COOPERATIVE EXTENSION

Kearney Plant Protection Group

PLANT PROTECTION QUARTERLY

April 1997 **Volume 7, Number 2**

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Editors

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ARTICLES

POPULATIONS OF *MUCOR PIRIFORMIS* IN SOILS OF APPLE ORCHARDS AND MANAGEMENT PRACTICES TO CONTROL MUCOR ROT

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Introduction

Mucor rot of apples is caused by *Mucor piriformis*, the post-harvest pathogen noted primarily for decaying pears and apples kept in cold storage in the Pacific Northwest. Although the optimum growth temperature for *M. piriformis* is 20°C, it can grow and produce spores even at 0 to 1°C. *M. piriformis* grows and sporulates in cold storage, resulting in increasingly significant fruit losses yearly. In the last several years, California apples suffered significant losses due to Mucor rot.

Research during this period of time focused on determining the source of inoculum and propagule population levels in orchard soil and dump tank water and studying the possibility of using solar radiation (and associated heat) and cultural practices to control the population levels in contaminated bins and in soil.

Objectives

1) Survey commercial apple orchards in the San Joaquin Valley to determine the levels of populations of *M. piriformis* in soils.

University of California and the United States Department of Agriculture cooperating

Cooperative Extension • Agricultural Experiment Station • Statewide IPM Project

This material is based upon work supported by the Extension Service, U.S. Department of Agriculture, under special project section 3(d), Integrated Pest Management

2) Survey packing houses to determine levels of *M. piriformis* in dump tank water.
3) Study the possibility of using solar radiation (and associated heat) for sanitizing harvest bins.
4) Compare populations of *M. piriformis* in soil with fruit left intact on the orchard floor, flailed, or removed from the orchard.

Procedures

1) Survey commercial apple orchards in the San Joaquin Valley to determine the levels of populations of *M. piriformis* in soils. Following a survey done in early 1995 for the presence of *M. piriformis* in commercial apple orchards, four orchards with Fuji and five orchards with Granny Smith apples located in Madera, Tulare, and Kern counties were selected for periodic sampling year round to determine the level of populations of *M. piriformis* in soil. Three soil samples each composed of 15 sub-samples were collected from each orchard with an agar soil sampler and processed using a procedure developed in previous research (Spotts & Cervantes, 1986).

2) Survey packing houses to determine levels of *M. piriformis* in dump tank water. Dump tank water samples were taken early in the morning, after mid-day operation and at the end of a normal apple-processing day in two packing houses located one each in Fresno and Tulare counties to determine the levels of spore inoculum. For each water sample, 10-100 ml of water were filtered through a 1-µl polycarbonate membrane using a filtration device and the spores collected on the membrane were spread on 3 acidified tergitol APDA plates. Colonies of *M. piriformis* were counted after 2 to 3 days incubation at 20°C.

3) Study the possibility of using solar radiation (and associated heat) for sanitizing harvest bins. The effect of solar radiation on the survival of sporangiospores of *M. piriformis* was determined by placing the sporangiospores on pieces of wood or on plastic (representing walls of wooden or plastic harvest bins).

a) Twenty-five µl of melted water agarose (0.8%) was placed on a small area (5×12 mm) on the surface of one piece of wood tissue. After it solidified, another drop of the same amount was placed over the solid bd agar, and the piece of wood was put outside under the sun for 1 hour so that the agarose deposits would dry to form a thin membrane. Five such membranes were prepared on each piece of wood, 5 µl of a spore suspension (2×10^5 spores/ml) of *M. piriformis* were placed in the center of each membrane. Fifteen pieces of wood were used for the five sampling times. After air-drying, the wood pieces were placed outside under the sunlight or shade for different periods of time while the control wood piece was left at room temperature. To recover the spores, a drop of water was placed over the membrane. After the water was adsorbed by the wood tissue, the layer of agarose membrane with spores was peeled off and ground in 1 ml of sterile deionized water. One-hundred µl of these grindings for each treatment were spread on each of five APDA plates (amended with tergitol). The colonies of *M. piriformis* were determined after 2 to 3 days incubation at 20°C.

b) Five µl of a spore suspension (2×10^5 spores/ml) of *M. piriformis* were put on plastic (pre-marked area) as a drop, air-dried, and then placed outside in sunlight or shade for 1 to 4 hours. The control plastic pieces were placed at room temperature (22-24°C) for 4 hours. Five preparations were made and three replicates were used for each treatment. After treatment, the area with the spores was cut off (7 mm in diameter) and 15 µl of sterile water was place over it. After exposure for about 1 hour, the piece of plastic was dragged over the surface of agar in an APDA plate with the side bearing the spores touching the medium. The percentage of spore germination was determined after 14 hours incubation of the plates at 20°C.

