Effect of Solarization and Fumigant Applications on Soilborne Pathogens and Root-knot Nematodes in Greenhouse-Grown Tomato in Turkey

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A study was conducted in two greenhouses with a history of Fusarium crown and root rot (*Fusarium oxysporum* f.sp. *radicis-lycopersici, Forl*) and root-knot nematodes (*Meloidogyne javanica* and *M. incognita*). During the 2005–06 growing season, the effectiveness of soil disinfestation by solarization in combination with low doses of metham-sodium (500, 750, 1000 and 1250 *l* ha^{-1}) or dazomet (400 g ha^{-1}), was tested against soilborne pathogens and nematodes in an attempt to find a suitable alternative to methyl bromide, which is soon to be phased out. Solarization alone was not effective in the greenhouse with a high incidence of *Forl*. In the greenhouse with a low level of *Forl,* all the treatments tested reduced disease incidence, and were therefore considered to be applicable for soil disinfestation. In addition, root-knot nematode density decreased with all the treatments tested in both of the greenhouses.
KEY WORDS: Dazomet; Fusarium crown and root rot; *Fusarium oxysporum* f.sp. *radicis lycopersici*; *Meloidogyne incognita*; *Meloidogyne javanica*; metham-sodium; methyl bromide; soil disinfestation.

INTRODUCTION

Root rot and wilt diseases caused by soilborne pathogens such as *Fusarium* spp., *Rhizoctonia* spp. and *Pythium* spp. result in considerable yield losses in greenhouse-grown vegetables unless soil disinfestation is conducted prior to planting. Pesticide applications done after disease onset are neither economical nor effective. In addition to soilborne pathogens, yield loss caused by root-knot nematodes ranges from 29% to 54% (17,20). Methyl bromide (MeBr), which has been widely used for soil disinfestation, will be banned in Turkey by the end of 2007, and hence there is an urgent need for alternative control measures for soilborne pathogens. There has been growing interest in some alternative control methods for soilborne pathogens and pests (7-9,19) since MeBr, except for critical uses and quarantine measures, is being phased out in many developed countries.

In Turkey the alternative methods involved solarization combined either with a low dose of fumigant (dazomet, 400 kg ha^{-1}) or fresh cow manure in greenhouse-grown pepper, eggplant and strawberry, to test their effect on disease incidence, nematodes and yield (23,25). Metham-sodium (MS) (sodium *N*-methyl dithiocarbamate) and dazomet (tetrahydro-3,5-dimethyl-2*H*-1,3,5-thiadiazine-2-thione) are recommended as MeBr alternative soil fumigators to be used in greenhouse-grown vegetables in many countries. They are decomposed

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to methyl-isothiocyanate (MITC) in moist soil so that they effectively control pathogens, pests and weeds. MITC constitutes approximately 90% of the degradation products of MS in soil (16), yet emissions of MITC have been reported to be risky for human health and environment (18). MITC toxicity to lasting structures of some pathogens such as *Verticillium* spp., *Sclerotium rolfsii* Sacc., *Sclerotinia sclerotiorum* (Lib.) de Bary, and its effect on *Fusarium oxysporum* Schlect. was reported to increase with soil temperature (2).

Solarization – solar heating of moistened soil by mulching during summer periods to increase temperature to that lethal to soilborne pathogenic organisms – was first introduced in the mid 1970s against soilborne pests and diseases (13). It was seriously considered again in the 1990s in the light of the banning of MeBr usage around the world, especially in the Mediterranean countries where ecological factors are suitable for its application. This approach is known to have wide and long-term effects on soilborne pathogens and diseases, and also to be environmentally friendly, being included in Integrated Pest Management programs in many countries (6,13,15).

However, when solarization is used alone, it has been reported to be unsatisfactory against some soilborne pathogens such as *Verticillium* spp. and root-knot nematodes (4,11). In order to increase the control effectiveness and to guard against environmental resistance, combined applications should be evaluated. Thus, the purpose of this study was to evaluate the effectiveness of solarization in combination with a reduced dose of MS against soilborne pathogens and nematodes in naturally contaminated tomato greenhouses in the eastern Mediterranean region of Turkey.

MATERIALS AND METHODS

Characteristics of the greenhouse soils The experiments were conducted in two greenhouses with a history of Fusarium crown and root rot caused by *F. oxysporum* sp. *radicis-lycopersici* (*Forl*) and nematodes (*Meloidogyne javanica* and *M. incognita*), in Erdemli and Mersin provinces in the eastern Mediterranean region of Turkey (3). Tomatoes had been cultivated in these greenhouses for the last 15 years, and the levels of *Forl* and nematodes were recorded in early 2000 (21). Disease incidence of 80% was detected in greenhouse 1 and of 30% in greenhouse 2; high galling indexes (6–7) were recorded from the previous cultivation. MS was applied for the first time in both greenhouses, which had similar soil structure, pH values and organic matter content (Table 1).

