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Effects of Soil Solarization and Organic Amendment Treatments for Controlling *Meloidogyne incognita* in Tomato Cultivars in Western Anatolia

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Abstract: The efficacy of soil solarization, Dazomet, chicken manure (CM), olive processing waste (OPW), and soil solarization in combination with CM or OPW or half doses of Dazomet against *Meloidogyne incognita* on tomato cultivars was investigated in greenhouses in western Anatolia, Turkey, between 2002 and 2004. The maximum soil temperature average was increased 47.1 °C by soil solarization alone at the 15 cm soil depth of soil in the first year. Soil solarization alone and in combination with CM increased the mean of maximum soil temperature by 41.2 and 40.9 °C respectively, at the 15 cm soil depth in the second year. Root galling caused by *M. incognita* in tomato plants in the soil solarization plus organic amendment plots (CM or OPW) was lower than in plots that underwent the other treatments. In addition, tomato yields in plots subjected to soil solarization and soil solarization in combination with organic amendment (CM or OPW) were similar to those in plots subjected to Dazomet and soil solarization plus half doses of Dazomet.

Key Words: *Meloidogyne incognita*, chicken manure, olive processing waste, soil solarization, Dazomet, tomato

Batı Anadolu Bölgesi'nde Domateslerde *Meloidogyne incognita* ile Mücadelede Toprak Solarizasyonu ve Organik Katkı Uygulamalarının Etkileri

Özet: Türkiye'nin Batı Anadolu Bölgesi'ndeki seralarda, 2002–2004 yıllarında, domates bitkilerinde *Meloidogyne incognita*'ya karşı toprak solarizasyonu, Dazomet, tavuk gübresi (CM), zeytin karasuyu (OPW) ile Solarizasyon + CM veya OPW veya yarı doz Dazomet ile kombine uygulamalarının etkinlikleri araştırılmıştır. Birinci yılda tek başına toprak solarizasyonu uygulaması ile 15 cm toprak derinliğinde maksimum toprak sıcaklık değerlerinin ortalaması 47.1 °C'ye kadar arttırılmıştır. İkinci yılda, solarizasyon ile tavuk gübresi kombinasyonunda ve tek başına solarizasyon uygulaması, sırasıyla maksimum toprak sıcaklık değerlerinin ortalamalarını 41.2 °C ve 40.9 °C'ye kadar arttırmıştır. *M. incognita*'nın domates bitkilerinin köklerinde neden olduğu urlar, tek başına solarizasyon ve solarizasyon ile organik katkı (CM veya OPW) kombine uygulamalarında diğer tüm uygulamalardan daha az olarak saptanmıştır. Ayrıca, solarizasyon ve solarizasyon + organik katkı (CM veya OPW) uygulamalarında elde edilen domates verimi, Dazomet ve solarizasyon + yarı doz Dazomet uygulanan parsellerden elde edilen verim değerlerine eşit olarak saptanmıştır.

Anahtar Sözcükler: *Meloidogyne incognita*, tavuk gübresi, zeytin karasuyu, solarizasyon, Dazomet, domates

Introduction

Tomato (*Lycopersicum esculentum* Mill.) is one of the most widely cultivated crops in Turkey, making this country the third largest tomato producer in the world after China and the USA, for both fresh and processing tomatoes, with a production rate of 9.82 million metric tons in 2003 (Sırtıoğlu, 2004; FAO, 2007). Tomato can be grown in all regions of Turkey, but the bulk of tomato production is concentrated in the Marmara, Aegean, and Mediterranean regions.

Root-knot nematodes are very common and the most important nematode species of greenhouse-grown tomatoes and other vegetables in southern and western Anatolia. *Meloidogyne incognita* Chitwood, 1949, *M. javanica* Chitwood, 1949, *M. arenaria* Chitwood, 1949, and *M. hapla* Chitwood, 1949 are the most common

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species in these regions (Yüksel, 1974; Elekçioğlu et al., 1994; Kaşkavalcı and Öncüer, 1999). Crop losses due to *Meloidogyne* spp. in tropical countries are estimated to be around 15% (Sasser, 1979). Yield losses of 50%-80% in vegetable crops from these nematodes are common (Siddiqi, 2000). Kaşkavalcı and Öncüer (1999) also reported that yield losses caused by root-knot nematodes in the processing tomato growing areas in Aydın province (western Anatolia) were approximately 80.1%, depending on nematode density.

