#23

SOIL SOLARIZATION

A NONCHEMICAL METHOD FOR CONTROLLING DISEASES AND PESTS

Soilborne diseases and pests cause major losses in field and horticultural crops important to California. For some vegetable and fruit crops, soilborne diseases, weeds, and nematodes have been partially controlled by soil-applied pesticides, including methyl bromide, chloropicrin, and metham. However, the use of soil fumigants for pest control is often undesirable due to unfavorable effects on animals or humans, resulting toxic plant and soil residues, complexity of treatments, and high cost.

Soil solarization, a nonchemical technique, will control many soilborne pathogens and pests. This simple technique captures radiant heat energy from the sun, thereby causing physical, chemical, and biological changes in the soil. Transparent polyethylene plastic placed on moist soil during the hot summer months increases soil temperatures to levels lethal to many soilborne plant pathogens, weed seeds, and seedlings (including parasitic seed plants), nematodes, and some soil residing mites. Soil solarization also improves plant nutrition by increasing the availability of nitrogen and other essential nutrients.

How to Solarize Soil

The area to be solarized should be level and free of weeds, debris, or large clods, which could raise the plastic off the ground. Transparent (not black or colored) plastic tarps or sheeting 1 to 4 mils (0.001 to 0.004 inch) thick are anchored to the soil by burying the edges in a trench around the treated area. Plastic tarps can be laid by hand for small farms or gardens or by commercial machinery for large farms. To prevent air pockets that retard the soil heating process, there should be a minimum of space between tarps and the soil surface. The soil under the plastic is then soaked with water by inserting one of more hose or pipe outlets under one end of the tarp. If the soaking step is impractical, the soil may be irrigated before laying the plastic, but care should be taken to apply the plastic as soon as possible to avoid water loss. If, however, heavy machinery is used, the soil must be dry enough to avoid soil compaction.

The plastic should be left in place 4 to 6 weeks to allow the soil to heat to the greatest depth possible. The plastic should then be removed and the soil allowed to dry to a workable texture. The soil can be planted to a fall or winter crop or left fallow until the next growing season. If the soil must be cultivated for planting, the cultivation should be shallow (less than 2 inches) to avoid moving viable weed seed to the surface.

Time of year. Highest soil temperatures are obtained when the day lengths are long, air temperatures are high, the sky is clear, and there is no wind. The heat peak in many areas of California is around July 15. Therefore the best time for solarization of soil in California is in

June and July. Good results may also be obtained in May, August, and September, depending on the weather and location.

Plastic color. Clear or transparent polyethylene plastic should be used, not black plastic. Transparent plastic results in greater transmission of solar energy to the soil which allows the soil to heat to higher temperatures than when black plastic is used.

Plastic thickness. Polyethylene plastic 1 mil thick is the most efficient and economical for soil heating. However, it is easier to rip or puncture and is less able to withstand high winds than thicker plastic. Users in windy areas may prefer to use plastic 1 1/2 to 2 mils thick. If holes or tears occur in the plastic, they should be patched with clear patching tape or duct tape. Thick transparent plastic (4 to 6 mils) reflects more solar energy than does thinner plastic (1 to 2 mils) and results in slightly lower temperatures.

Transparent polyethylene plastic containing ultra violet (UV) inhibitors that slow the deterioration of polyethylene can be purchased in large quantities. The use of UV inhibitors may allow the soil to be solarized longer, the plastic to be reused, or the plastic to be left in place and used as a mulch during the following growing season.

Preparation of the soil. It is important that the area to be treated is level and free of weeds, plants, debris, and large clods which would raise the plastic off the ground. Maximum soil heating occurs when the plastic is close to the soil; therefore, air pockets caused by large clods or deep furrows should be avoided. The soil should be disked, rototilled, or turned over by hand and raked smooth to provide and even surface and to help water penetrate and moisten the soil profile.