Fumigant applications The greenhouses were divided into blocks of 45 $\times$ 5.5 m, and seven treatments (solarization, MS 1250 l ha^{-1}, MS 500 l ha^{-1} + solarization, MS 1000 l ha^{-1} + solarization, MS 750 l ha^{-1} + solarization, dazomet + solarization, and control) were tested. MS (Sniper Fluid, 500 g a.i. l^{-1}) and dazomet (Basamid, 98%, granules) were used as soil fumigants, and low dosages of MS were combined with solarization (Table 3). Dazomet (400 kg ha^{-1}) was added, and mixed with greenhouse soil irrigated to field capacity. Following soil preparation, a drip irrigation system was installed, and mulching was done with 0.04-mm-thick plastic sheeting. For MS application, pipes were arranged at 30-cm intervals. The required amount of MS was prepared according to the manufacturer's instructions. It was then applied to mulched soil through the drip irrigation system. In order to wash out the remaining MS within the drip irrigation system, a further irrigation was applied. The total amount of water used for application of MS was 10 l m^{-2}.

Each plot measured approximately 35 m^2 (7 m × 5 m), and consisted of five rows, each of which had 16 plants. The distance between rows and between plants was 90 cm and 40 cm, respectively. Thirty plants for each plot were evaluated, and two border rows were not considered in the calculations. The experimental design consisted of four replications of each of the seven treatments.

Treatments continued for 5 weeks, from July 15 to August 19. Only the MS 1250 *l* ha^{-1} application was done 2 weeks before transplanting; tomato seedlings were planted on August 27, 2005.

Soil temperatures were recorded by data loggers (Onset Computer Corporation, Bourne, MA, USA) placed at depths of 5, 15 and 25 cm in solarized and non-solarized soil.

Effects of treatment on soilborne pathogens and nematodes The plants were periodically examined during the vegetation period for soilborne diseases. Thirty plants from each plot were uprooted approximately 5 months (on January 21) after transplanting and were examined for diseases. Records were kept of plants exhibiting discoloration at the crown, or in xylem and phloem tissues, and the plants were taken to the laboratory for pathogen isolation studies.

Disease incidence was calculated according to the formula: $MG_1\% = [(D_C - D_T)/D_C].100$, where $MG_1\%$ = the percent effect, D_C = number of diseased plants in control, and D_T = number of diseased plants in treatments.

The population density changes of *M. incognita* second stage juveniles (J2) from soil were recorded for each replicate before treatment applications and at the end of the growing season in order to determine both initial population (IP) density and final population (FP) density. Soil samples were taken from replicated plots (12 m^2 each) by removing three cores from the 0 – 30-cm soil layer. Soil nematodes were extracted using a modified Baermann funnel method (12). J2 root-knot nematodes were collected from 100 g of soil and counted under a light microscope.

The root galling index was determined on ten plant root systems per plot using a galling index scale of 0 to 10 (1), where 0 = roots with no galls and 10 = roots with maximal degree of galling at the end of the growing season.

Statistical analysis The data were statistically analyzed according to Student's t-test, and all analyses were performed by least significant difference (LSD) at the P=0.05 confidence level.

RESULTS

Forl was isolated from the plants exhibiting root rot and wilting (3), and the gall-forming nematodes were identified as *M. incognita* (21).

TABLE 1. Soil characteristics in the two greenhouse experiments

Site	Soil type	Organic matter (%)	Clay (%)	Silt (%)	Sand (%)	pH
Greenhouse 1	Sandy clay loam	3.0	26	26	48	8.1
Greenhouse 2	Loam	3.3	26	30	44	8.0

Soil temperatures Maximum soil temperature (49.0°C) was recorded at the 5-cm soil depth, and was 6°C higher than that of non-solarized control plots. The maximum soil temperatures in solarized plots at the 15- and 25-cm soil depths were 45.3°C and 40.2°C, respectively. In non-solarized plots, the corresponding soil temperatures were 39.6°C and 36.0°C (Table 2). The mean soil temperatures at the 15-cm soil depth in solarized and non-solarized plots are shown in Figure 1.

