Solarizing Soil Planted with Cherry Tomatoes vs. Solarizing Fallow Ground for Control of Verticillium Wilt

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ABSTRACT

Morgan, D. P., Liebman, J. A., Epstein, L., and Jimenez, M. J. 1991. Solarizing soil planted with cherry tomatoes vs. solarizing fallow ground for control of Verticillium wilt. Plant Dis. 75:148-151.

Soil solarization reduces inoculum of *Verticillium dahliae* in the San Joaquin Valley, California, but is in limited use, partly because the treatment must be applied during the summer, which interferes with normal production schedules. We compared the efficacy of polyethylene mulches applied to fallow ground with mulches applied to ground planted with cherry tomatoes (*Lycopersicon esculentum*). Mulches applied on tomato plots for the entire growing season (17 April–1 September) controlled Verticillium wilt as effectively as mulches on fallow soil. Compared with nonsolarization, full-season solarization significantly reduced soil inoculum density of *V. dahliae*, reduced the percentage of infected plants the year the mulches were applied and the subsequent year on cherry tomatoes and eggplants (*Solanum melongena*), and increased yields of tomatoes and eggplants the year after the mulch application. Although mulches applied midseason (25 June) to tomatoes were relatively ineffective in controlling Verticillium wilt, mulches applied late in the season (30 July) to fallow plots were somewhat effective in controlling Verticillium wilt. Because soil solarization did not unduly interfere with normal agronomic practices, application of polyethylene mulches early in the season may provide a useful means of controlling Verticillium wilt in cherry tomatoes.

Verticillium wilt of cherry tomato (*Lycopersicon esculentum* Mill. var. *cerasiforme*) and eggplant (*Solanum melongena* L.), caused by *Verticillium dahliae* Kleb., is a serious disease in California's San Joaquin Valley. All commercially desirable cherry tomato and eggplant cultivars are susceptible to Verticillium wilt. Although this disease can be controlled by fumigation with chloropicrin-methyl bromide (17), less expensive and nonchemical methods are desired.

Soil solarization has controlled *V. dahliae* and other soilborne pathogens (6,9,10,15), certain nematodes (12), and weeds (5,8,14) in some areas. To solarize soil, polyethylene mulches generally are laid on fallow ground during the warmer summer months (16). Although this treatment reduces inoculum density of *V. dahliae* (13), few San Joaquin Valley growers use the technique because losing a season's production is too expensive.

In a limited number of studies, mulches have been applied to planted, rather than fallow, fields (1). The efficacy of mulching in planted fields appears to depend on the distribution of foliage. In solarized cotton, inoculum density of *V. dahliae* was reduced in the sunny areas between cotton rows to a greater extent than in the shaded areas within the rows (11).

We postulated that solarizing cherry tomatoes could reduce the inoculum density of *V. dahliae* and disease incidence because cherry tomato vines are staked and the soil surface remains relatively unshaded. In addition, plastic mulches are compatible with standard procedures for cherry tomato production.

We compared the efficacy of solarizing fields planted with cherry tomatoes with that of solarizing fallow ground. Mulches were applied at several times during the growing season. We monitored inoculum density in the soil, incidence of Verticillium wilt, and fruit yield during both the year mulches were applied and the following year.

Accepted for publication 16 July 1990 (submitted for electronic processing).

MATERIALS AND METHODS

Field site. The experiments were conducted in a plot with Panoche sandy clay loam at the Westside Field Station, University of California, Five Points. The field had a history of cotton cultivation and a high inoculum density of *V. dahliae*.

Experimental design. In 1987, there were six treatments, each with four replicate plots: nonmulched tomato control, tomatoes mulched 3 days before planting on 17 April, tomatoes mulched midseason on 25 June, nonmulched fallow control, fallow mulched on 17 April, and fallow mulched late in the season on 30 July.

The rationale for each mulching date was as follows: 17 April was sufficiently late in the season to expect good solarization yet early enough to still obtain a good yield; 25 June was appropriate for a grower who, after realizing the severity of the problem, wanted to apply a midseason treatment to reduce *V. dahliae*; and 30 July was sufficiently late in the season that a grower could obtain most of the season's yield, remove the plants, and still have sufficient time for solarization on fallow ground.

To determine the long-term effect of the 1987 mulching treatments, alternating rows of FSU Dwarf cherry tomatoes and Black Bell eggplants were planted in all plots on 6 April 1988.

