Solarization: an Environment-Friendly Technology for Pest Management*

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Abstract

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Solarization is a mulching process that occurs in moist soil which is covered by plastic film and exposed to sunlight, especially during summer months. Heat is trapped in the soil and rising soil temperatures become lethal as a function of time to most plant pathogens. Associated with solarization are complex changes in the biological, chemical, and physical properties of soil. These changes include sharp decreases in the populations of soilborne pathogens with increased populations of beneficial bacteria and fungi. Improved tilth of soil, increased availability of plant nutrients, especially nitrogen, and a rapid increase in populations of plant growth-promoting bacteria in solarized soil are associated with increases in plant growth and crop yields. Soil solarization is a nonchemical process and encompasses the main principles of integrated pest management; it is an effective alternative to chemical disinfestation of soil and promotes a sustained and natural system of biological control of plant diseases. In contrast with chemical soil fumigants such as methyl bromide, solarization is an environment-friendly technology. The most intensive use of soil solarization has been in plastic houses although field applications have been successful in some agricultural regions.

Key words: Solarization, weeds, pathogens, IPM.

Introduction

Disinfestation of soil of various plant pathogens and pests has a long history involving the uses of chemical fumigants dating back to 1869 and soil steaming since 1893 (5, 21). In some situations, soil flooding and other cultural practices have been used effectively, but they are limited in their availability and spectrum of activity (21, 23). More recently, it was discovered that plastic mulching of soil, which is widely used for warming soils during spring months for early planting, could actually be used to disinfest soil. If moist soil is covered with a plastic film during the warm summer months for an extended period, such as one month, the solar heating of soil will reach temperatures which in time are lethal to most plant pathogens and pests. Additionally, chemical and biological changes in the soil will occur which involve improved tilth, reduced salinity, increased availability of mineral nutrients, and increased populations of beneficial microorganisms, all contributing to the increased growth and yield responses of crop plants associated with soil solarization. Thus, the development and application of soil solarization, discovered in 1976, have offered a significant and effective technology for soil disinfestation and soil improvement (10, 18).

Mulching of soil for improving plant growth has been done since ancient time and various materials have been used (28). It was during the 1970s, however, that research on the use of solar heating of moist soil under plastic films for controlling plant pathogenic organisms became widely known and practiced. Greenhouse applications were pioneered by the Kodama and Horiuchi in Japan (16), while field applications were developed by Katan and DeVay and their coworkers in Israel and California, respectively (8). Since 1976, over 300 papers have been published on soil solarization, including several reviews (17, 22, 28) and two books (10, 18). The purpose of this paper is to highlight those aspects of soil solarization that focus on its use as an environment-friendly technology.

Benefits and Limitations of Soil Solarization

In contrast to soil steaming and soil fumigation, soil solarization is an environment-friendly technology, it is nonchemical, is selective in its effects on populations of soil microorganisms and improves the tilth and nutrient status of soil (28). Changes in populations of soil microorganisms during and after soil solarization are also reflected in the biological control of soilborne plant diseases, often lasting up to two years. In contrast, the near-sterilization or pasteurization of soils by soil steaming, where soil temperatures exceed the maximum temperatures tolerated by eucaryotic organisms, is of concern because some of the beneficial and biotic

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elements of soil essential for plant health are destroyed (5, 7). Similarly, most chemical soil fumigants are harsh in their effects on soils, and cause an indiscriminate killing of soilborne organisms in relation to plant health. Contamination of soil and ground water are also serious problems associated with the use of chemical fumigants.

With the early uses of formaldehyde and substances such as carbon bisulfide to fumigate soil, and later developments involving 1,3-dicloropropene, dibromochloropropane, ethylene dibromide, chloropicrin, and methyl bromide, farmers came to rely heavily on soil fumigation to control plant pathogens and pests. In recent years, public awareness of the dangers associated with the uses of these chemical fumigants, has restricted their use, and in several instances, prohibited their broad use as fumigants. The situation for continued use of methyl bromide is acute, since it is used to fumigate buildings, ships, grain and other postharvest commodities.