4) Compare populations of *M. piriformis* in soil with fruit left intact on the orchard floor, flailed, or removed from the orchard. An experiment was established in early January 1996 at KAC. About 40 kg of soil collected from a field at KAC were passed through the 6-mm sieve and infested with 200 ml of a sporangiospore suspension (2×10^4 spores/ml) of *M. piriformis*. Three and one quarter kg of soil were distributed in each of 12 wire baskets which were placed in a prune orchard. Whole apples (three per basket) with seven wounds each made with a nail were half-buried so that the wounds touched the soil to represent the treatment of the intact apple left on the orchard floor. Twelve pieces of cut apple, resulting from three whole apples were half buried in the soil to represent the flailed apple treatment. Baskets without apples or apple pieces were used as a control treatment. The populations of *M. piriformis* propagules in the soil from these baskets were determined in early March 1996.

Results and Discussion

1) Survey commercial apple orchards in the San Joaquin Valley to determine the levels of populations of *M. piriformis* in soils. In the apple orchard in Tulare County, *M. piriformis* was detected only in June 95. In the other four orchards, the population of *M. piriformis* was high in the spring, gradually declined during the summer and fall, and increased again in winter or early spring (Figures 1 - 2). Isolates from soil in two apple orchards in Kern county contained (+), (–), and neutral mating types (Table 1). Isolates from the orchard at Madera County contained only (+) and (–) mating types. Because *M. piriformis* cannot tolerate temperatures higher than 27°C but can grow well at low temperatures (including 0°C), high temperatures in summer can be destructive to the survival of *M. piriformis* and can cause a decrease of spore inoculum level in soil. However, low temperatures in winter and apples left on the orchard floor at the end of the season provide suitable conditions and sufficient substrate for reproduction of *M. piriformis*, resulting in an increase of inoculum during the winter months. Therefore, removal of apples from the orchard in the fall should prevent or reduce the increase of spore inoculum level. Results from this survey also suggest that the best time for soil sampling to determine the occurrence of *M. piriformis* in an orchard is from February to April. Summer samplings may lead to erroneous results on the presence or absence of and levels of propagule populations of *M. piriformis.*

2) Survey packing houses to determine levels of *M. piriformis* in dump tank water. The results of a survey done in 1995 from a packing-house in Fresno County showed that the first source of *M. piriformis* inoculum in dump tanks was from spores left in the tank from the previous season. The highest levels of *M. piriformis* in dump tanks were detected near the end of the season during and after re-packing of fruit (Table 2). Both (+) and (–) mating types of *M. piriformis* were present among the 15 randomly selected and tested isolates (Table 1). The same survey was repeated in 1996 following a cleaning of the dump tank. No *M. piriformis* was detected from litter in the dump tank. However, in this packing-house, we could not obtain any data on the levels of *M. piriformis* during fruit packing since no packing took place in that year. The survey done in February 1996, in a packing house in Tulare County during fruit packing, did not reveal any *M. piriformis* in dump tank water.

3) Study the possibility of using solar radiation (and associated heat) for sanitizing harvest bins. From August to early October, during mid-day when maximum temperature was 32.8°C, no colonies of (+) mating type isolate were recovered from wood pieces that were placed directly under the sun for 20 minutes or longer, while 35 and 33 colonies per plate were recovered from the wood piece kept at room temperature and under shade outside, respectively (Figure 3). It took longer to inactivate spores of *M. piriformis* when they were kept under the shade. Similar results were obtained for (–) mating type isolate of *M. piriformis*. For spores recovered from plastic pieces, the germination percentage decreased with the increase of time under the sun. No colonies were observed after a 2-day incubation on APDA plates for those treated for 2 hours or longer. However, the spores which germinated formed abnormal germination structures, and the germination percentage decreased to 0 after keeping them under the sunlight for 4 hours (Figure 4). In contrast, spores of *M. piriformis* kept in shade outside, they survived at higher levels than when kept under the sun. These findings suggest that solar radiation can be an effective way for sanitation of harvest bins contaminated with *M. piriformis* propagules.