Polyethylene mulches. For the mulched treatments, the soil surface was covered with clear, 4-mil, ultraviolet-stabilized polyethylene (Nutri-Gro Greenhouse FS, Visqueen Division, Ethyl Corporation, Richmond, VA). Polyethylene strips, 2.4 m wide, were rolled onto the soil and secured with metal prongs 10 cm long. Adjacent strips were taped together (Monsanto All-Purpose Tape). To further hold the mulch in place, soil was piled onto the polyethylene around the perimeter of each replicate plot. For the fallow mulched treatments, the plots were flood-irrigated 7 days before mulching. For the 17 April mulch on plots with tomatoes, the seedlings were planted through 5-cm holes cut in the polyethylene sheets. For the 25 June mulch on plots with established tomatoes, the polyethylene strips were pulled between the rows. Each 2.4-m wide strip had approximately 0.25 m turned under on each side so that the sheets in adjacent rows overlapped. The strips of polyethylene in adjacent rows were attached with tape and metal prongs. All mulches were removed on 1 September 1987.

Plots. In 1987 for the treatments with tomatoes, each plot consisted of six east-west-oriented rows, 9 m long, with 1.52 m between rows and 0.6 m between plants in a row. Drip irrigation lines were installed before any plastic mulches were applied. FSU Dwarf cherry tomato seedlings (70 days old) were planted on 20 April 1987. Plant growth was directed upward by confining the plants with string interwoven between stakes placed every 1.2 m. At the end of the growing season, the tomato plants and adhering roots were removed from the field and the plots were plowed.

In 1988, 70-day-old FSU Dwarf cherry tomatoes and 90-day-old Black Bell eggplants were transplanted into every plot. Alternating rows of tomatoes and eggplants were planted 0.92 m apart. The rows were oriented north-south, which was perpendicular to their orientation in 1987.

A preplant application of napropamide (Devrinol) was used to control weeds. In plots with plants, soil moisture levels were monitored with tensiometers in 1987 and neutron probes in 1988. Irrigation levels were adjusted to maintain the water potential at approximately field capacity (−35 kPa).

Inoculum density. To monitor the inoculum density of *V. dahliae*, soil cores 2 cm in diameter were collected from depths of 0–30 and 30–60 cm. In 1987 in fallow plots, the cores were collected randomly. In plots with tomatoes, separate samples were taken within and between plant rows. In 1987, four soil cores per replicate plot were collected 5 days before planting and 43, 87, and 135 days after planting. In 1988, 10 or 20 cores were collected from plots that were fallow or planted in 1987, respectively. In 1988, soil samples were collected 5 and 195 days after planting. The multiple soil samples for each replicate plot were combined and air-dried. The density of *V. dahliae* microsclerotia in soil was determined on two aliquots per replicate using the wet sieving method (4). Pectate agar (7) amended with 200 mg/L of penicillin G sodium salt was used as a selective medium.

Plant infections. To determine the percentage of plants infected with *V. dahliae*, basal stem sections, 10–15 cm long, were excised from plants after the final harvest. On 10 September 1987, 20 plants were sampled from each plot. On 13 and 26 October 1988, 18 tomato plants and 24 eggplants were sampled per plot, respectively. Stem sections were dipped in 70% EtOH for 1 min, then immersed in 0.5% NaOCl for 5–7 min. Approximately 1-mm-thick cross sections from each stem piece were plated onto pectate agar (7). A plant was considered infected if *V. dahliae* was detected in any of the sections from a single plant.

Fruit yield. In 1987, tomatoes in the middle rows of each plot were harvested on 21 July and 28 August. In the tomato plots mulched on 17 April, approximately 25% of the transplants died from excessive temperature during an unusual heat wave the week following transplanting. Plants that survived transplanting grew normally. For the 17 April treatment only, yields in 1987 were calculated from portions of rows in which there was a minimum of 4 m of contiguous plants. Consequently, total length of row used for yield determination of the 17 April treatment was approximately 68% of the standard length of row.

In 1988, tomatoes from the three center rows were harvested on 19 July, 9 August, 14 September, and 11 October 1988. In addition to determining yield, for the final two harvests in 1988, tomatoes were sorted by size; tomatoes having a diameter ≤2.2 cm were considered undersized.

At the end of the summer growing season in 1988, the eggplants were cut back to allow regrowth. New eggplant fruits were harvested in October. For all eggplant harvests, eggplants from the two center rows were graded as either marketable or nonmarketable, then weighed. Marketable eggplants had a diameter ≥8.2 cm and a uniform dark color; nonmarketable eggplants were classified as discolored (pale), sunburned, or undersized (<8.2 cm diameter). Marketable eggplants were harvested and weighed on 12, 19, and 29 July; 28 September; and 10, 17, and 24 October. Nonmarketable fruits were picked and weighed on 28 July and 24 October.