Partial vs. complete soil coverage. Polyethylene tarps may be applied in strips (a minimum of 2 to 3 feet wide) over the planting bed or as continuous sheeting glued, heat-fused, or held in place by soil. If the tarps are glued together, a long-lasting, heat-resistant glue must be used. In some cases strip coverage may be more practical and economical than full soil coverage, because less plastic is needed and plastic connection costs are avoided. In addition, if planting beds are covered with tarps with UV inhibitors to avoid plastic deterioration, the tarps may be used as a mulch during the following growing season by planting through the plastic. Partial soil coverage, however, may lose the long-term benefits or soil solarization by leaving substantial amounts of pest-infected soil to contaminate and reinfest treated areas.

Soil moisture. Soil must be moist for maximum effect as moisture not only makes organisms more sensitive to heat, but it also conducts heat faster and deeper into the soil. Soil can be moistened by preirrigation or by drip or furrow irrigation following laying of the plastic. With machine application of the plastic, irrigation water may be run underneath the tarps in the tractor-wheel depressions, which act as shallow furrows. Irrigation under the plastic usually controls pests slightly faster and to a greater extent than when irrigation is done before the plastic is laid.

Duration of soil coverage. Killing of pathogens and pests is related to time and temperature exposure. The longer the soil is heated, the deeper the control. In addition, longer soil coverage increases the opportunity for biological control mechanisms to work. Although some pest organisms are killed within days, 4 to 6 weeks of treatment in full sun during the summer is usually best.

Benefits of Soil Solarization

Disease control. In the Sacramento and San Joaquin valleys, soil solarized during June or July often reaches temperatures of 140°F at 2 inches and 102°F as deep as 18 inches. As a result, many diseases-causing organisms are controlled to 18 inches or deeper. Soil solarization has provided excellent control of several diseases (Table 1) in California and Israel, and for some diseases, control has continued for at least two growing seasons.

Preliminary evidence suggests that some pathogens may reinfest solarized soil at slower rates than nontreated soil.

Weed control. Seed and seedlings of many annual and perennial weeds have been controlled with soil solarization (Table 2). Some weed species are very sensitive to solarization. Others are moderately resistant and require for control optimum soil moisture, tight-fitting plastic close to the soil surface, and high radiation.

Control of winter weed species is often evident for more than 1 year after treatment. Winter annual grasses seem to be especially sensitive to solarization, while weeds such as sweet clover (*Melilotus alba*) or yellow nutsedge (*Cyperus esculentus*) and purple nutsedge (*C. rotundus*). are only partially controlled. The summer annuals purslane (*Portulaca oleracea*) and crabgrass (*Digitaria sanguinalis*) are also only partially controlled. If solarization is attempted during cooler seasons, weed growth usually is increased. It may thus be used to promote germination and growth before cultivating.

Nematode control. Soil solarization reduces nematode populations, but less dramatically than it does fungal pathogens and weeds. Nematodes generally are more tolerant of heat and control of them is less effective in soil depths beyond 12 inches. Solarization may therefore be useful and economically feasible for shallow-rooted crops and home gardens, but probably should not be used where nematode populations must be reduced by 90 to 99 percent to depths of 18 inches to several feet before planting.

Increased plant growth response. Plants often grow faster and produce yields of increased quantity and quality (size and appearance) when grown in solarized compared to nontreated soil. This phenomenon can be attributed, in part, to pathogen and weed control, but it is largely unexplained. For example, when soil apparently free of pests is solarized, increases in plant growth are still observed. A partial explanation may be found in a combination of mechanisms. First, because major pathogens and pests are controlled, it is likely that minor or unknown pathogens and pests are also controlled. Second, some soluble nutrients such as nitrogen ($NO3^-$, $NH4^+$), calcium (Ca^{++}), and magnesium (Mg^{++}) may be increased and made more available to plants in solarized soil. Third, beneficial microorganisms, such as mycorrhizal fungi, *Trichoderma* sp., actinomycetes, and some beneficial bacteria survive the solarization process or recolonize the soil rapidly. These is turn may contribute to a biological control of pathogens and pests and/or stimulate plant growth.