4) Compare population of *M. piriformis* in soil with fruit left intact on the orchard floor, flailed, or removed from the orchard. By March the soil with the cut apple had 25,000 spores of *M. piriformis* per gram of dry soil while there were only 105 and 50 spores per gram of dry soil in soil with whole apples and without apples, respectively. Apple pieces left on the orchard floor in January (or flailed apples) would increase the levels of propagules of *M. piriformis* in soil. Because this experiment was set up in January when the activity of other microorganisms in soil is low, it took a long time for the apples (or apple pieces) to decompose. This situation provided the opportunity for *M. piriformis* to colonize these fruit since this fungus grows and reproduces at low temperatures. The experiment was repeated in December 1996 and will be completed in January to February 1997.

Conclusions:

1) In general, the population levels of *Mucor piriformis* in soil of apple orchards in California are high in the spring, gradually decline in summer, and increase again in winter or spring of the following year.

2) The best time for sampling soils to determine the occurrence of *Mucor piriformis* in apple orchards is from February to April.
3) In packing houses, spores left in the dump tank from the previous season can be the first source of inoculum for *Mucor piriformis* in the tank water. Therefore, thorough cleaning of the dump tank is recommended at the end of the season to prevent re-contamination by *M. piriformis* in the following year.
4) Solar radiation can be an effective way for sanitation of fruit harvest bins contaminated with *M. piriformis* propagules. Direct exposure to sunlight is more effective than exposure under shade. At least 20 minutes exposure under sunlight is necessary to kill (or make defective) the propagules of *M. piriformis.*
5) Apples flailed and left on the orchard floor in January would increase the levels of propagules of *M. piriformis* in soil. However, removal of apples from the orchard in the fall should prevent any increase of *M. piriformis* spore inoculum in the soil.

Reference

Spotts, R.A., and Cervantes, L. A. 1986. Populations of *Mucor piriformis* in soil of pear orchards in the Hood River Valley of Oregon. Plant Disease 70:935-937.

Table 1. Mating types of isolates of *Mucor piriformis* from soil of apple orchards and from dump tank water in packing houses.

Source	Number of isolates	Mating type (+)	(–)	Neutral
Orchard in Madera county	6	1	5	0
Orchard I in Kern county	60	39	1	20
Orchard II (field 1) in Kern county	14	11	1	2
Orchard II (field 2) in Kern county	52	28	21	3
Packing house in Fresno County	15	8	7	0

Table 2. Population levels of *M. piriformis* in water samples collected from dump tanks of apple packinghouses.

Sample date and activity	Sample time	No. of spores/100 ml water
Packinghouse in Fresno County		
Before packing		
20 Sept. 95	3:00 pm	5
During packing		
8 Nov. 95	10:00 am	6.7
	1:00 pm	70
	4:00 pm	0
9 Nov. 95	9:00 am	0
	1:00 pm	0
	4:00 pm	3
15 Nov. 95	9:00 am	27
	1:00 pm	10
	4:00 pm	6.7
17 Nov. 95	9:00 am	13
	1:00 pm	6.7
	4:00 pm	23
During re-packing		
13 Dec. 95	1:00 pm	437
14 Dec. 95	9:00 am	403
	1:00 pm	270
Packing house in Tulare County		
During packing	9:00 am	0
22 Feb. 95		
	11:45 am	0
23 Feb. 95	8:30 am	0
	12:00 pm	0
	3:00 pm	0

(Figure not available)

Fig. 1. Apple orchard in Madera County.

(Figure not available)

Figure 2. Apple orchard II field (1) in Kern County.

(Figure not available)

Figure 3. Survival of *M. piriformis* (+) on wood tissue.

(Figure not available)

Figure 4. Survival of *M. piriformis* (+) on plastic sheet.

ABSTRACTS

ANNUAL INTERNATIONAL RESEARCH CONFERENCE ON METHYL BROMIDE ALTERNATIVES AND EMISSIONS REDUCTIONS, Orlando, FL, November, 1996

Solarization to Disinfest Soil for Containerized Plants in the Inland Valleys of California, *James J. Stapleton and Louise Ferguson, UC Kearney Agricultural Center*

Growers of containerized plants in the San Joaquin Valley (SJV) have several options for obtaining clean planting substrates. Many purchase "virgin" soil or organic media from off-site locations, while others use various methods of chemical soil disinfestation. Solarization was tested during the summer months of 1995 and 1996 for its potential to disinfest nursery soils of certain nematode and fungal pathogens which attack a variety of perennial crops in California.

