Supplement to Journal of Nematology 24(4S):681–687. 1992.

Establishment of Orchards With Black Polyethylene Film Mulching: Effect on Nematode and Fungal Pathogens, Water Conservation, and Tree Growth

R. A. DUNCAN,[1] J. J. STAPLETON,[1] AND M. V. MCKENRY[2]

Abstract: Placement of a 3-m-wide, black, polyethylene film mulch down rows of peach (*Prunus persica* 'Red Haven' on 'Lovell' rootstock) and almond (*Prunus dulcis* 'Nonpareil' on 'Lovell') trees in the San Joaquin Valley of California resulted in irrigation water conservation of 75%, higher soil temperature in the surface 30 cm, a tendency toward greater root mass, elimination of weeds, and a greater abundance of *Meloidogyne incognita* second-stage juveniles in soil but reduced root galling when compared to the nonmulched control. Population levels of *Pratylenchus hexincisus*, a nematode found within tree roots, were reduced by mulching, as were those of *Tylenchulus semipenetrans*, which survived on old grape roots remaining from a previously planted vineyard, and *Paratrichodorus minor*, which probably fed on roots of various weed species growing in the nonmulched soil. Populations of *Pythium ultimum* were not significantly changed, probably also due to the biological refuge of the old grape roots and moderate soil heating level. Trunk diameters of peach trees were increased by mulching, but those of almond trees were reduced by the treatment. Leaf petiole analysis indicated that concentrations of mineral nutrients were inconsistent, except for a significant increase in Ca in both tree species.
Key words: almond, irrigation management, *Meloidogyne incognita*, mulching, nematode, peach, *Paratrichodorus minor*, *Paratylenchus hamatus*, *Pratylenchus hexincisus*, *Prunus dulcis*, *Prunus persica*, *Pythium ultimum*, soil heating, solarization, *Tylenchulus semipenetrans*.

Long-term mulching with plastic film, commonly practiced in row crop culture, has been tested successfully for water conservation, weed management, and growth promotion in landscape and fruit tree culture (2,3,15). Because this type of mulching normally elevates soil temperature, a solarization effect might be expected, resulting in reductions of soil-borne pests including certain nematode species, fungal pathogens, and nonspecific replant diseases perhaps involving complexes of pathogens and nematodes (1,5,7,11,12,14, 16). Young trees can be injured by excessive root temperature (6,9,11), and in the San Joaquin Valley of California, which is characterized by hot summers, such injury resulting from in-season film mulching has sometimes been found, especially when clear film (resulting in maximal heating), rather than black film (milder heating), has been used (14). Other reports have indicated no injury or growth retardation (13). Previous experiments indicated that up to 90% reduction in irrigation water volume could be achieved using in-season mulching under various irrigation systems (11,13).

As a result of reductions in irrigation water quotas and restrictions on groundwater usage in California due to a prolonged drought, as well as interest in producing crops with minimal pesticide input, the possibility of using film mulching to conserve irrigation water during orchard establishment while managing soilborne pests by solarization is under investigation.

The field experiments described in this paper were designed to evaluate effects of in-season mulching with black polyethylene film on numbers of soilborne nematodes and fungal pathogens, on plant and soil water status, and on growth and establishment of first-leaf peach and almond or-

Received for publication 16 March 1992.
[1] Statewide Integrated Pest Management Project, Kearney Agricultural Center, University of California, Parlier, CA 93648.
[2] Department of Nematology, University of California, Riverside; headquartered at Kearney Agricultural Center.
We thank R. S. Johnson and S. Kaku for technical assistance; The Burchell Nursery Inc., Modesto, California, and Agri-Sun Nursery, Selma, California for gifts of bareroot trees; and AEP Industries Inc., Moonachie, New Jersey, and Trical, Inc., Hollister, California, for providing polyethylene film. We acknowledge the USDA-CE Smith-Lever IPM Implementation Fund for partial financial support of these studies.

chard trees in an area with a hot summer climate.

