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Solar Pasteurization of Soils for Disease

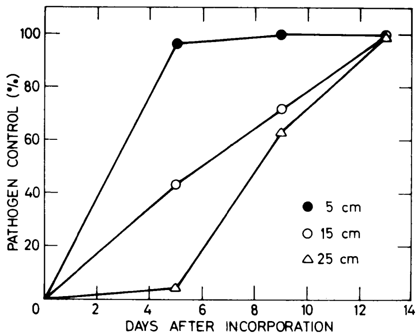

Fig. 1. Effect of solar heating of soil on control of *Verticillium dahliae*. Microsclerotia were incorporated at three depths in either polyethylene-mulched or nonmulched soil and were removed after various periods. Results are expressed as percent control of the pathogen at each layer in the mulching treatment.

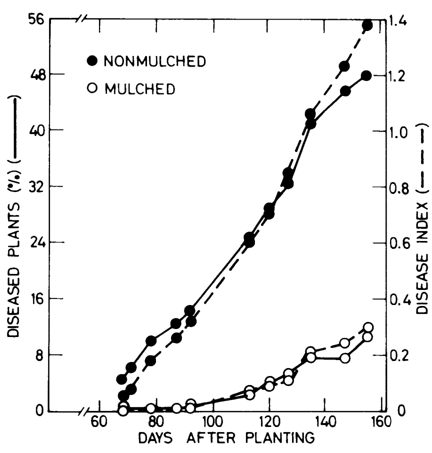

Fig. 2. Effect of solar heating of soil on Verticillium wilt of eggplant. Disease index: scale of 0–4, with 0 = healthy.

Soilborne pathogens cause severe damage to most agricultural crops and reduce both yield and quality. High losses often force a change to less profitable crops or abandonment of the affected area. This happens especially in regions where a few crops are planted frequently in the same soil. Thus, development of effective and economic methods to control these diseases is necessary to assure consistently high and profitable yields.

Economic losses can be reduced by manipulating one or more of the living components involved in disease, namely, the pathogen, host plant, and surrounding soil microorganisms. Although many control methods have been developed in the last decades, only a small proportion of the successes in the laboratory or greenhouse have been translated to practical routine procedures for the field. Moreover, no method is applicable in all instances. Thus, the search for new, effective, inexpensive, and nonhazardous methods for controlling soilborne diseases, especially wilt diseases, continues.

Biologic, chemical, and physical methods have been used before planting to reduce inoculum density or inoculum potential of pathogens in the soil. Currently, soil disinfestation is mainly accomplished through such drastic means as fumigation (chemical) or steaming (physical). This approach is highly effective in controlling such severe diseases as those caused by *Fusarium, Verticillium,* and *Phytophthora* but is limited by safety considerations, the need for complicated equipment and highly trained personnel, high cost, pesticide residues, phytotoxicity, and reinfestation of the soil resulting from drastic reductions in antagonistic microorganisms. Attempts to improve these methods and to minimize the negative side effects are continuing.

In this article, a new method for controlling soilborne diseases is described, with its range of application and prospects for future use.

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Principles of Solar Heating

Artificial heating of the soil, usually by steam, to temperatures of about 100 C was being used to control soilborne pests in greenhouses by the end of the 19th century (3). Although some improvements were introduced, such as obtaining lower temperatures with aerated steam (3), use of the method in large areas is still limited.

Solar energy has a long tradition in agriculture, through the use of glasshouses to protect plants in the cold season. In recent years, polyethylene and other plastic materials have often replaced glass. Heating the soil by covering it with transparent polyethylene ("mulching" or "tarping") has been used extensively. When this is done, the mechanism of solar heating is attributed to the "greenhouse effect," elimination of evaporation from the soil, and other mechanisms (11).