In a preliminary experiment at Kearney (central SJV) in 1995, moist field soil naturally infested with the citrus nematode (*Tylenchulus semipenetrans*) and with the fungal pathogen *Pythium ultimum* was placed in black polyethylene (poly) planting sleeves (20 x 45 cm) and subjected to one of four treatments for a period of four weeks: (1) placed on a sheet of black poly in the field and exposed daily to open sun; (2) as #1, but also covered with a single layer of transparent poly film; (3) as #1, but also covered with two layers of transparent poly separated by wire hoops; or (4) maintained in an incubator at 4 ^{o}C. Soil temperatures in the center of the bags reached 48, 69, and 72 ^{o}C in treatments 1, 2, and 3, respectively. Numbers of *T. semipenetrans* and *P. ultimum* were reduced by 89-99% in sealed but untented bags, and the organisms were undetectable after treatment in either single- or double-tented bags.

Two subsequent experiments were conducted at a cooler site near Oakdale (northern SJV) during 1996, using soil mounds (914 cm x 914 cm x 23 cm) infested with the lesion nematode *Pratylenchus vulnus* and placed on black poly sheets. Two solarization methods were used - single tent, and double tent, using clear plastic film in both cases. Each experiment was mulched for a period of two weeks during July-August 1996. The control treatment consisted of mounds of soil not covered by plastic. Typical maximum temperatures at the bottom center of the soil mounds were 44 ^{o}C in the single tent, 68 ^{o}C in the double tent, and 36 ^{o}C in the noncovered control. In both experiments, each of the solarization treatments reduced *P. vulnus* to undetectable levels by the end of the two-week treatment period. Soil from the mounds was then placed in black poly planting bags to conduct bioassays for production of nematode-free plants.

Eradication of the test pathogens in these experiments indicated that solarization may be used commercially in nursery operations in the SJV and other desert areas in California; further tests are underway.

Nutritional Deficiencies as a Component of the Peach Replant Problem
Michael V. McKenry and Tom Buzo, U.C. Kearney Agricultural Center

A benefit associated with soil fumigation is the increased growth response (IGR) it provides to the planting that follows. IGRs are demonstrated by their occurrence in the absence of known soil problems and they appear to be a result of improved nitrogen availability or status. In this work we set out to identify alternative methods for providing an IGR, but instead we learned that subtle nutritional deficiencies are a common occurrence when peaches or walnuts are replanted.

In a peach replant site infested with *Pratylenchus vulnus* three preplant soil treatments were imposed in the fall with replanting the next spring. Treatments included: 1) A solution of Vapam® at 500 ppm (mg/l) methyl isothiocyanate (MIT) delivered in an 8 hr irrigation using a drip line with 2 l/hr emitters spaced 0.6 m apart; 2) methyl bromide (MB) applied by injecting 1.12 kg/ha at 0.6 m depth every 3.3 m in distance; and 3) nontreated check. There were four replicates of each treatment randomly placed down the old tree rows with 30 trees/row spaced 1.3 m apart. Tree rows were 6.6 m apart. Six sub-treatments having the possibility to promote an IGR were then randomly applied to each of five adjacent trees down each row. Enzone® was applied to planting sites 45 days before planting by digging a 0.5 m by 0.6 m deep hole caving in the side walls and then drenching 40 l water containing 1000 ppm CS_2. Other sub-treatments were made on the day of planting and they included: New Era Compost® mixed into planting hole at 0.18 kg/site; 0.36 kg/site steer manure sprayed with 92 ml/site Hinder®; an ammonium soap; Hinder® sprayed alone; complete fertilizer consisting of

NPK + Super Micro®, and a nontreated comparison. The fertilizer treatment consisted of solubilizing 100 g 15-15-15 fertilizer into 8 l water adding 8.3 ml Super Micro® to it and drenching it to the selected tree sites. Once planted the dripper tube was also used to deliver monthly fertilizations of 11 kg/ha nitrogen in the form of calcium nitrate to all plants.

Within four weeks of treatment the Enzone® treated trees appeared to be negatively impacted. At six weeks the treatment of NPK + Super Micro® yielded the best appearing trees. At 12 weeks after planting the MB treated trees were visibly better than the more chlorotic and stunted Vapam or nontreated check comparisons. The compost treatment did not appear beneficial until 20 to 25 weeks after planting. In the fall all trees were cut to ground level and weighed. Soil samples were collected, and *P. vulnus* extracted by sieve-misting and then counted.