Moreover, commodities, such as strawberries, often rely completely on the annual preplant application of methyl bromide to disinfest soil for their culture. New cultivars of strawberry have been developed based on their performance in soil sterilized with methyl bromide. It is expected that methyl bromide will be prohibited for use in the USA as a soil fumigant by the year 2001 (33). In view of increasing restrictions on the use of chemical fumigants and other pesticides, there has been an increased interest in the application and use of soil solarization.

Because of the simplicity of soil solarization and its effectiveness without contaminating the environment or exposure of workers to pesticidal chemicals, this new technology is environment-friendly and offers a valuable alternative to the use of chemical soil fumigants. However, general acceptance and use of soil solarization has been slower than expected and is probably related to disruption of conventional cropping practices during its use, lack of readily available film applicators, unfavorable climatic conditions, and its cost (in USA approximately $750-$1000 per hectare). In regard to cost, however, practical experience has shown that increases in growth and yields of crop plants on solarized soil more than compensate for the cost, a cost that is usually much less than fumigation with methyl bromide (approximately $2500-$3000 per hectare).

Technology of Soil Solarization

Soil solarization is a hydrothermal process whose effectiveness in soil disinfestation is directly related to soil moisture, wave length transmittancy and thickness of plastic covering sheets, intensity of irradiation, day length, air temperature, and soil preparation prior to covering it with plastic sheets. During solarization, temperature maxima of soils increase with increasing moisture content (8). For best results, soil should be about 70 percent of field capacity in the upper zones and moist to a depth of at least 60 cm.

Various kinds of plastic films have been used with success for soil solarization including polyethylene, polyvinylchloride, and ethylene vinyl acetate. Polyethylene has been widely used because it is transparent to most solar radiation (280 to 2500 nm), while being much less transparent to terrestrial radiation (5,000 to 35,000 nm), which reduces the escape of heat from solarized soil (9). The addition of ultra-violet stabilizers to plastic films increases their durability in sunlight. Under experimental conditions, the accumulation of heat in the soil is enhanced by using a double layer of plastic film separated by a layer of air, 3 to 5 cm (6). The use of a double layer of plastic film mimics the phenomenon and the high increases in soil temperature found in plastic houses during solarization of soil. Also, the thickness of the plastic film and whether or not it is black or transparent have strong effects on the amount of soil heating (2, 8, 29). In general, the use of thin, transparent plastic films (1 to 1.5 mil), in contrast to black film, result in the greater soil heating.

The duration of soil solarization is important since the effectiveness of the technology is time and temperature dependent which are inversely related (8, 24). Ideally, temperatures of at least 45 °C in the upper 15 cm of soil during several daylight hours for approximately one month of solarization would be desirable for disinfestation of soil. For example, for *Verticillium dahliae,* two hours at 45° C is required to result in an ED_{90} of propagules in a field soil. Whereas approximately three hours at 45° C are required to result in an ED_{90} for *Rhizoctonia solani* (24). Soil temperatures decrease with increasing soil depth and under ideal conditions for solarization, soil temperatures as low as 37 °C at 45 cm are effective in controlling populations of plant pathogens (9).

Complex of Soil Changes Resulting from Soil Solarization

Although the effects of soil solarization may be direct, that is, the direct thermal killing of soilborne pathogens and pests, other effects are indirect and are related to an increase in soluble mineral substances available for plant and microbial growth, to an enhanced friability or improved tilth of soil, to a decrease in salinity, and most importantly, to a selective enhancement of soilborne organisms benefiting plant growth and development.

Direct effects.- Most plant pathogens and crop pests are mesophilic, that is, they are most active at temperatures less than 31° C. However, when soilborne pathogens are exposed to higher temperatures for extended periods of time, metabolic changes induced by high temperatures are injurious and lethal to all but a few (8, 9). For example, at 37° C. an ED_{90} may require from two to four weeks; whereas, at 47° C, an ED_{90} may occur within one to six hours (24). Mesophilic organisms have lower melting fatty acids in their membrane lipids and lower phase transition temperatures for the lipids. Thus, the heat sensitivity of these organisms including pathogens and pests is related to an upper limit in the fluidity of membranes, beyond which membrane function is destroyed (9).