Soil fumigant pesticides, especially methyl bromide (MB), were commonly used for controlling root-knot nematodes, soil-borne pathogens, and weeds in greenhouses, and most producers rely on a production system with preplant soil treatment fumigation to control these pathogens. However, MB was banned in many countries or some restrictions were placed on its use due to its hazardous effect on stratospheric ozone. This has led to an intensive search for non-chemical alternatives and/or chemical replacements for MB in many countries (Dickson et al., 1995; D'Addabbo et al., 2000; Hafez et al., 2000; Ioannou, 2000; Benlioğlu et al., 2001, 2002, 2005; Besri, 2001; Noling et al., 2001; Yücel et al., 2001; Bello et al., 2002; Cartia, 2002; Öztürk et al., 2002; Tjamos et al., 2002). Turkey has accepted an incremental phase-out schedule to reduce MB consumption to zero in soil fumigants by January 1, 2008.

The basis of solarization is to increase soil temperature by covering the moist soil with a clear polyethylene sheet and to maintain this temperature for 4-6 weeks before planting. Soil solarization, developed in Israel in the mid-1970s, provides economical control of many soil-borne pests and weeds, enhances the physical and chemical properties of soil, increases the yield subsequent crops, and is cost effective (Katan and De Vay, 1991).

The main objective of this study was to investigate the effects of soil solarization, chicken manure (CM), olive processing waste (OPW), and soil solarization combined with CM or OPW or half doses of Dazomet and Dazomet alone as a comparison pesticide for the integrated management strategies of *M. incognita* in tomato cultivars in western Anatolia.

Materials and Methods

Experiments were conducted on tomato cultivars (*Lycopersicon esculentum* L.) in 2 greenhouses in the towns of İncirliova and Germencik in Aydın province, Turkey, in the summer of 2002 and 2003. Previously hosted tomato cultivars in all greenhouses were heavily infested by southern root-knot nematodes (*M. incognita*).

Experiments for each greenhouse consisted of 8 treatments including soil solarization alone, CM (10 t ha^{-1}) alone, OPW (30 t ha^{-1}) alone, Dazomet a.i. (Basamid^{R} 485 kg ha^{-1}) alone as a comparison pesticide (covered 7 days), soil solarization + CM (10 t ha^{-1}), soil solarization + OPW (30 t ha^{-1}), soil solarization + half doses of Dazomet a.i. (Basamid^{R} 242.5 kg ha^{-1}), and an untreated control. The Beril-7314 (Rijk Zwaan) tomato cultivar was grown in each greenhouse (Table 1).

Experimental plots consisted of 4 rows arranged in a randomized complete block design with 4 replications at 4 different blocks per treatment and the size of each plot was approximately 6 m x 2.7 m.

Prior to the treatments, the soil was prepared using a moldboard plow followed by a disk harrow and was irrigated to a depth of 50 to 60 cm. One week later, raised beds were prepared on moistened soil; they were 25 cm in height and 40 cm in width, with 50 cm between rows. Drip irrigation pipes were placed on the raised beds during soil solarization periods to maintain the soil moisture.

For soil solarization, plots were covered manually with 110 µm thickness clear polyethylene sheets including the soil between 2 raised beds. Polyethylene sheets were covered during June-August for 7 weeks in year 1 and for 6 weeks in year 2 (Table 1).

Composted CM and exhausted OPW were used as organic amendments. CM and OPW were applied once 1 week before plants were transferred to the plots (Table 1). CM was uniformly distributed on the soil surface at 10 t ha^{-1} for each plot and similarly OPW in solid form was uniformly applied to the soil surface at 30 t ha^{-1} for each plot. Then CM and OPW were incorporated into a depth 15 cm with a rotary tiller and raised beds prepared.

