soil of the olive orchard in Greece. But the maximum temperature recorded at 10 cm by Tjamos (1991) was higher (58 °C) than in our study (44.4°C).

It is well known that, the efficacy of solarization is primarily affected by the soil temperature and the duration of exposure. Pullman et al. (1981a) showed that *V. dahliae* was undetectable at soil depths of 15 and 30 cm after a 4-week solarization period with maximum soil temperatures of 46 and 38 °C, respectively. Ashworth and Goana (1982) also reported that *V. dahliae* were eliminated from 0-20 cm of soil after 1-4 weeks of solarization with maximum soil temperature of 45 °C. Soil temperature values obtained in our study appeared to be close to the effective range of temperatures necessary to eradicate population of the pathogen in soil, when compared with those results. Unfortunately the considerable level of increase in soil temperature did not bring about a significant reduction in mean disease severity in either of two solarization experiments. Although both single and double solarization applications slightly reduced the disease severity compared with the non- solarized trees, there was no statistical significance *($P=0.05$)* between treatment and control.

Despite the adequate rise in soil temperature, the failure to obtain a significant effect on disease progress in our study is in agreement with observations in Spain. Lopez-Escudero and Blanco-Lopez (2001) reported that disease severity was reduced only in two of the four soil solarization experiments conducted in three commercial orchards. As already mentioned above, temperature increases reached in those experiments were nearly the same that we obtained in the present study. The variation in experimental results was explained by the authors through the differences in initial inoculum densities of *V. dahliae* in soil of the orchards. But, as we couldn't determine the population of the pathogen in our experimental site, we were not able to verify that.

The first application in 2001 led surprisingly to more marked recovery and symptom remission in those trees with initial disease indices of 2 and 3, whereas these criteria couldn't exceed the degree of natural recovery in trees with initially mild symptoms (disease index 1). Our findings are inconsistent with those of Tjamos (1991) who observed more pronounced recovery in trees with mild symptoms of wilt.

The second solarization resulted with nearly no additive effect in disease control. As the difference between the recovery rate resulted from the second application and the natural recovery rate appeared in non-treated trees was so insignificant, the double-solarization doesn't seem to worth applying. The effect of the double-solarization was found non-significant also by Lopez-Escudero and Blanco-Lopez (2001).

During trial period for three years, a general deceleration in disease progress which occurred probably as a result of the appropriate disease management techniques (leaving off intercropping, deep ploughing, and furrow watering) performed by the farmer upon our advices, was clearly evident in our orchard. Presumably, those measures might have favourable influence on avoiding of new infections and enhanced the recovery in the whole orchard including the control trees used in this study. Therefore, the effect of the solarization might be masked.

Soil solarization is generally accepted as a useful method to contribute in controlling Verticillium wilt (Katan, 1981; Stapleton and De Vay, 1986; Malero-Vara et al., 1995). Despite the limited success attained in this experiment, we think that soil solarization may be recommended anyhow as a complement of integrated control strategy for Verticillium wilt of olive.

ÖZET

Ege Bölgesi'nde Zeytinde Verticillium Solgunluğunun Toprak Solarizasyonu ile Kontrolü

Manisa ili Akhisar ilçesinde *Verticillium dahliae* ile bulaşık olan ve tipik solgunluk belirtileri gösteren 7 yaşlı ağaçlara sahip bir zeytinlikte solarizasyonun hastalıkla mücadelesi üzerindeki etkisi araştırılmıştır. Solarizasyon ağaçlara bir kez veya iki yıl arka arkaya uygulandı. Solarize edilen toprakta 10 cm derinlikte maksimum toprak sıcaklıkları ilk yıl 42.9 C, ikinci yıl 44.4 C olarak saptandı. Solarizasyon her iki uygulama şeklinde de kontrole göre ortalama hastalık şiddetinde istatiksel açıdan anlamlı olmayan hafif bir azalma sağladı. İki yıl arka arkaya solarizasyon uygulaması tek yıllık uygulamaya göre ilave bir katkı sağlamadı.

Anahtar sözcükler: *Verticillium dahliae*, *Olea europaea,* solarizasyon

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