Statistical analysis. There were four replicate plots per treatment in a completely randomized design. Treatment means were compared with Fisher's protected *F* test.

RESULTS

Inoculum density. The 17 April mulch with tomatoes and the 17 April fallow mulch were equally effective in reducing

Table 1. Effect of polyethylene mulches on inoculum densities of *Verticillium dahliae* in soil[v]

Treatment 1987			Microsclerotia per gram of soil[w]					
				Midseason 1987			Postmulching 1988	
Mulching date	**Crop**	**Sampling location**	**Premulching 1987**	**1 June**	**15 July**	**2 Sept.**	**12 Apr.**	**1 Nov.**
Sampling depth: 0–30 cm								
17 April	Tomatoes	Between row	77 ± 22[x]	3 ± 3	0.03 ± 0.02	0.0 ± 0	0.05 ± 0.06	0.07 ± 0.08
		Within row	NA	20 ± 10	5 ± 4	3 ± 2	NA	NA
	Fallow	NA	80 ± 13[x]	0.5 ± 0.4	0.01 ± 0.02	0.0 ± 0	0.05 ± 0.07	0.2 ± 0.4
25 June	Tomatoes	Between row	101 ± 10[y]	NA	3 ± 3	0.02 ± 0.04	4 ± 2	4 ± 2
		Within row	112 ± 29[y]	NA	101 ± 27	23 ± 4	NA	NA
30 July	Fallow	NA	52 ± 6[z]	NA	NA	0.0 ± 0	0.04 ± 0.05	0.05 ± 0.07
Nonmulched	Tomatoes	Between row	83 ± 10[x]	101 ± 10	89 ± 25	71 ± 20	63 ± 11	57 ± 16
		Within row	NA	112 ± 29	101 ± 23	107 ± 6	NA	NA
	Fallow	NA	65 ± 21[x]	86 ± 11	52 ± 6	77 ± 20	61 ± 11	48 ± 5
Sampling depth: 30–60 cm								
17 April	Tomatoes	Between row	5 ± 3[x]	3 ± 3	0.01 ± 0.02	0.0 ± 0	0.009 ± 0.02	0.009 ± 0.02
		Within row	NA	3 ± 1	0.4 ± 0.8	0.1 ± 0.05	NA	NA
	Fallow	NA	9 ± 8[x]	1 ± 1	0.01 ± 0.02	0.0 ± 0	0.009 ± 0.02	0.03 ± 0.04
25 June	Tomatoes	Between row	12 ± 4[y]	NA	3 ± 5	0.03 ± 0.04	0.09 ± 0.05	0.2 ± 0.2
		Within row	13 ± 9[y]	NA	11 ± 7	1 ± 0.4	NA	NA
30 July	Fallow	NA	15 ± 9[z]	NA	NA	0.0 ± 0	0.02 ± 0.02	0.6 ± 1
Nonmulched	Tomatoes	Between row	4 ± 2[x]	12 ± 4	12 ± 6	6 ± 6	3 ± 1	3 ± 2
		Within row	NA	13 ± 9	14 ± 9	9 ± 5	NA	NA
	Fallow	NA	6 ± 5[x]	15 ± 6	15 ± 9	7 ± 3	3 ± 1	2 ± 1

[v] Mulches were clear, 4-mil, ultraviolet-stabilized polyethylene; all were removed on 1 September 1987. Cherry tomatoes (FSU Dwarf) were transplanted on 20 April 1987. In 1988, all plots were planted to alternating rows of cherry tomatoes (FSU Dwarf) and eggplants (Black Bell).

[w] Soil cores (2-cm diameter) were collected from depths of 0–30 and 30–60 cm. In 1987, four cores per replicate plot were collected. In 1988, 10 or 20 cores per replicate plot were collected from plots either fallow or planted in 1987, respectively. Cores from each plot were bulked, and the number of microsclerotia of *V. dahliae* per gram of soil was determined by the wet sieving method (4). There were two determinations of microsclerotial density for each soil sample and four replicate plots per treatment. Values are the means ± the standard deviation. NA = not applicable.

[x] Sampled 15 April 1987.

[y] Sampled 1 June 1987.

[z] Sampled 13 July 1987.

inoculum of *V. dahliae* (Table 1), although inoculum levels declined faster in the fallow mulch. In the 17 April mulch treatments, the inoculum density declined faster in soil samples taken between the tomato rows than in samples taken within the rows.

The 25 June mulch on tomato plots was relatively effective in reducing inoculum of *V. dahliae* in soil from between the rows but ineffective in fully reducing soil inoculum within the rows. The 30 July mulch on fallow ground effectively reduced *V. dahliae* soil inoculum by the 2 September sampling date.