Results are depicted in Table 1. The strip treatments of MB or MIT gave one year of nematode protection. The NPK + Super Micro® treatment was highly beneficial to plant growth regardless of preplant treatment. In this experiment even the nonfumigated trees benefited from NPK + Super Micro®. In other experiments the fertilizer treatment appeared to be of benefit even when trees were planted into nonreplant sites and was as beneficial to walnut trees as to peach but applications needed to be made before mid summer of the first year. The cost of NPK + Super Micro® is 6¢/tree and it corrects a nutritional need experienced by young trees. Its benefit may not be a result of the replant problem. It is not the IGR response we were searching for and it is not nematicidal. However, the benefit it provides is even greater than that from the IGR and any experimentation with MB alternatives for tree and vine crops should include the use of complete fertilizers. Conventional wisdom of fertilizing first-year trees with only a nitrogen source appears to be in error.

This work partially supported by Cling Peach Board, California Almond Board, California Tree Fruit Agreement, and California Table Grape Commission
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Table 1. First-year growth of peach replants and buildup of *P. vulnus* following three preplant treatments and six planting site treatments.

Treatment				*Pratylenchus vulnus*/	
Preplant	At Planting Site	Growth in kg/tree		250 cm^3 Soil Sample	
MB	NPK+ Super Micro®	2.24	a	0.25	c
MIT	NPK + Super Micro®	1.82	ab	23.	c
MB	Compost	1.75	abc	66.	bc
Nontreated	NPK + Super Micro®	1.64	bcd	316.	c
MB	Hinder®	1.54	bcde	0.5	c
MB	Enone®	1.42	bcdef	0	c
MB	Nontreated	1.25	cdef	0	c
MB	Manure + Hinder®	1.24	cdef	0.25	c
MIT	Compost	1.20	cdef	2.	c
Nontreated	Compost	1.17	def	688.	a
Nontreated	Hinder®	1.13	def	335.	abc
MIT	Hinder®	1.05	ef	1.	c
Nontreated	Nontreated	1.03	ef	450.	abc
MIT	Enzone	1.02	ef	0.4	c
MIT	Nontreated	0.99	ef	18.	c
MIT	Manure + Hinder®	0.98	ef	432.	abc
Nontreated	Manure + Hinder®	0.95	f	552.	ab
Nontreated	Enzone®	0.93	f	88.	bc

Note: Values followed by a different letter are significantly different at P = 0.05.

A Novel Approach to Provide Partial Relief from the Walnut Replant Problem

Michael V. McKenry and Tom Buzo, U.C. Kearney Agricultural Center

Remnants of woody roots and associated rhizosphere microbes can survive a number of years after tree or vine trunks have been removed. Live roots of *Prunus* spp. may survive for two years, *Juglans* spp. for more than three years and *Vitis* spp. for more than eight years. Soil fumigations involving methyl bromide or 1,3-

dichloropropene have historically provided a method for complete and quick kill of remnant roots within the surface 1.5 to 2 m depth. Kill of these roots results in rhizosphere changes that provide partial relief from the replant problem. In a recent study foliar-applied glyphosate herbicide resulted in 85 to 95% root kill to a peach orchard six months after treatment. Unfortunately, the eggs of *Pratylenchus vulnus* survived within killed roots for two years after treatment.

Two hundred trees of the two major walnut rootstocks, *J. hindsii* and *J. hindsii* x *J. regia*, were planted in 1989 in a 0.5 acre planting site near Parlier, CA. In October 1994 each of five trees of each rootstock received a 10 g ai herbicide treatment applied either to the foliage or to the cut trunk surface. Over the next year above- and below-ground assessments of tree viability were made. Foliar sprays of Envy®, Garlon® or Roundup® were compared with trunk-paint treatments with or without the addition of diesel oil. Trunk applications involved chain saw removal of the 10 to 25 cm diameter trunks followed by the forming of a concave surface on the cut trunk. Into each newly-formed trunk cup was painted 10 g ai of each herbicide with or without a smaller quantity of diesel oil. One year after treatment a backhoe trench was dug to enable visual rating of root viability down to 2 m depth. At that time roots were collected, rinsed free of soil and the *P. vulnus* were mist-extracted from a known root mass and counted.

Foliar applications of the herbicides were generally ineffective as indicated by new growth above ground and the abundance of live roots present one year later (see Table 1). However, there was also a significant reduction in the count of *P. vulnus* from roots of trees receiving some of the foliar herbicides.