Materials and Methods

Two field experiments were conducted on Hanford sandy loam soil (46% sand, 45% silt, 9% clay) at the University of California Kearney Agricultural Center, Parlier, California, in 1991–92. Both plots were planted in nonfumigated soil that contained remnants of grape (*Vitis vinifera*) roots from a vineyard removed the previous year. Both sites harbored populations of several pathogens, including *Meloidogyne incognita, Pratylenchus hexincisus, Tylenchulus semipenetrans, Paratrichodorus minor,* and *Pythium ultimum.* A crop of oats (*Avena sativa*) was grown between the removal of the vineyard and the initiation of these experiments. Initial levels of *P. ultimum* in each site were determined by removing 6 soil cores (2-cm-d) at depths of 0–30 cm and 30–60 cm. Soil populations of *P. ultimum* were determined by dry-plating aliquots of soil on selective agar medium (13).

Bareroot peach (*Prunus persica* 'Red Haven' on 'Lovell' peach rootstock) and almond (*Prunus dulcis* 'Nonpareil' on 'Lovell') trees were planted in adjacent blocks in May 1991 and flood irrigated. The Lovell rootstock is susceptible to *M. incognita.* Both experiments were arranged as randomized complete blocks with six replications of mulched or nonmulched trees and 10 trees per replication. The plots were flooded again 2 weeks later to bring the soil moisture back to field capacity prior to mulch application. Black, embossed, 0.031 mm-thick polyethylene film ('Sunfilm-200'; AEP Industries, Inc., Moonachie, NJ) was applied to half of the replications in each experiment on May 31. The mulch was applied by unrolling a strip of polyethylene film (1.5 m wide) down both sides of the tree row, gluing them together along the center, and burying the outside edges, forming a seal over the soil. Soil temperature data at 15 and 30 cm depths in mulched and nonmulched plots were continuously recorded during June–August using a CR21X data logger and soil temperature probes (Campbell Scientific, Logan, UT).

Nonmulched trees were flood irrigated on a 2 to 2.5-week schedule (ca. 227 liters/tree/irrigation) and were fertilized twice during the season with calcium-ammonium-nitrate (11.6% NO_3-N, 5.4% NH_4-N, 8.8%; Ca; CAN-17, Chevron Fertilizers, Pasadena, CA) at a rate of 57 g/tree. After the polyethylene film was applied, mulched trees received only one irrigation and fertilizer application (29 July) during the growing season. Soil moisture percentage was monitored weekly in the root zones of mulched and nonmulched trees by taking 2-cm-d cores at two depths, 0–30 and 30–60 cm, and oven-drying them. Midday leaf water potential of trees in all plots (three leaves/replication) was monitored by weekly pressure bomb readings (Soil Moisture Equipment Corp., Santa Barbara, CA) (8). Film mulch was kept in place from 31 May to 5 December 1991, a total of 27 weeks. After removing the mulch, soil was sampled to determine population densities of nematodes and *P. ultimum* in the root zones of mulched and nonmulched trees. Ten soil cores per replication were sampled ca. 10 cm from trunks at depths of 0–23 and 23–46 cm in peach and at depths of 0–7.5, 7.5–15, 15–23, and 23–46 cm in the almond trial. Nematodes were extracted from a 250-cm^3 aliquot of each soil sample by a combination of Cobb sieving and mist extraction, and then identified to species and counted.

Root samples (two samples per replication at the same depth ranges as soil samples) were taken from trees in February 1992. Volumes of soil (ca. 30 × 20 cm) were removed from the root zones ca. 8–10 cm from the tree trunks. Soil was washed through a 0.64-cm screen and roots were separated, weighed, and visually rated for severity of galling on the entire root mass (0–4 scale, with 0 = no galls; 1 = 1–25% galled; 2 = 26–50%; 3 = 51–75%; and 4 = 76–100% of root mass galled). Root samples were then cut into 5–10 mm lengths and nematodes were extracted in a mist chamber, identified, and counted.