Dazomet a.i. 485 kg ha^{-1} alone was applied once with a special granular sprayer and incorporated into a depth of 0-15 cm soil with a rotary tiller. Raised beds were

Table 1. General introduction of experiment designs in years 1 and 2.

Years	Treatments	Application doses (a.i. per ha) and/or days of treatments
1	1. Control	–
	2. CM	10 t
	3. OPW	30 t
	4. Solarization	7 weeks
	5. CM + solarization	10 t + 7 weeks
	6. OPW + solarization	30 t + 7 weeks
	7. Dazomet	485 kg + 7 days
	8. 1/2 Dose Dazomet + solarization	242.5 kg + 7 weeks
2	1. Control	–
	2. CM	10 t
	3. OPW	30 t
	4. Solarization	6 weeks
	5. CM + solarization	10 t + 6 weeks
	6. OPW + solarization	30 t + 6 weeks
	7. Dazomet	485 kg + 7 days
	8. 1/2 Dose Dazomet + short-term solarization	242.5 kg + 3 weeks

formed and covered with clear polyethylene sheets (110 µm thickness) and watered for 1 h by drip irrigation. After 7 days, the polyethylene sheets were removed for aeration.

Soil solarization combined with CM, OPW, and half doses of Dazomet were used as separate treatments in the experiments. Combination treatments involving CM, OPW, and half doses of Dazomet were applied as described above for each treatment. Then raised beds were prepared and the soil surface was manually covered with a clear polyethylene sheets for 7 weeks in year 1 and for 6 weeks in year 2 (Table 1).

Soil temperature was recorded using a data logger at a depth of 15 cm in solarized soil and untreated control plots in 1 greenhouse representing another greenhouse as well.

Each year air temperature and humidity were recorded from the beginning to the end of the experiment in the greenhouse using a data logger in 1 greenhouse representing another greenhouse as well.

Effect of treatments on root-knot nematode

Root galling is the most important symptom for root-knot nematodes. Randomly, 4 plants in each plot were chosen and uprooted at the end of the growing season. Then the effect of treatments on the *M. incognita* was evaluated using the galling index scale of 0 to 10 (Zeck, 1971), where 0 represented root with no galls and 10 represented maximal degree of galling (root functioning is loose and decaying) at the end of the growing season.

Assessment of tomato yield

Tomato yields were taken from 4 plants in each plot which were chosen and marked randomly at the beginning of the season. These plants were harvested weekly and the yield per plant was measured.

SPSS 12.0 software (SPSS Inc., Chicago, IL, USA) was used for analyses of variance. Root galling index and tomato yields were analyzed following standard procedures for analysis of variance. The galling index data were transformed by using log10 (X + 1) prior to the statistical analyses. Means were compared according to Duncan's multiple range test at $P \leq 0.05$ level.

Results

Soil temperature

In year 1, the maximum soil temperature average was 47.1 °C in the solarized plot. However, the maximum soil temperature average was 39.3 °C in the non-solarized soil (Figure 1). In year 2, the maximum soil temperature average in solarization + CM plots, solarization, and control plots were 41.2, 40.9, and 34.8 °C, respectively (Figure 2). In both years, soil temperatures at a depth of 15 cm were approximately 10 °C higher in solarized plots compared with non-solarized plots. Furthermore, soil temperature was slightly higher in CM amended solarization plots than in unamended solarized soil in year 2.

Effects of treatments on root galling

In both years, solarization alone and soil solarization combined with CM, OPW, and half doses of Dazomet dramatically reduced root galling in tomato. Root galling indices of these treatments were lower than those in all other treatments, including soil Dazomet alone (Table 2). However, the highest root galling indices were found in the untreated control plots and the differences between untreated control plots and other treatments were significant (Table 2). CM and OPW alone as organic amendments did not influence root-knot nematodes effectively; in these plots root galling indices were nearly as high as those in untreated control plots.