Effects of treatments on soilborne pathogens Disease incidence (*Forl*) in non-solarized control plots in greenhouses 1 and 2 was 82.4% and 34.1%, respectively (Table 3). Solarization alone reduced the disease incidence to 49.9% and 10.8% in greenhouses 1 and 2, respectively.

TABLE 2. Maximum soil temperatures (°C) in solarized and non-solarized plots during the application period, July 7 – Aug. 19, 2005 (temperatures were recorded hourly with a data logger)

Depth (cm)	Solarized soil	Non-solarized soil
5	49.0	42.9
15	45.3	39.6
25	40.2	36.0

TABLE 3. Incidence of tomato Fusarium crown and root rot and effectiveness of treatments in two greenhouses

Treatment	Greenhouse 1		Greenhouse 2	
	Disease incidence (%)	Effectiveness (%)	Disease incidence (%)	Effectiveness (%)
Solarization (Sol)	49.9.0 b[z]	39.0 c	10.8 b	67.2 b
MS 1250[y]	40.8 c	50.2 b	5.8 bc	81.5 ab
MS 500 + Sol	46.6 bc	43.1 bc	9.1 bc	72.3 ab
MS 750 + Sol	44.9 bc	45.3 bc	8.3 bc	75.7 ab
MS 1000 + Sol	22.4 d	72.5 a	4.1 bc	88.6 ab
Dazomet + Sol	21.6 d	73.9 a	3.3 c	90.9 a
Control	82.4 a		34.1 a	
LSD (*P*=0.05)	3.8	4.2	6.4	12.9

[z]Within columns, means followed by a common letter do not differ statistically (one-way ANOVA at $P\leq0.05$).
[y]MS = metham-sodium, at 1250, 500, 750 or 1000 l ha^{-1}.

The effectiveness of reduced doses of MS (500, 750, 1000 l ha^{-1}) in combination with solarization in controlling pathogens was 43.1%, 45.3% and 72.5%, respectively, in greenhouse 1. Even better results were obtained in greenhouse 2, where the effectiveness of 1000 l ha^{-1} of MS in controlling soilborne pathogens was 88.6% (Table 3). However, dazomet combined with solarization reduced the disease incidence to 21.6% and 3.3% in greenhouses 1 and 2, respectively (Table 3). The effect of this treatment on disease incidence was similar to that of MS (1000 l ha^{-1}) combined with solarization in greenhouse 1. In greenhouse 2, having lower disease prevalence, the effectiveness in disease control of solarization combined with dazomet 400 kg ha^{-1} and MS 1000 l ha^{-1} applications was 90.9% and 88.6%, respectively.

Galling index and number of J2 larvae within the plant roots in treated plots were very low. Galling indexes of untreated control plots were 6.6 to 5.7, and all the treatments tested controlled root-knot nematodes until the end of the vegetation period. In summary, the MeBr alternatives tested in this study were effective in controlling gall formation caused by the root-knot nematodes; no statistical difference was observed among the various treatments (Table 4).

TABLE 4. Effect of different treatments on *Meloidogyne* spp. in tomato greenhouses during the 2005–06 growing season

Treatment	Greenhouse 1			Greenhouse 2		
	IP[z] (larva/ 100 g soil)	FP[z] (larva/ 100 g soil)	Galling index	IP (larva/ 100 g soil)	FP (larva/ 100 g soil)	Galling index
Solarization (Sol)	960	60 b[x]	0.3 b	368	20 b	0.2 b
MS 1250[y]	944	8 b	0 b	344	0 b	0 b
MS 500 + Sol	852	32 b	0.4 b	652	24 b	0.4 b
MS 750 + Sol	664	0 b	0 b	408	0 b	0 b
MS 1000 + Sol	892	8 b	0 b	572	0 b	0 b
Dazomet + Sol	472	16 b	0.2 b	388	0 b	0.2 b
Control	668	1460 a	6.6 a	448	1040 a	5.7 a
LSD (*P*=0.05)	n.s.	296	0.4	ns	137	0.3

[z] IP = initial population; FP = final population.
[y] MS = metham-sodium, at 1250, 500, 750 or 1000 *l* ha^{-1}.
[x] Within columns, means followed by the same letter do not differ statistically (one-way ANOVA at $P \leq 0.05$). n.s., not significant.