Tree height and trunk girth were recorded at the end of the growing season. Leaf samples were collected in August and sent to the University of California Division of Agriculture and Natural Resources Diagnostic Laboratory in Davis for nutritional analysis.

F-tests were used to compare plant growth measurements, nematode densities and ratings, and *P. ultimum* densities between mulched and nonmulched treatments. All nematode and *P. ultimum* data were log-transformed ($\log_{10}$ [x + 1]) prior to data analysis. Nontransformed means are reported.

RESULTS

Soil moisture percentage in the root zones of the nonmulched trees decreased more rapidly than in the mulched trees due to the reduction in evaporative water loss by the polyethylene film (Fig. 1). Soil moisture levels were similar in the root zones of both tree species, decreasing about 50% by mass in the upper root zone (0–30) and 35–40% in the lower root zone (30–60 cm) of the nonmulched trees between each of the eight irrigations. In contrast, soil moisture percentage decreased only about 10% in the upper root zone and 22% in the lower root zone in a similar 2-week period following the irrigation in the mulched trees. Whereas the nonmulched soil lost moisture more quickly in the upper 30 cm of the root zone than in the 30–60 cm range, soil moisture under mulched trees was retained longer in the upper 30 cm than in the lower 30 cm. By the date of the midseason irrigation (62 days after the premulch irrigation) soil moisture had decreased to 7.0% and 6.4% in the upper and lower root zones of the mulched almond trees, respectively, and to 8.6% and 7.5% in the upper and lower root zones, respectively, of the mulched peach trees.

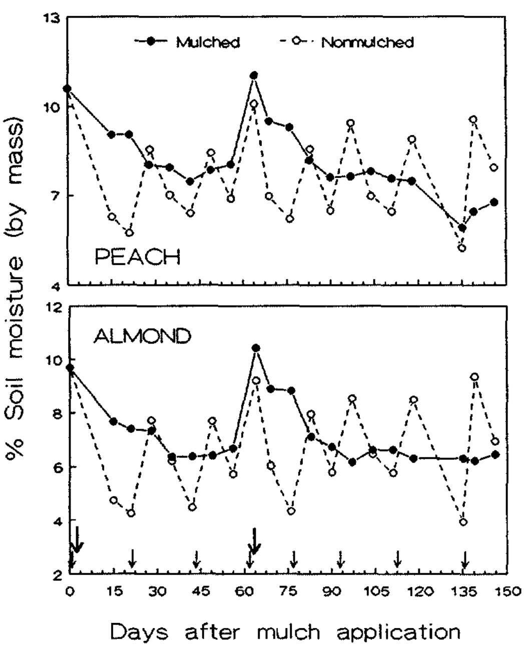

FIG. 1. Soil moisture depletion dynamics in the surface 60 cm of root zone of polyethylene mulched and nonmulched peach and almond trees. Light arrows indicate irrigations of nonmulched trees; heavy arrows indicate irrigations of mulched trees.

Midday leaf water potential became increasingly more negative in mulched trees, as compared to nonmulched trees, beginning in early July (ca. 1 month after first irrigation) until the mulched trees received a second irrigation in late July (Fig. 2). After the mulched trees were irrigated, leaf water potential generally remained 1.5–2.5 bars lower than in nonmulched trees throughout the rest of the growing season, even though moisture levels in mulched soil were adequate.

Mean diurnal soil temperatures were ca. 5 C higher at 15 and 30 cm depths during June–August in the mulched plots (Fig. 3). Maximum soil temperatures at 15 cm in the mulched and nonmulched plots were 44 C and 39 C, respectively, and 39 C and 34 C, respectively, at 30 cm (Fig. 4). Soil under the mulch exceeded 38 C for a cumulative total of 312 hours in the 0–23 cm depth during June–August, but for only 11 hours in the nonmulched soil. No temperatures above 40 C were recorded in the nonmulched treatment, but temperatures at 0–23 cm exceeded 40 C for a total of 129 hours in the mulched soil.