Special Uses for Soil Solarization

Soil solarization has been used successfully on a large scale to control Verticillium wilt in pistachio orchards in California. Using both hand labor and plastic-laying machinery, the orchard floor was completely covered in plastic. Plastic strips were hand applied around tree bases and connected to a strip of machine-applied plastic between the tree rows with heat-resistant glue or by using narrow bands of earth to hold the strips down. The 5 to 10-year-old trees partially shaded the soil and plastic but not enough to prevent soil heating, which the trees survived with no visible detrimental effects. Although expensive, success of this method in existing orchards indicates the high potential of solarization to control some soilborne problems.

Soil solarization has also been used successfully in Israel to control soilborne pests in greenhouses.

Special Considerations of Soil Solarization

Soil solarization requires that soil be out of production for at least 2 months during the summer. To avoid losing a growing season, special attention should be given to crop rotations and sequences that allow solarization but also take advantage of the land before and after treatment. In the Imperial and Coachella valleys, where summer temperatures are too hot for most crops, soil can be solarized during summer and planted during fall or winter.

Sensitivity to heat of plant pathogens, weeds, and other soilborne organisms differ. Some organisms will not be controlled by solarization and will require other control measures. This appears to be the case with sweet clover (*Melilotus sp.*) and some high temperature fungi in the general *Macrophomina, Synchitrium,* and *Pythium*. Conversely, some organisms difficult to control with soil fumigation, such as seeds of cheeseweed (*Malv parviflora*) and field bindweed (*Convolvulus arvensis*), are easily controlled by soil solarization.

Economic Feasibility

The costs of soil solarization depend on the thickness of plastic, areas of soil covered (partial vs. complete coverage), the method of providing moisture, and the methods of plastic application, connection, and removal. These costs should be balanced against the benefits, and (in most cases) should be viewed over a period of more than 1 year or growing season.

Conclusions.

Soil solarization can control many soilborne pathogens and pests. The method is simple, safe, and effective, leaves no toxic residues, and can be easily used on a small or large scale. Large increases in plant growth, harvestable yield, and crop quality often occur in solarized soil and often continue for more than one growing season. The potential use of soil solarization for disease and pest control in California are great.

Questions and Answers

Can soil solarization be combined with chemical control?

Yes, preliminary experiments combining solarization with low application rates of fungicides, fumigants, or herbicides have led to improved control of pathogens, nematodes, and weeds. Solarization chemical combinations may be especially useful in cooler areas, for heat-tolerant organisms, or to increase the long-term benefits of solarization.

Does soil solarization kill beneficial soil organisms?

Populations of some beneficial organisms, such as *Trichoderma* spp. or actinomycetes, may be increased by solarization. Other important soilborne organisms, such as mycorrhizal fungi, may be decreased in the upper soil profile but not enough to lessen their beneficial action. Populations of some microorganisms, such as beneficial bacteria (*Bacillus* and *Pseudomonas* spp.) are partially decreased during solarization but afterwards recolonize the soil rapidly. However, populations of *Rhizobium* spp. of bacteria, which fix nitrogen in root nodules, are killed and must be reintroduced with seeds of legume crops. Survival and activation of beneficial organisms appear to play an important role in the increased plant growth commonly observed in solarized soils.

Can soil solarization be used in cooler areas such as those near the coast?

Soil solarization may be partially effective in cooler coastal areas if treatment occurs during periods of highest air temperatures and when skies are clear. However, pest control may not extend as deeply into the soil as in areas of higher temperatures, and some organisms may not be controlled.

Can I leave the plastic on the soil too long?

Yes, if 1 mil transparent polyethlene plastic without UV inhibitor is left on the soil longer than 6 to 7 weeks during summer it becomes brittle and begins to tear. Brittle plastic is difficult to remove from the soil. This problem may be overcome by using plastic containing ultra violet inhibitors; such plastic, however, is usually only available when large quantities are specially ordered.