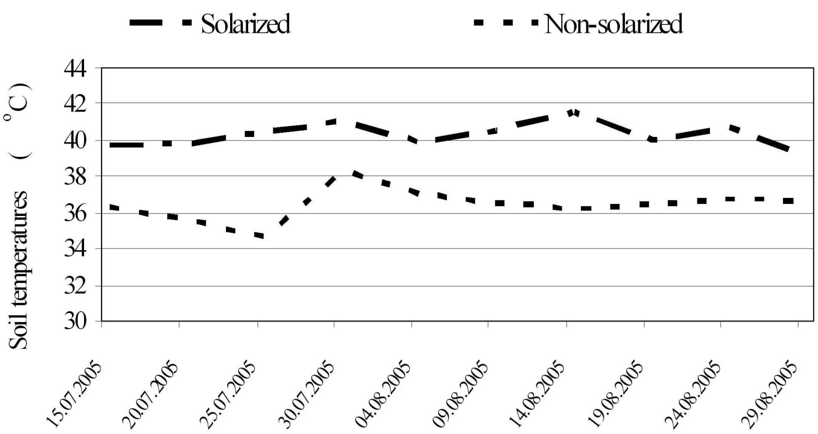

Fig. 1. Mean soil temperatures (°C) in solarized and non-solarized (control) plots during July and August 2005, at 15-cm depth.

DISCUSSION

Tomato, with total production of 9,440,000 t over an area of 255,000 ha, is an important crop in Turkey. Major fresh market tomato production is distributed over the Aegean, Mediterranean and Marmara regions, and extensive greenhouses are scattered over the eastern Mediterranean region of Turkey. The major factors restricting greenhouse tomato production are the soilborne pathogens and nematodes in the region (25). MeBr formerly was widely used to control these diseases and pests in greenhouse vegetable production in the area, but alternative methods have been tested extensively in the region since 1998 because of the need to phase out MeBr use by the end of 2007.

Data obtained in this study indicate that effective soil disinfestation could be achieved by a combination of physical and chemical applications to control Fusarium crown and root rot and root-knot nematodes in the eastern Mediterranean region of Turkey. Solarization combined with a low dose of MS (1000 *l* ha^{-1}) reduced disease incidence of *Forl* to a level similar to that of solarization in combination with dazomet that is widely applied by the farmers. A related study (10) comparing the effects of MS at 900 *l* ha^{-1}, solarization and the two treatments combined, revealed that yields of peanut pods without necrotic spots increased by 114%, 440% and 893%, respectively. The study reported that pre-wetting the soil with MS instead of water when preparing the soil for solarization may be useful in controlling additional soilborne disease agents. Similar results were reported by Tjosvold in floriculture and nurseries (22), and MS (935 *l* ha^{-1}) combined with solarization for 6 weeks was considered to be a good alternative to MeBr.

Root-knot nematodes were also effectively reduced, and gall formation decreased during the growth period, by all the treatments tested in this study, without any statistical difference among them. Previous tests conducted in the same region by our group in greenhouses where cucumber, pepper, eggplant and strawberry were grown resulted in effective control of root-knot nematodes by solarization alone or in combination with a low dose of dazomet (24).

Studies have revealed that MS, chloropicrin, 1,3-dichloropropene, 1,3-dichloropropene + 17% chloropicrin, and 1,3-dichloropropene + 35% chloropicrin as alternatives to MeBr are effective in tobacco, tomato and pepper pest and disease control (5). The fumigants were used alone or in combination for 2 years in three different areas for weed, insect and nematode control, and MS application was found to be the most effective.

The soil temperature values reported in this study are 2–3°C lower than those in similar studies conducted in the eastern Mediterranean region (23). The latter study was conducted in a greenhouse close to the Mediterranean Sea and having sandy soil, whereas the soil used in the present study was a sandy clay loam (medium heavy). It is assumed that the difference in soil temperature may have resulted from such factors as variations in soil structure, different climate, or the geographical characteristics of the experimental area.

Forl and root-knot nematodes in the greenhouse-grown tomatoes could be effectively controlled by solarization combined with 1000 *l* ha^{-1} MS, similar to solarization combined with 400 kg ha^{-1} dazomet. Furthermore, both of these combined treatments had the same effect on disease incidence in greenhouse 1, with its history of high *Forl* incidence (Table 3), indicating that solarization increased the effect of MS applied at low doses.

The results of the present study suggest that all the treatments tested in greenhouses with soilborne pathogens and nematodes could be adopted in the eastern Mediterranean region of Turkey. In this region a combined treatment of solarization and fresh cow manure has already been accepted and is applied in greenhouses with a history of minor disease contamination. The farmers, however, prefer solarization in combination with low doses of soil fumigants in monoculture greenhouses having high disease incidence. This necessitates more research on the effect of solarization combined with reduced doses of soil fumigants. Further studies are planned in order to determine whether or not there is a substantial decrease in the effect of MS following several years of repeated applications.

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