As a result of observations made in the Jordan Valley by extension workers and growers, our team, which included A. Greenberger, A. Grinstein, and H. Alon, decided to attempt control of soilborne pathogens and weeds by means of a natural source of energy (9). This was done by combining the heating principle for pest control with that of soil heating by polyethylene mulching. The concept differed in principle from previous uses of polyethylene mulching in that soil heating was done during the hottest months, rather than the coldest, in order to increase the maximal temperatures to levels lethal to the pathogens. The method had four a priori requirements: 1) Polyethylene mulching of the soil had to be completed before planting (as with other soil disinfestation methods) to avoid damage to plants. 2) Soil had to be kept wet during mulching to increase thermal sensitivity of resting structures and improve heat conduction. 3) The mulching period had to be extended to control pathogens in deeper soil layers where temperatures were expected to be lower. 4) Thin *transparent* polyethylene

Control: Status and Prospects

had to be used when possible because the material is relatively cheap, yet effective in soil heating. Experiments done during the last 6 yr in Israel and in California (where the term "soil solarization" is used) confirm these assumptions.

The first stage in our work was to examine this hypothesis on a small scale. Inocula of selected pathogens were buried at various depths in the soil in small plots, with or without polyethylene cover. Inocula were recovered periodically and the rate and extent of thermal killing determined. Typical results with sclerotia of *Verticillium dahliae* are shown in Fig. 1. As expected, inocula in the upper layer of the soil were killed most rapidly. When heating was extended for 2 wk, sclerotia were killed in the lower layers as well. Typical maximal temperatures in the mulched plots at 5 and 20 cm were 50 and 44 C, respectively; these were about 8–12 C higher than in corresponding nonmulched plots. The rate of reduction in pathogen viability resulting from repeated heating at relatively mild temperatures indicates that solar heat treatment of the soil can be regarded as a pasteurization process.

The use of solar irradiation for crop protection has been suggested in the past by various workers. As early as 1939, *Thielaviopsis basicola* in tobacco was controlled by heating the soil with direct sunlight (7).

Disease and Weed Control in the Field

The results obtained from additional small plot experiments were essentially the same as those shown in Fig. 1. This

Fig. 3. Effect of solar heating of soil on control of pink root disease (*Pyrenochaeta terrestris*) of onions. Plants in untreated plots (foreground) are severely damaged. Solar-heated plots are in background.

strengthened our belief that soil pasteurization by solar heating could be used as a control measure under field conditions. Thus, the effectiveness of this method in naturally infested soils was tested in many field experiments in Israel with a variety of crops during several seasons. The following diseases were effectively controlled: Verticillium diseases of tomato, eggplant (Fig. 2), and potato; *Rhizoctonia solani* on potato and onion; *Sclerotium rolfsii* on peanut; *Pyrenochaeta lycopersici* on tomato; *Pyrenochaeta terrestris* on onion (Fig. 3); Fusarium diseases of cotton (Fig. 4), tomato, and onion; the free nematode *Pratylenchus thornei* on potato; *Orobanche* on carrot (Fig. 5) and eggplant; pod rots of peanuts; and others (4–6,9,10,16; *unpublished*). The effectiveness of solar heating against root-knot nematodes (*Meloidogyne* spp.) is not yet clear; results differed in various experiments.

In field experiments done in California, *V. dahliae, R. solani, T. basicola,* and *Pythium* spp. were effectively controlled (12–15). The incidence of Verticillium wilt in cotton was greatly reduced (12,14). In a pistachio nut grove (2), populations of *V. dahliae* were drastically reduced to the depth of 60 cm after tarping in both unshaded and partially shaded areas for 6 wk, without damage to the trees.

Weed control was evident in these experiments and in others and should be considered an additional benefit. Weed species are similar to pathogens in that they differ in their sensitivity to solar treatment. In many instances, even at the end of the growing season and nearly 1 yr after mulching, weed populations in the solar-heated plots were still much lower than in the untreated ones. Most annual and many perennial weeds were effectively controlled, including species of the following genera: *Amaranthus, Anagallis, Avena, Capsella, Chenopodium, Cynodon, Digitaria, Eleusine, Fumaria, Lactuca, Mercurialis, Montia, Notobasis, Phalaris, Poa, Portulaca, Sisymbrium, Solanum, Stellaria,* and *Xanthium.* Many gramineae are especially sensitive to this treatment, while weeds such as *Melilotus* are unaffected.