Applications of the herbicides to cut trunks provided greater root destruction, and in many cases no regrowth aboveground the following year. The addition of diesel oil to the painting solution improved root kill. The rootstock choice did not influence root kill so the data sets in Table 1 are compiled across the two rootstocks. Root kill of 97% plus reductions in the *P. vulnus* populations by 98% resulted from a trunk treatment of Garlon 3A® plus diesel oil. Unlike our previous work with peach, the roots of *Juglans* spp. degenerate into a moistened, sloughing surface when killed by systemic herbicides. The leaking of tannins and phenolic compounds throughout the root cortex is likely important in the reduction in *P. vulnus* populations surviving there. Ninety-eight percent reductions in *P. vulnus* will not protect the new trees beyond one year so an additional soil treatment will need to be coupled into the replanting strategy.

This work partially supported by California Walnut Board

Table 1. Root viability and *Pratylenchus vulnus* populations in walnut roots one year after various systemic herbicide treatments.

Foliar Applications	Surviving Tree Tops	Surviving Roots	Surviving *P. vulnus*/g root
Nontreated	100%	99.5 a	258 a
3% Envy®	100	86 a b	10 b c
3% Garlon®	Trunks only	72 b	54 b c
3% Roundup®	100%	87 a b	34 a b c
Applications to Cut Trunk	(Trunk Cup Method using 10 g ai herbicide)		
Nontreated		100 a	150 a b c
22 ml Envy®		85 a b	150 a b
27 ml Garlon®		30 c	0 c
27 ml Roundup®		95 a	9 b c
22 ml Envy® + 11 ml diesel		35 c	1.5 c
27 ml Garlon® + 13.5 ml diesel		3 d	3 c
27 ml Roundup® + 13.5 ml diesel		72 b	27 b c

Note: Values followed by a different letter are significantly different ($P = 0.05$) based on ANOVA and Duncan's Multiple Range Test

PROCEEDINGS, AG FRESNO, November, 1996, Fresno, CA

Growth Benefit of Adding "Virgin Soil" When Replanting An Orchard

Michael V. McKenry and Tom Buzo, U. C. Kearney Ag Center

Virgin soil, or a better term "non replant problem soil" (NRPS), is a soil that has not supported a perennial crop for 10 to 15 or more years and does not harbor soil pests or chemical residues that might limit the growth of subsequent perennial crops. Replant problem soil (RPS), by contrast, is the soil that can be collected from anywhere near the roots of established trees or vines and when as little as 2 or 3 pounds is added to a young tree or vine at planting the first year plant growth is markedly reduced even when no known soil pests are present.

For the field tests reported here NRPS was collected from the center of an 80-foot-wide zone located between an old orchard and an old vineyard. This NRPS zone had received occasional tillage but had not supported perennial plants for 15 years. The NRPS was collected by the use of a Vermeer Tree Spade that dug a hole 50 inches square at the surface and tapering down to a point 36 inches in depth. This ½yard volume of soil was transported to the orchard and inserted into a tree site where the same equipment had previously dug a hole. On April 12, 1996 almond trees on nemaguard rootstock were planted into sites having complete NRPS, complete RPS, ½yard NRPS surrounded by RPS, and ½yard RPS surrounded by NRPS. For comparison two additional treatments included RPS but were backhoed before planting and RPS backhoed and treated with 1 lb/tree site of methyl bromide (MB).

Four weeks after replanting the NRPS soil supported almond/nemaguard trees with two times more top growth than those trees planted into replant soil (RPS). At 8 weeks after replanting the trees replanted to NRPS or ½ yard NRPS were similar in size and four times larger than those of any other treatment. By mid-July or 12 weeks after replanting those trees planted into ½yard NRPS began to slow their growth as their roots invaded the surrounding RPS soil. Also the trees in MB treated sites were by this time half the size of the NRPS trees although they were much more rank in appearance and slightly yellower. By mid-September the trees growing in RPS or backhoed RPS were beginning to grow well so that by mid-October they appeared to have grown past the replant problem. Trees planted in complete NRPS never slowed their growth while trees planted to ½yard NRPS had not yet resumed their growth by mid-October. The final 1996 trunk circumferences for each treatment are detailed in Table 1. This site was selected because it contained the replant problem without pathogenic nematodes present. These data show that methyl bromide does not solve the complete replant problem.

In this orchard site that did not have a nematode component, the replant problem still occurred. I refer to this major and most visible component of the replant problem as the rejection component. The new trees had overcome the rejection phenomena six warm months after they encountered it. We know that the rejection phenomena can be transported by physically transporting RPS but within soil it does not appear to be mobile. Rather, it is an entity that the roots can encounter and then adjust to. These rejection phenomenon can slow even the most vigorous of root systems. This field trial will continue for two more years.