In year 1, the highest galling indices were recorded from the untreated control plots at the end of the growing season ($P < 0.05$). However, the lowest galling indices were recorded from soil solarization combined with CM and OPW plots ($P < 0.05$). Moreover, these combination treatments had less root galling than plots subjected to Dazomet alone or soil solarization combined with half doses of Dazomet ($P < 0.05$). Soil solarization alone resulted in significantly better control of *M. incognita* than these chemical treatments ($P < 0.05$) (Table 2).

In year 2, similarly galling indices in the untreated control plots had the highest ratio ($P < 0.05$). However, the lowest gall indices were recorded from short-term soil solarization combined with half doses of Dazomet

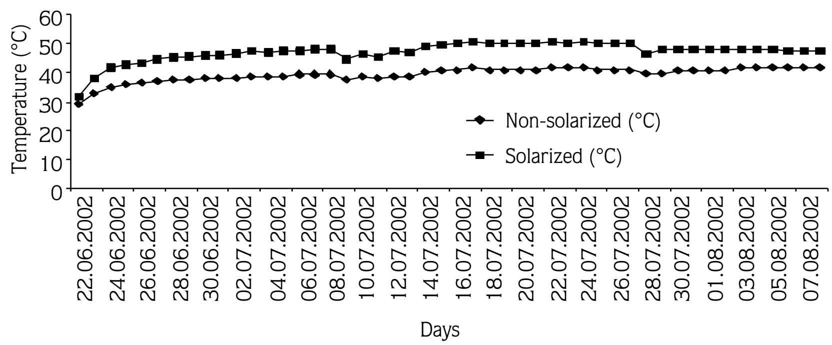

Figure 1. Daily temperature values at 15-cm depth of solarized and non-solarized soil in experimental plots in year 1.

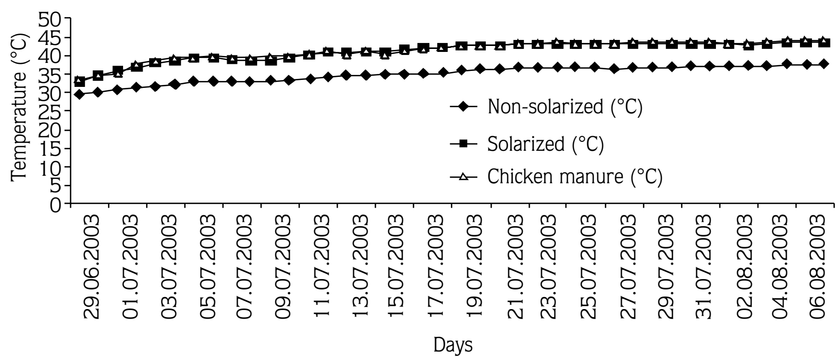

Figure 2. Daily temperature values at 15 cm depth of solarized, chicken manure plus solarized and non-solarized soil in experimental plots in year 2.

Table 2. The effects of the soil solarization and organic amendment treatments on the root galling of tomato plants caused by root-knot nematodes (*Meloidogyne incognita*) in years 1 and 2.

Treatments	Galling index*	
	Year 1	Year 2
1. Control	7.03 ± 0.52 a**	8.22 ± 0.49 a
2. CM	4.63 ± 0.63 b	6.53 ± 0.56 ab
3. OPW	2.47 ± 0.58 cd	5.94 ± 0.72 b
4. Solarization	1.13 ± 0.37 de	0.16 ± 0.13 d
5. CM + solarization	0.88 ± 0.36 e	0.53 ± 0.33 d
6. OPW + solarization	0.91 ± 0.37 e	0.34 ± 0.28 d
7. Dazomet	2.50 ± 0.47 c	1.56 ± 0.39 c
8. 1/2 Doses Dazomet + solarization	1.84 ± 0.59 cde	NA
9. 1/2 Doses Dazomet + short-term solarization	NA***	0.09 ± 0.05 d

* The data of gall index were transformed by using log10 (X + 1) transformation prior to statistical analyses. Data are mean values of 4 replicates at 4 different blocks.

** Values in the same column with different letters show significant differences at P ≤ 0.05 according to Duncan's multiple range test.