Numbers of *M. incognita* second-stage

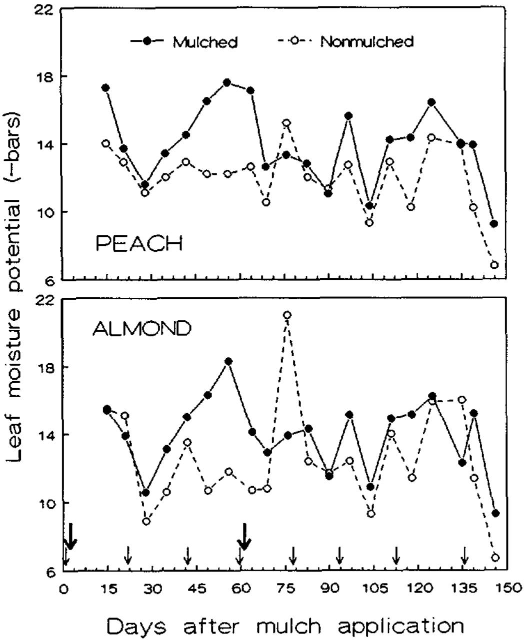

FIG. 2. Leaf water potential dynamics of polyethylene mulched and nonmulched peach and almond trees. Light arrows indicate irrigations of nonmulched trees; heavy arrows indicate irrigations of mulched trees.

juveniles (J2) were higher in mulched soil at the sampled depths of 0–23 cm and 23–46 cm within the peach root zone in December 1991, 7 months after mulch treatment was initiated (Table 1). Similarly, more *M. incognita* J2 were recovered from soil of mulched almond root zones at three depths (Table 1). Mist chamber extraction of roots gave similar results, although almond data were significant ($P \leq 0.05$) only at the 23–46-cm soil depth (Table 1). However, results of a visual gall rating indi-

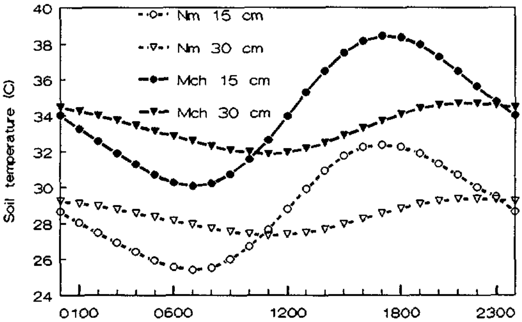

FIG. 3. Mean diurnal soil temperatures of polyethylene mulched (Mch) and nonmulched (Nm) soil at 15-cm and 30-cm depths (June–August 1991).

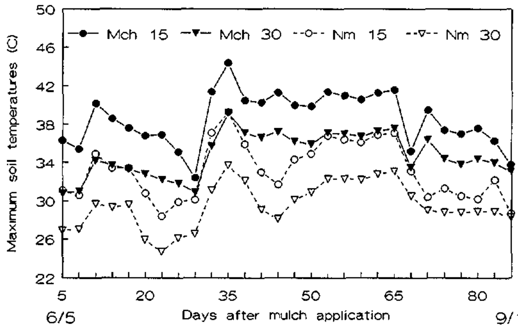

FIG. 4. Maximum temperatures in polyethylene mulched (Mch) and nonmulched (Nm) soil at 15–cm and 30–cm depths (data given for every third day; 5 June–1 September 1991).

cated that roots of mulched almond trees were less severely galled than roots of nonmulched trees (Table 1).

Numbers of soilborne *P. hexincisus* and *T. semipenetrans* were reduced ($P \leq 0.05$) within the root zones of the mulched almond trees and tended to be lower in soil around mulched peach trees (Table 1). *Paratrichodorus minor* populations were reduced ($P \leq 0.01$) within the root zones of mulched trees of both species (Table 1). Numbers of *Paratylenchus hamatus* were reduced ($P \leq 0.01$) within the root zones of mulched almond trees, but no *P. hamatus* were detected in peach. Root extractions showed no differences in numbers of *P. hexincisus* in mulched or nonmulched peach roots.