Table 1. First-year growth of almond/nemaguard replanted 4 months following removal of an almond/nemaguard orchard that did not have a nematode problem.

Treatment	Trunk Circumference (cm)	
Complete NRPS (= virgin soil)	3.62	a
½ yard NRPS surrounded by RPS	3.54	a
RPS backhoed + 1 lb MB	2.98	b
RPS nontreated	2.41	c
½ yard RPS surrounded by NRPS	2.35	c
RPS backhoed only	2.27	c

Numbers followed by the same letter are not significantly different from one another ($P = 0.01$). RPS is replant soil.

SECOND INTERNATIONAL CONFERENCE ON SOIL SOLARIZATION AND INTEGRATED MANAGEMENT OF SOILBORNE PESTS, Aleppo, Syria, March, 1997

Range of Pests Controlled by Solarization and Their Heat Sensitivity. C. L. Elmore, U. C. Davis

Soil solarization controls a broad spectrum of soil pests. Organisms have a thermal tolerance range after which they can be killed or injured severely and become susceptible to other biotic and abiotic factors. Organisms that are active during moderate temperatures (15 to 35^{o}C), such as winter annual weeds, all seem to be

sensitive to the change of temperatures of solarization. Organisms active during high temperatures are more tolerant to solarization. Characteristics such as hard seed (*Melilotus* sp.), mobility (nematodes) and exceptionally deep perennial structures such as rhizomes and tubers also reduce the level of residual effectiveness of soil solarization. Some organisms have a high tolerance to heat such as certain members of the genera *Macrophomina, Fusarium* and *Pythium* and the soil-borne bacterium *Pseudomonas solanacearum*. A time and temperature relationship will be discussed for several organisms.

The Economics of Soil Solarization Compared to Conventional Agricultural Production. C. E. Bell, UCCE, Imperial County

Soil solarization has been repeatedly shown to be an effective way to manage soilborne pests. Under most conditions, solarization will also improve crop yield compared to conventional practices. Adoption of solarization as part of routine farming practice has, however, been slow worldwide. Reasons that solarization is still an uncommon practice after 20 years of research and development would include the availability of familiar and trustworthy alternatives, the lack of concerted educational effort on the value of solarization, and the lack of reliable comparative data on the economic value of solarization relative to conventional practices. The agricultural areas of southern California and Arizona in the USA are ideal locations to utilize soil solarization. Thousands of hectares of high value vegetables are sown in the fall after a summer fallow for a winter harvest. Combined soilborne pest control costs (e.g. for weeds, soil fungi, and nematodes) are only slightly less than the cost of solarization. An analysis of five of these crops (broccoli, cabbage, carrot, crisphead lettuce, and onions) indicated costs are small, from 1 to 5%, when all other costs and crop market values are held the same. Yet, at present, the only adoption of solarization has been for about 600 hectares of organically grown carrots. The most important factor influencing the use of soil solarization for organic crop production is the high cost of hand labor for weeding. Solarization also is used to improve soil fertility and tilth by enhancing the decomposition of organic matter before planting. This use of solarization has demonstrated that growers can substitute solarization for conventional soilborne pest control practices without extensive disruption of other crop production practices.

Establishment, Survival, and Growth of Apple Trees (*Malus domestica* 'Granny Smith') Using Post-Plant Solarization in Soil Infested with *Sclerotium rolfsii*. J. J. Stapleton, U.C. Kearney Ag Center

An eight-year field experiment was initiated in 1988 to study the effect of various post-plant solarization treatments for control of southern blight (*Sclerotium rolfsii*) in replanted apple trees (*Malus domestica* 'Granny Smith' on 'Malling 111' rootstock) in the San Joaquin Valley. Transparent or black plastic mulches were placed around replanted trees for 11-20 week in summer 1988. Soil temperatures reached 46, 39, and 34 ^{o}C at 23 cm depth under transparent, black, and nonmulched treatments, respectively. No damage to trees from treatments was visible. Two years after treatment, tree survival was 38, 86, 86, and 75% after no treatment, or solarization with black film, transparent film (11 weeks), or transparent film (20 weeks), respectively. No significant differences in tree growth among treatments as measured by tree girth were found from 1988-96.