*** Not Applicable: Treatment not applied at this season.

(P < 0.05). Similarly, soil solarization alone, and soil solarization combined with CM and OPW dramatically reduced the root galling of tomato roots, and there were no significant differences among these treatments (P < 0.05) (Table 2).

Yield assessment

All treatments significantly increased tomato yield compared to untreated control plots (P < 0.05) (Table 3).

In year 1, the lowest tomato yield was recorded from the untreated control plots (P < 0.05); however, the highest yield was recorded from Dazomet alone plots (P < 0.05). Soil solarization combined with CM and half doses of Dazomet and CM alone and soil solarization alone increased tomato yields close to Dazomet alone treatments and also there were no significant differences (Table 3).

In year 2, the lowest tomato yield was recorded from the untreated control plots (P < 0.05). In contrast, the highest yield was recorded from soil solarization combined with OPW and short-term solarization combined with half doses of Dazomet (P < 0.05). Tomato yield in plots that received Dazomet alone and soil solarization alone was similar to these treatments (P < 0.05).

Discussion

The mean maximum temperature was 47.1 °C in the raised bed solarized soil in year 1, and 41.2 and 40.9 °C in the raised bed CM amended solarized soil and in the unamended solarized soil in year 2, respectively (Figures 1 and 2). Increments of soil temperature at a depth of 15 cm soil in soil solarization plots were 7.8 °C in year 1, and 6.4 and 6.1 °C in CM amended solarized soil and unamended solarized soil, respectively, in year 2. Soil temperature increments at a 15 cm depth of soil were compatible with observations from most of the investigations. A number of researchers have recorded the same soil temperature. Cartia et al. (1991) reported 42.3 °C at a 15 cm depth of soil in Italy, while Mejeias-Guisado et al. (1993) and Tacconi and Santi (1994) reported 46.0 and 43.2 °C at a 10 cm depth of soil in Spain and Italy, respectively. Moreover, soil temperature was increased 44.0, 35.0, and 33.0 °C by using 4-mm thick transparent polyethylene sheet at 5, 15, and 30 cm depth of soil, respectively, in the USA (West Samoa) (Ragone and Wilson, 1998). Herrera et al. (1999) determined similar results in Chile. Lazarovits et al. (1991), Chellemi and Olson (1994), Rao and Krishnappa (1995), Eddaoudi and Ammati (1995), Nasr-Esfehani et al. (2000), and Söğüt and Elekçioğlu (2007) reported

Table 3. The effects of the soil solarization and organic amendment treatments on the yield assessment of tomato plants in years 1 and 2.

Treatments	Yield (g plant^{-1})	
	Year 1	Year 2
1. Control	1710.69 ± 159.12 a*	2622.00 ± 183.22 a
2. CM	2440.50 ± 185.19 b	2809.31 ± 138.89 ab
3. OPW	2086.25 ± 180.68 ab	2853.44 ± 133.31 ab
4. Solarization	2329.28 ± 217.64 b	3196.06 ± 173.34 bc
5. CM + solarization	2341.63 ± 226.50 b	3104.91 ± 175.75 abc
6. OPW + solarization	2063.19 ± 264.82 ab	3748.75 ± 197.34 d
7. Dazomet	2617.38 ± 151.04 b	3349.19 ± 112.94 cd
8. 1/2 Doses Dazomet + solarization	2529.63 ± 215.66 b	NA
9. 1/2 Doses Dazomet + short-term solarization	NA**	3748.31 ± 164.15 d

* Values in the same column with different letters show significant differences at P ≤ 0.05 according to Duncan's multiple range test. Data are mean values of 4 replicates at 4 different blocks.

** Not Applicable: Treatment not applied at this season.

that soil temperature was increased by soil solarization between 7 and 10 °C at a 10-15 cm depth of soil in the different agricultural areas of the world.

Solarization alone and solarization combined with CM or OPW or half doses of Dazomet dramatically reduced root galling due to root-knot nematodes, and these methods were better than the other treatments, including Dazomet alone (Table 2). The highest gall index ratio was determined in untreated control plots and differences between untreated control and treatments were significant.