After inoculum levels were reduced in 1987, *V. dahliae* soil inoculum remained low throughout the 1988 growing season. Inoculum densities in soil 30–60 cm deep were generally similar to those in the 0–30 cm soil profile.

Plant infections. Almost 100% of the plants in the nonmulched control plots were infected with *V. dahliae* during both 1987 and 1988 (Table 2). Early (preseason) application of the mulch (17 April) reduced the percentage of infected plants to 6% in 1987. The percentage of infected plants in the preseason mulched plots was reduced again in the following year, but not as dramatically as in the year the mulches were applied. In the plots that were mulched on 17 April 1987, the percentage of infected plants was similar on eggplants and tomatoes in 1988, regardless of whether the preseason mulches were left fallow or planted with tomatoes.

The midseason (25 June) mulch on tomatoes did not reduce the percentage of infected plants. However, the late-season (30 July) mulch on fallow ground did reduce the percentage of infected tomatoes and eggplants in the subsequent year.

Fruit yield. In 1987, tomato yields were similar in all mulching treatments (Table 3). In the year following mulching, tomato yields were significantly greater in all mulching treatments than in nonmulched treatments. Tomato yields in 1988 were higher in plots mulched in 1987 on 17 April than in plots mulched on 25 June or 30 July. Overall, mulching on 17 April 1987, on either fallow plots or plots planted with tomatoes, resulted in 38 and 55% increases in tomato yields in 1988, respectively. However, the economic gains of the mulching treatment are not fully indicated by the total yield data. In the final two harvests in 1988, undersized tomatoes were weighed separately. Plots mulched on 17 April 1987 produced significantly fewer undersized fruit in 1988 than plants on nonmulched plots.

In 1988, eggplant yields also were significantly increased in the plots solarized on 17 April compared with the nonmulched controls. Solarization on 25 June or 30 July increased eggplant yields in the subsequent year, but not as much as when mulches were applied on 17 April.

The significant increase in the marketable eggplant yield in plots mulched on 17 April was attributed to two factors: 1) a significant increase in total fruit biomass produced in the mulched plots (statistical analysis not shown) and 2) a general increase in the percentage of nonmarketable fruits, particularly undersized fruits, in the eggplants in the nonmulched plots.

DISCUSSION

This study confirms other reports (1,11,15) that soil inoculum densities of *V. dahliae* can be reduced with polyethylene mulches applied on planted fields. In this study, mulches applied 3 days before tomatoes were transplanted through the polyethylene were as effective at reducing *V. dahliae* inoculum as mulches applied on the same date on fallow soil. However, mulches applied to nearly full-size plants on 25 June were less effective in controlling *V. dahliae* than the 17 April mulches. For both the 17 April and 25 June mulching treatments, the mulches were less effective in reducing *V. dahliae* inoculum within the tomato rows than between the rows. These and other data (1,3,11,15) suggest that polyethylene mulches can effectively reduce *V. dahliae* inoculum if the foliage density is sparse and the soil is not shaded. In the current study, tomato transplants provided sufficient shade to reduce the efficacy of the solarization treatment within plant rows. Apparently, mulches in planted fields need to be applied early in the growing season

Table 2. Effect of polyethylene mulches on incidence of Verticillium wilt[y]

Treatment 1987		Percentage of plants infected[z]		
		1987	1988	
Mulching date	Crop	Tomato	Tomato	Eggplant
17 April	Tomato	6 a	39 a	39 a
	Fallow	NA	28 a	45 a
25 June	Tomato	94 b	85 b	94 c
30 July	Fallow	NA	35 a	66 b
Nonmulched	Tomato	99 b	100 b	100 c
	Fallow	NA	99 b	99 c

[y] Mulches were clear, 4-mil, ultraviolet-stabilized polyethylene; all were removed on 1 September 1987. Cherry tomatoes (FSU Dwarf) were transplanted on 20 April 1987. In 1988, all plots were planted to alternating rows of cherry tomatoes (FSU Dwarf) and eggplants (Black Bell).

[z] Basal stem sections approximately 1 mm thick from each of 18–24 plants from each of four replicate plots were plated onto selective pectate medium (7). A plant was considered infected if *V. dahliae* was detected in any section. Values followed by the same letter within a column were not significantly different (Fisher's protected *F* test, $P = 0.05$). NA = not applicable.