Solarization of infested soils increased yields to various degrees. For example, in soil infested with *V. dahliae* and *P. thornei*, potato yield increased 35% (6); in *S. rolfsii*-infested soil, peanut yield increased 123% (5); and in *V. dahliae*-infested soil, eggplant yield increased 215% (9). Yields of cotton, onion, tomato, and carrot were similarly increased. Solar heating also improved the quality of the peanuts harvested, and the proportion of grade A was increased even more than the total yield (5). In California, the yield of cotton after soil solarization was 60% greater (G. S. Pullman, *personal communication*).

Fig. 4. Effect of solar heating of soil on control of Fusarium disease of cotton. Most plants in untreated plot (arrow) were destroyed.

Fig. 5. Effect of solar heating of soil on control of *Orobanche* and weeds in a carrot field. Plants in untreated plots were destroyed and plots are entirely covered with weeds.

Changes in Solar-Heated Soil

The impact of any soil disinfestation method extends beyond the direct influence on pathogen populations. Studying the accompanying changes in treated soils may enable us to make use of beneficial effects and avoid undesirable ones. The possibility that biologic control is involved in disease control in solarized soils (in addition to the physical mechanism of thermal killing) was raised in early work (9). Pathogen populations in deeper soil layers, where relatively low temperatures prevail, were also reduced. During and after solar heating, biologic control can operate through 1) reduction of pathogen populations or activity by antagonistic microorganisms whose effect is enhanced by the heating process and 2) a shift in the biologic equilibrium of the soil in favor of microorganisms that prevent reinfestation by the pathogen and buildup of its population during the season. If such a beneficial shift occurs, disease control would be expected to last longer.

Three mechanisms are related to the first pathway: 1) partial or complete nullification of fungistasis as a result of soil heating, thus exposing the sensitive germinating propagules to the action of antagonistic soil microorganisms; 2) weakening of the resting structures at sublethal temperatures, rendering them more vulnerable to soil microorganisms that otherwise cannot attack them; and 3) stimulation of antagonistic soil micro-

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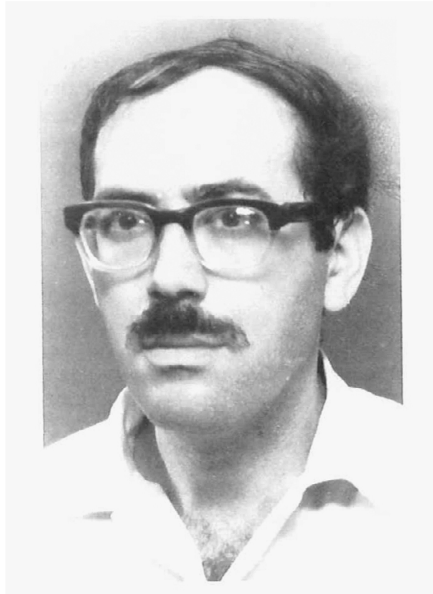

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organisms that directly affect the pathogen.

Data from various experiments with solar pasteurization show that one or more of these mechanisms of biologic control may be involved in disease control. Soil fungistasis to *Fusarium* was partially nullified and its population declined more rapidly in preheated soil (9). Populations of the potential antagonist *Trichoderma* increased and buildup of *R. solani* inoculum slowed in solar-heated soils (4). Sublethal heating of sclerotia of *S. rolfsii* resulted in 1) greater exudation from the sclerotia, 2) an increase in their colonization by bacteria and streptomycetes, and 3) subsequent reduction in their pathogenic capacity (R. Lifshitz et al, *unpublished*). In many of our field experiments, disease control lasted for the whole season, even a year after mulching, without evidence of reinfestation. The relative importance of biologic control in disease reduction by solar heating probably differs for various pathogens.