Integrated Pest Management in Fresh Market Tomato (*Lycopersicon esculentum* 'Shady Lady') Using Combined Soil Solarization and Reflectorized Mulch. J. J. Stapleton and C. G. Summers, U.C. Kearney Ag Center

Vegetable crops in the San Joaquin Valley of California are attacked by flying insects, insect-vectored virus diseases, and soilborne pests. Solarization can rid the soil of pests, while use of reflectorized mulches can reduce damage due to insects and the viruses they vector. A field experiment was conducted during summer 1996 to test effects of solarization, reflectorized mulch, and various combinations on yield of fresh-market tomato. The greatest yield was obtained from plots treated with solarization with transparent plastic, then the mulch sprayed with silver paint and left in place as a mulch, followed by a similar treatment using commercially formulated silver mulch for both solarization and plant mulch. These two treatments produced mature green or ripe tomato yields 2.8-fold and 1.9-fold greater, respectively, than the nontreated control plots.

Modes of Action of Solarization and Biofumigation. J. J. Stapleton, U.C. Kearney Agricultural Center

Solarization is a passive hydrothermal process of disinfesting soil which utilizes solar radiation trapped under plastic mulch to create a "greenhouse effect", heating soil to temperatures which are deleterious or lethal to a broad spectrum of soilborne pathogens and pests. In addition to heat, other mechanisms of physical, chemical, and biological control have been shown to be involved in the solarization process. There is now a long list of organisms which have been shown to be susceptible to the effects of solarization, including many fungi, bacteria, nematodes, and weeds. The "heat dosage" of solarization, which is a relationship of soil temperature x time, is affected by numerous factors. Some of the more important physical components

affecting soil temperature during solarization include diurnal air temperature maxima, minima, and duration, wind speed and duration, soil texture, color, and moisture content, and characteristics of the mulch film. Another critical treatment component is the thermal sensitivity of the target pest(s), which varies widely among species. In many cases, it is not necessary to kill pest organisms - they may be weakened by "sub-lethal" heat to the extent that they are unable to cause damage to plants. Even in the hottest climates, users may wish to combine solarization with more active methods of soilborne pest management. Many types of fertilizers and organic soil amendments can increase the pesticidal effects of solarization when incorporated in soil prior to heating by releasing biotoxic volatile compounds when heated to increase the effect of solarization through a process of "biofumigation", or by stimulating enhanced biological control. Combining solarization with either soil pesticides or biological control agents can also improve the treatment effect.

Comparison of Solarization Techniques to Disinfest Soil for Containerized Nursery Production. J. J. Stapleton, L. Ferguson, and M. V. McKenry, U.C. Kearney Ag Center

Solarization was tested during summer 1995 and 1996 for its potential to disinfest nursery soils of certain nematode and fungal pathogens which attack a variety of perennial crops in California's inland valleys. Moist field soils naturally infested with nematode pathogens including the citrus nematode (*Tylenchulus semipenetrans*), lesion nematode (*Pratylenchus vulnus*), or ring nematode (*Criconemella xenoplax*), and with the fungal pathogen *Pythium ultimum*, were placed in black polyethylene (poly) planting sleeves (20 x 45 cm) or left in 30 cm high piles and subjected to one of four treatments for a period of one to four weeks: (1) placed on a sheet of black poly in the field and exposed daily to open sun; (2) as #1, but also covered with a single layer of transparent poly film; (3) as #1, but also covered with two layers of transparent poly separated by wire hoops; or (4) not heated. Soil temperatures reached as high as 48, 69, and 72 ^{o}C in treatments 1, 2, and 3, respectively. Numbers of each of the test pathogens were reduced by 89-100% by the various solarization techniques. Results of these experiments indicated that solarization may be used commercially in nursery operations in the SJV and other desert areas in California; further tests are underway.

Soil Solarization: Past, Present, and Future. J. E. DeVay and J. J. Stapleton, U.C. Davis and U.C. Kearney Ag Center

Soil solarization, a procedure used primarily for the disinfestation of soil, was described over 20 years ago and quickly became of intense interest because it was nonchemical, environment friendly, and was an effective approach for integrated pest management. The principles of soil solarization and its multiple mechanisms of action for managing plant pathogens have been well defined. However, much remains to be done to define the changes in soil chemistry and biology that induce the increase growth response and crop yields which are associated with its use. Environmental conditions, such as air temperature, day length, and hours of sunlight are limiting in some agricultural regions for effective soil solarization; however, these limitations may be compensated for during solarization in greenhouses. This greenhouse effect can also be accomplished by using double layers of plastic sheets separated by 2 to 3 cm under field conditions. Future advances in soil solarization can be accomplished with improvements in plastic films, the use of double layers of plastic sheets, addition of organic amendments to soil, and the introduction of biocontrol organisms into solarized soil.