Initial (May 1991) levels of *P. ultimum* in peach soil were ca. 36 and 6 colony-forming units (cfu) per gram of air-dried soil at depths of 0–30 cm and 30–60 cm, respectively. Populations of *P. ultimum* were ca. 27 and 14 cfu per gram at 0–30 and 30–60 cm, respectively, in the almond test. In December 1991, no difference in numbers of *P. ultimum* were found in soil sampled from the root zones of mulched or nonmulched trees at depths of 0–23 cm and 23–46 cm (Table 1).

Results showed that growth of first-leaf peach trees was generally stimulated by polyethylene film mulching. Although there was no difference in peach tree height (86–87 cm), the mean trunk diameter in mulched peach trees (18.1 mm) was greater ($P \leq 0.05$) than the mean diameter

TABLE 1. Effect of black polyethylene film mulch on root development, galling by root-knot nematode, and population densities of *Meloidogyne incognita, Pratylenchus hexincisus, Paratrichodorus minor, Tylenchulus semipenetrans, Paratylenchus hamatus,* and *Pythium ultimum* in soil from the root zone of first-leaf peach (*Prunus persica*) and almond (*Prunus dulcis*) trees on 'Lovell' peach rootstock (Parlier, CA 1991–92).

Soil depth	Treatment	Root mass (g)†	Gall‡ rating	*M. incognita* J2 per g root tissue	Nematodes per $250\ cm^3$ soil: *M. incognita*	*P. hexincisus*	*P. minor*	*T. semipenetrans*	*P. hamatus*	*P. ultimum* colony forming units per g soil
					'Red Haven' peach					
0–23 cm	Mulch	32.2	1.6	51.9	249.3*	3.3	5.2**	0.5	0.0	106
	No mulch	34.2	2.4	30.1	47.2	8.3	37.0	6.2	0.0	167
23–46 cm	Mulch	33.2*	2.8	147.9*	604.0**	0.8	13.8**	0.0	0.0	86
	No mulch	14.0	2.6	52.0	86.4	2.0	54.2	107.6	0.0	117
					'Nonpareil' almond					
0–7.5 cm	Mulch	1.1	2.3	5.5	22.7	1.2**	0.0*	0.0	0.0	48§
	No mulch	0.0	—‖	—	3.7	15.0	2.5	0.0	0.2	78
7.5–15 cm	Mulch	29.9	3.0*	12.0	89.5**	8.7*	0.3**	0.0*	0.0*	
	No mulch	15.6	3.8	10.6	8.3	29.3	14.2	9.8	4.2	
15–23 cm	Mulch	54.0	2.5**	44.8	179.3**	4.3**	1.0**	0.0	0.0**	
	No mulch	59.9	3.8	10.5	36.5	14.3	57.5	15.0	8.0	
23–46 cm	Mulch	63.6	2.8	62.9**	355.3**	2.5	7.2**	3.7	0.0**	127
	No mulch	36.6	4.0	8.1	45.5	5.7	145.5	37.0	24.2	47

Data are untransformed means of six replications, *, ** indicate significant differences from nonmulched control at $P \leq 0.05$ and $P \leq 0.01$, respectively, according to F-test performed on log-transformed data.

† g roots per $0.0135\ m^3$ soil.

‡ Gall rating: 0 = no galls; 1 = 1–25% galled; 2 = 26–50%; 3 = 51–75%; 4 = 76–100%.

§ 0–23 cm soil depth.

‖ No roots at 0–7.5 cm depth.

in the nonmulched trees (15.0 mm). In contrast, trees in the almond experiment generally suffered from the mulch treatment, with tree height (131 cm in mulched, 149 cm in nonmulched) and trunk diameter (17.5 cm in mulched, 20.6 cm in nonmulched) reduced ($P \leq 0.05$) in the mulch treatment. Mulched trees of both species tended to have larger root masses per soil volume, especially in the 23–46 cm depth range (Table 1).