The phenomenon of increased growth of plants in soil that is partially sterilized and free of known pathogens has been known for decades (1) and was also observed in many of our experiments. This often occurs in steamed as well as in fumigated soils. Several mechanisms may be responsible for such growth, including release of minerals in the soil, stimulation of beneficial microorganisms, and control of minor pathogens. In our work (Y. Chen and J. Katan, *unpublished*), we found increased amounts of soluble minerals (eg, NO_3^-, NH_4^+, K^+, Ca^{2+}) and organic materials in solar-heated soils. Also, extracts of these soils improved plant growth. Further chemical analyses may enable us to develop methods for chemical characterization of the soil solarization process. A polyethylene covering also affects the composition of gases in the soil. This in turn may affect disease control, directly or indirectly.

Heating the polyethylene-mulched soil results in an energy balance in which part of the solar energy is transmitted into the soil while the remainder either is absorbed into the polyethylene mulch or is reflected to the atmosphere. Factors involved in this heating process include solar irradiation intensity, air temperature, humidity, polyethylene and soil properties, and soil heat flux. Mahrer (11) has developed a computerized model that utilizes climatic and other data and enables us to predict the extent of soil heating at various soil depths at any time of day. This model helps us to choose suitable climatic regions for solar pasteurization and to estimate the relative importance of each factor in the heating process.

Lines of Research to Follow

Various kinds of research might be done to improve the solar heating method and adapt it to a wider range of conditions:

1. The method should be tested against additional important soilborne pests, such as bacteria, nematodes, insects, and viruses.
2. The method should be examined for potential use in orchard crops and small gardens and for eradication of pests from infested plant material in the field.
3. Because continuous soil coverage by polyethylene is preferable to strip mulching (the soil is completely disinfested and the chances for reinfestation are smaller), suitable glues, heat fusion methods, and machinery to connect the polyethylene sheets are needed.
4. Effects on disease control and crop yield should be observed for more than one season, especially with low-value field crops. Costs are reduced when effectiveness lasts longer than one season, as with Fusarium wilt of cotton. Another approach to reducing cost would be to reuse the polyethylene sheets whenever possible.
5. Future developments in plastic technology may provide improved mulching materials with greater heating efficiency and increased durability. In addition, plastics that degrade after precise time periods and polyethylene recycling processes should be developed.
6. Long-term field experiments with a variety of crops should be done to detect possible negative side effects and to examine the likelihood of heat-tolerant pathotypes developing. When solarization was used in the field for three successive years, no evidence of decreased effectiveness was found.
7. Cultural practices (date of planting, seeding rates, fertilizer regimens, etc.) must be examined and adapted to obtain optimal plant growth and yields in solarized soils.
8. The possibility of improving disease control by combining solar heating with other methods such as pesticides at reduced dosages or with one or more biocontrol agents should also be explored. In experiments with *R. solani*, a combination of solar heating and application of *Trichoderma harzianum* improved disease control (4).

These lines of research, as well as many others, may help overcome future difficulties, especially in geographic areas where the technique has not been tested.

Advantages and Limitations

Soil solarization should not be regarded as a universal method of disease control but, rather, as an additional method that, used correctly, has many advantages. The method is safe and nonchemical, does not produce phytotoxic residues, is relatively inexpensive, and is simple to use. Application can be made in large areas by machine or in small plots by individuals. Its use, however, is limited to regions where the climate is suitable and the soil is free of a crop for about 1 mo before mulching. Although the method is currently used for certain commercial crops, it is too expensive for some crops. The research involved for its establishment in new areas is complicated and requires interdisciplinary efforts. Development should proceed in stages, starting with small plots of a few square meters, then moving to standard field experiments, semicommercial crops, and finally full-scale commercial practice.

The scope and rate of dissemination of solar heating for soil pasteurization will depend on how well it is used. The method has the characteristics of integrated control (8) because both physical and biologic mechanisms are involved and because a variety of pathogens and weeds are controlled simultaneously. Integration with other control methods may increase benefits. Temperatures with solar heating are lower than those with artificial heating for soil disinfestation; comparable results may be possible with other sources of cheap energy providing similar temperatures.

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