Table 3. Effect of polyethylene mulches on yield of cherry tomato and eggplant[y]

Treatment 1987		Yield (kg/ha)[z]					
		Cherry tomatoes			Eggplant 1988		
		1987	1988			Nonmarketable	
Mulching date	Crop	Total	Total	Undersized yield from final two of four harvests	Marketable	Undersized	Discolored or sunburned
April 17	Tomato	59,616 a	99,330 a	1,651 a	56,739 a	7,208 a	1,038 a
	Fallow	NA	83,652 b	945 a	48,683 ab	13,454 bc	1,072 a
June 25	Tomato	64,547 a	74,550 c	3,312 bc	40,442 bc	12,119 b	1,314 a
July 30	Fallow	NA	78,652 bc	1,904 ab	32,094 c	14,899 c	1,398 a
Nonmulched	Tomato	62,529 a	64,160 d	3,264 bc	33,666 c	13,966 bc	1,470 a
	Fallow	NA	60,770 d	3,801 c	21,615 d	17,717 d	3,047 a

[y] Mulches were clear, 4-mil, ultraviolet-stabilized polyethylene; all were removed on 1 September 1987. In 1987, cherry tomatoes (FSU Dwarf) were transplanted on 20 April. In 1988, all plots were planted to alternating rows of cherry tomatoes (FSU Dwarf) and eggplants (Black Bell).

[z] Fruit of cherry tomatoes (FSU Dwarf) and eggplants (Black Beauty) from each of four replicate plots were harvested and weighed. Cherry tomatoes ≤2.2 and eggplants <8.2 cm in diameter were considered undersized. Values followed by the same letter within a column were not significantly different (Fisher's protected *F* test, $P = 0.05$). NA = not applicable.

before the plant canopy creates too much shade. Mulches in planted fields may also need to be left on the ground for longer periods of time than mulches on fallow ground. It is important to note that while solarization of planted fields can reduce the inoculum density of *V. dahliae* in soil, there is no evidence that solarization affects *V. dahliae* in infected root tissue.

Even though inoculum density was greatly reduced in the mulched treatments, the percentage of infected plants was still relatively high. This was true for solarization of both planted and fallow plots. Several factors may have contributed to this result. First, the tomato and eggplant cultivars were both susceptible to Verticillium wilt. Second, the initial inoculum density in our field was unusually high. Relatively low inoculum densities of *V. dahliae* can cause high levels of disease incidence in several crops (2,13). For example, Ashworth et al (2) reported nearly 100% infection of tomatoes grown in soil with only 0.1 microsclerotia per gram of soil. We sampled soil from five local commercial tomato fields that had histories of Verticillium wilt and in which plants had symptoms of Verticillium wilt in the current year. In the 0- to 30-cm cores, the soil inoculum density of *V. dahliae* was 0.03, 0.04, 0.19, 0.21, and 0.41 microsclerotia per gram. In contrast, our experimental plots initially contained 52–112 microsclerotia per gram of soil. Although the high inoculum levels allowed us to detect treatment effects on inoculum density, the high inoculum levels also appear to have caused higher disease incidence overall, which masked the effects of the treatments on disease incidence.

We used plastic 4 mil thick to ensure that the polyethylene would withstand the foot traffic while vines were being tied and fruit were being harvested. The cost of polyethylene is proportional to the thickness, and 2-mil ultraviolet-stabilized plastic would be cheaper and should be satisfactory for a single season. We did not drive tractors or heavy equipment over the mulch.

Further research is needed to determine whether the 17 April mulching date is the most advantageous. Most commercial growers in the San Joaquin Valley transplant during late February to early March rather than mid-April, as we did. Mulching and planting earlier in the season would reduce the risk of heat shock. However, mulching earlier in the season may result in a slower decline of *V. dahliae* (1) and a higher percentage of infection in the crop.

In conclusion, once soil inoculum levels of *V. dahliae* were reduced with a polyethylene mulch, the inoculum density remained low throughout the next growing season. Our data suggest that polyethylene mulches on fields with cherry tomatoes can be as effective in reducing *V. dahliae* as mulches on fallow soil. Transplanting cherry tomatoes through polyethylene does not adversely affect yield in the current year and results in a significant reduction of *V. dahliae* in soil, a reduction in percentage of infected plants, and an increase in yield in the subsequent year. Applying mulches at midseason is less effective. If early-season mulching is not possible, our data suggest that after an early harvest, late-season mulches on fallow ground may be more effective than midseason mulches on cropped ground.

ACKNOWLEDGMENTS

We thank the Ethyl Corporation, Visqueen Film Products Division, Richmond, Virginia, for the donation of polyethylene, and the Westside Field Station employees for their assistance. This research was partly supported by a grant from the University of California Statewide Integrated Pest Management Project.

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