In several studies, it has been reported that many plant nematodes could be controlled by soil solarization in many countries (Barbercheck and Von Broembsen, 1986; Heald and Robinson, 1987; Jain and Gupta, 1997; Randig et al., 1998; Lamberti et al., 2000; Tanaka et al., 2000). Moreover, there were several studies concerning the effect of soil solarization on nematodes in Turkey. A number of plant parasitic nematodes in solarized pots were reduced 50%-96% compared with nonsolarized plots in the East Mediterranean region of Turkey (Elekçioğlu et al., 1995). In Antalya province, root-knot nematodes in greenhouse-grown eggplants were reduced dramatically 73.4%-100% by 6-week soil solarization (Göçmen and Elekçioğlu, 1996). Similarly, Tekin et al. (1997) reported that soil solarization alone or in combination with half doses of MB efficiently controlled root-knot nematodes in greenhouses in Mediterranean regions.

CM alone or in combination with soil solarization has been used as an organic amendment for high nitrogen contents and/or biofumigation materials in several countries and found to be useful for the control of nematodes, weeds, soil-borne diseases, and pests (Gamliel and Stapleton, 1993; Lazorovits et al. 1997; Gamliel et al., 1999; Yücel et al., 2001, 2002; Bello et al., 2002; Öztürk et al., 2002).

Gamliel and Stapleton (1993) reported that commercially formulated chicken compost (10 t ha^{-1}) or ammonium sulfate amendment to soil before a 4-week solarization period increased soil temperature and lettuce yield, and efficiently controlled *M. incognita* and *Pythium ultimum*; however, solarization alone gave a partial effect against root-knot nematodes. Kaplan et al. (1992) reported that the nematode population was reduced gradually according to increments in chicken litter dose. Furthermore, another investigation showed that combinations of olive pomace and CM were more suppressive than Fenamiphos on *M. incognita* (D'Addabbo et al., 2000).

Fresh and exhausted olive pomace or olive remains have been used as organic amendments or biofumigation material by researchers. D'Addabbo et al. (2000) reported that fresh and exhausted olive pomace as organic amendments had significant nematicidal effects on root-knot nematodes and increased tomato yields in Italy. In Uruguay, olive remains as biofumigation material were as effective as conventional pesticides in the control of root-knot nematodes, fungi, insects, and weeds (Bello et al., 2002).

All treatments significantly increased tomato yield compared to the untreated control plots. Soil solarization alone or combined with CM or OPW increased tomato yield as much as Dazomet alone or half doses of Dazomet plus short-term solarization treatments and there were no significant differences. Furthermore, it is clear that soil solarization alone and combined with organic amendment are more beneficial than soil fumigation alone and half doses of fumigants for farmers' profits. In addition, soil solarization and alternative treatments increased the release of macro- and micronutrients, release of plant growth regulators, development of mycorrhizae, and stimulation of beneficial microflora (Takatori et al., 1964; Ratan, 1974; Chen and Katan, 1980, Katan, 1980; Gamliel and Katan, 1989). In agreement with previous reports (Katan, 1980; Katan et al., 1987; Gamliel and Stapleton, 1993; Gamliel et al., 1999; Yücel et al., 2001, 2002; Öztürk et al., 2002; Söğüt and Elekçioğlu, 2007), our results showed that solarization alone or in combination with organic amendments was an effective soil disinfestation method, providing satisfactory control of nematodes and soil-borne diseases, and pests, and resulting in high yield.

Soil solarization and its combination cause a chain reaction of chemical and microbial degradation, leading to the generation of toxic compounds in the vapor or solid phase. Gamliel et al. (1999) reported that the generation of toxic compounds increased with temperature and accumulated under plastic mulch, and enhanced toxic activity against soil flora and fauna.

In conclusion, soil solarization alone and combined with CM or OPW effectively controlled *M. incognita* and increased tomato yield as much as Dazomet alone or half doses of Dazomet fumigation plus short-term solarization. Therefore, these treatments could be used for root-knot nematode control in IPM programs in tomato in greenhouses in Turkey.

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