Foliage of the mulched peach trees appeared visually greener than the nonmulched trees, especially late in the season after the fertilizer application. Leaf color differences were not obvious in the almond trees. Leaf analysis performed by the UC/DANR Diagnostic Laboratory indicated that nutrient levels were within the adequate range (10), regardless of tree species or mulching treatment. The only consistent nutritional difference between treatments was a higher Ca concentration in mulched peach and almond trees.

Discussion

The black polyethylene mulch minimized evaporative moisture loss from the soil, thus reducing the amount of irrigation water necessary for tree establishment from ca. 1,816 to 454 liters per tree. The mulch also prevented weed growth and subsequent soil moisture loss due to transpiration of unwanted vegetation in the root zone of the trees. The mulch retained moisture most effectively in the upper 30 cm of the soil. Moisture continuously condensed on the underside of the film, rewetting the surface soil. The more constant moisture levels under the mulch may have led to the tendency of an increase in root mass. Despite adequate soil moisture, water potential readings indicated slightly higher water stress in the mulched trees, presumably as a result of higher air and root temperatures exacerbated by stress from *M. incognita.*

The film mulch significantly increased soil temperatures as deep as 30 cm, which may have differentially affected growth of the two tree species and provided a solarization effect. Heat likely accounted for reduced numbers of certain nematode species.

Results of these experiments indicate that the solarization effect of black film mulching is not sufficient to manage *M. incognita* on a susceptible host without preplant fumigation, especially in a replant situation with residual roots from the previous crop remaining in the soil. Root galling by *M. incognita* was reduced in mulched almond trees, even though higher numbers of J2 were found. This suggests that egg hatching and juvenile development may have been stimulated at some point in the season, whereas development of syncytia was retarded by the mulch. Although there were larger numbers of galls on mulched roots, the size of galls was smaller and resulted in a less severe gall rating. The smaller galls on mulched tree roots may have been a host and/or pathogen response to higher soil temperatures or more constant soil moisture regime within the root zone. During the hot months of June–August, soil temperatures at 15 cm deep were frequently higher than 40 C for 5–6 hours daily, and reproduction of *M. incognita* may have been inhibited. Cumulative hours above 40 C were greater than required at constant temperature for 90% mortality of *M. javanica* juveniles in a laboratory study (4). However, during the cooler months of September–November, prior to collection of nematode samples, the warmer but nonlethal soil temperatures beneath the mulch may have increased numbers of infective juveniles.

Other phytoparasitic nematodes, including *Pratylenchus hexincisus, T. semipenetrans, Paratrichodorus minor,* and *Paratylenchus hamatus,* were significantly reduced in the root zones of the mulched trees. The solarization effect could account for these reductions, although lack of weed hosts or competition with large numbers of *M. incognita* in mulched plots also could have been involved.

Populations of *Pythium ultimum* tended to be reduced in the upper 30 cm of the root zone, but not in the lower almond tree root zone, where the temperatures were not as highly elevated. There was also an increase in root mass in the lower root zone of the mulched trees, and undecomposed roots of the previous grape vineyard were also present in this depth range. The grape roots were undoubtedly colonized by the nematodes and *Pythium* fungi, and provided both refuge and a reservoir of inoculum.

Increased trunk girth and root mass of peach indicate that black film mulch may be beneficial for establishment of first-leaf trees. However, a decrease in almond tree height and trunk girth may reflect a difference in graft compatibility or tolerance among *Prunus* spp. to soil heating. Many of the mulched almond trees were observed to stop growing during July and August and formed thickened leaves and more fruiting spurs ($P \leq 0.01$) than the nonmulched trees. Once soil temperature maxima dropped to below 35 C in September, mulched almond trees flushed and grew rapidly. However, this late growth was not enough to catch up to the nonmulched almond trees. Past results indicate that, when film mulch is removed, trees will grow faster and often surpass their nonmulched counterparts (13,14).

Establishment of permanent crops with polyethylene film mulching has promise for reducing irrigation water requirements and chemical pest management input in warm and hot climates. However, a mulch affects many components of orchard ecology. Additional field experiments have been initiated to clarify effects of the mulch treatment on orchard crops using drip irrigation and preplant fumigation.

Literature Cited

1. Abu-Gharbieh, W., H. Saleh, and H. Abu-Blan. 1991. Use of black plastic for soil solarization and post-plant mulching. Pp. 229–242 *in* J. E. DeVay, J. J. Stapleton, and C. E. Elmore, eds. Soil solarization. Plant Production and Protection Paper 109. Food and Agriculture Organization of the United Nations, Rome.

2. Balerdi, C. F. 1976. Plastic and hay mulches for tropical fruit crops: Observations and economics. Proceedings of the Florida State Horticultural Society 89:234–236.

3. Bredell, G. S. 1973. Response of citrus trees to plastic mulching. Proceedings of the World Congress of Citriculture 1:387–394.

4. Cenis, J. L., and J. Argemi. 1984. Modelización del efecto de la desinfección solar en la supervivencia de *Meloidogyne javanica* (Treub.) Chit. Proceedings of the Congress of the Spanish Phytopathological Society 3:152–160.

5. Freeman, S., A. Sztejnberg, E. Shabi, and J. Katan. 1990. Long-term effect of soil solarization for the control of *Rosellinia necatrix* in apple. Crop Protection 9:312–316.

6. Gur, A., B. Bravdo, and Y. Mizrahi. 1972. Physiological responses of apple trees to supraoptimal root temperatures. Physiologia Plantarum 27:130–138.

7. Jensen, P., and D. Buszard. 1988. The effects of chemical fumigants, nitrogen, plastic mulch and metalaxyl on the establishment of young apple trees in apple replant disease soil. Canadian Journal of Plant Science 68:255–260.

8. McCutchan, H., and K. A. Shackel. 1992. Stem water potential as a sensitive indicator of water stress in prune trees (*Prunus domestica* L. cv. French). Journal of the American Society for Horticultural Science 117: (in press).

9. Neilsen, K. F. 1974. Roots and root temperatures. Pp. 293–333 *in* E. N. Carson, ed. The plant root and its environment. Charlottesville: University Press of Virginia.

10. Reisenauer, H. M., ed. 1978. Soil and plant-tissue testing in California. Bulletin 1879. University of California, Division of Agricultural Sciences, Berkeley.

11. Stapleton, J. J., and J. G. Garza-Lopez. 1988. Mulching of soils with transparent (solarization) and black polyethylene films to increase growth of annual and perennial crops in southwestern Mexico. Tropical Agriculture (Trinidad) 65:29–33.

12. Stapleton, J. J., and C. M. Heald. 1991. Management of phytoparasitic nematodes by soil solarization. Pp. 51–59 *in* J. Katan and J. E. DeVay, eds. Soil solarization. Boca Raton: CRC Press.

13. Stapleton, J. J., W. K. Asai, and J. E. DeVay. 1989. Use of polymer mulches in integrated pest management programs for establishment of perennial fruit crops. Acta Horticulturae 255:161–168.

14. Stapleton, J. J., E. J. Paplomatas, R. J. Wakeman, and J. E. DeVay. 1992. Establishment of apricot and almond trees using soil mulching (solarization) with transparent and black polyethylene film: Effects on Verticillium wilt and tree health. Plant Pathology 41: (in press).

15. Whitcomb, C. E. 1980. Effects of black plastic and mulches on growth and survival of landscape plants. Journal of Arboriculture 80:10–12.

16. Wicks, T. J. 1988. Effect of solarisation on the control of *Phytophthora cambivora* in almond and cherry. Australian Journal of Experimental Agriculture 28:539–545.