The number of species of plant pathogenic fungi, bacteria, and nematodes, as well as weeds that have been managed or controlled by soil solarization is large and continually expanding (12, 17, 22, 28). However, several pathogens and pests have been difficult to control by soil solarization and these include the fungi, *Macrophomina phaseolina* and *Pythium aphanidermatum* and species of weeds such as *Melilotus* and *Cyperus* (12, 28). Variable results have occurred in the control of some plant pathogenic fungi, nematodes, and weeds depending on the amount and duration of soil heating during solarization. Notable among these are *Fusarium oxysporum, Meloidogyne* spp. and *Portulaca* sp (12, 28).

Indirect effects.- Mineral nutrients.- Changes in concentrations of mineral nutrients resulting from soil steaming (7) and soil solarization have been reported (30). However, increases in soluble nutrients during soil solarization occurred only where soil temperatures increased, but not when wet, film-covered soil was insulated against solar heating (27). Significant increases in KCl-extractable nitrate and ammonium nitrogen, $NaHCO_3$-extractable P, and less frequently water-soluble Ca^{2+} and Mg^{2+} were usually found in solarized soils. Consistent increases in several other mineral nutrients, including extractable K^+, Zn^{2+}, Cu^{2+}, Mn^{2+}, Fe^{3+}, and Cl^- were not found when comparisons of different solarized soils were made (30).

Soil salinity.- Soil solarization is a dynamic process which involves a diurnal heating and cooling of soil layers. During daylight, the upper layer of solarized soil increases in temperature while at night, this soil layer tend to cool. A gradual movement of soil moisture occurs with the changes in soil temperature. At night, moisture moves upward as the soil cools while during the sunlight hours the temperature of the upper soil layer increases and the moisture moves deeper into the soil. As solarization progresses and the soil heats to deeper layers, a reduction in salinity or salt concentrations occurs in the upper soil layers that may be associated with the leaching action of water. Additionally, an extensive study in Iraq (3) has shown that polyethylene mulch reduces water evaporation from the soil to the atmosphere, keeping the soil wet during the mulching period. This limits water movement from the saline ground water towards the mulched soil surface. In contrast, in the non-solarized soil, an active upward movement of saline ground water to the soil surface (site of evaporation) occurs, concentrating salts in the upper layer of soil. This study (3) included analyses of soil samples taken at three locations in each experimental plot to a depth of 90 cm at 10 cm intervals. Soil sampling was done before and after the solarization period and the samples were analysed for EC and water soluble Ca, Mg. Na, Cl, SO_4, and HCO_3. Moreover, chloride and sulfate values of the soil surface (0-30 cm) and ground water were determined on weekly basis to calculate the salinity index. The ground water-table level fluctuated between 90-95 cm from the soil surface. The index showed that after eight to 10 weeks, the salinity of the solarized soil was less than half that of the non-solarized soil (Fig. 1). Additionally, the hydraulic conductivity of the top layer (0-30 cm) in the solarized soil was 9.3 cm.h in contrast to 1.7 cm.h for nonsolarized soil, thus favoring the leaching of the salts in solarized soil. Likewise, studies in Spain (20) and Egypt (1) both showed significant decreases in electrical conductivity (EC) where soil was sampled from the top layer (0-15 cm) following soil solarization. The results of these studies indicate the importance of soil solarization in avoiding salt accumulation in the soil top layer.

Changes in populations of soilborne microorganisms.- Associated with the sharp decline of most plant pathogens during soil solarization are population changes in other fungal and bacterial species. Immediately after soil solarization, populations of soil fungi were reduced by 85-90 percent, however, population densities of thermotolerant and thermophylic fungi remained relatively high and increased to levels higher than those present in nonsolarized soil (26). The fungi most frequently isolated were thermotolerant species of *Aspergillus and Penicillium.* Most important is the ability of mycorrhizal fungi to withstand soil solarization and maintain populations that provide the necessary interaction with following crops, a great advantage over soil steaming and soil fumigation practices where these plant symbionts are often destroyed (27, 28).

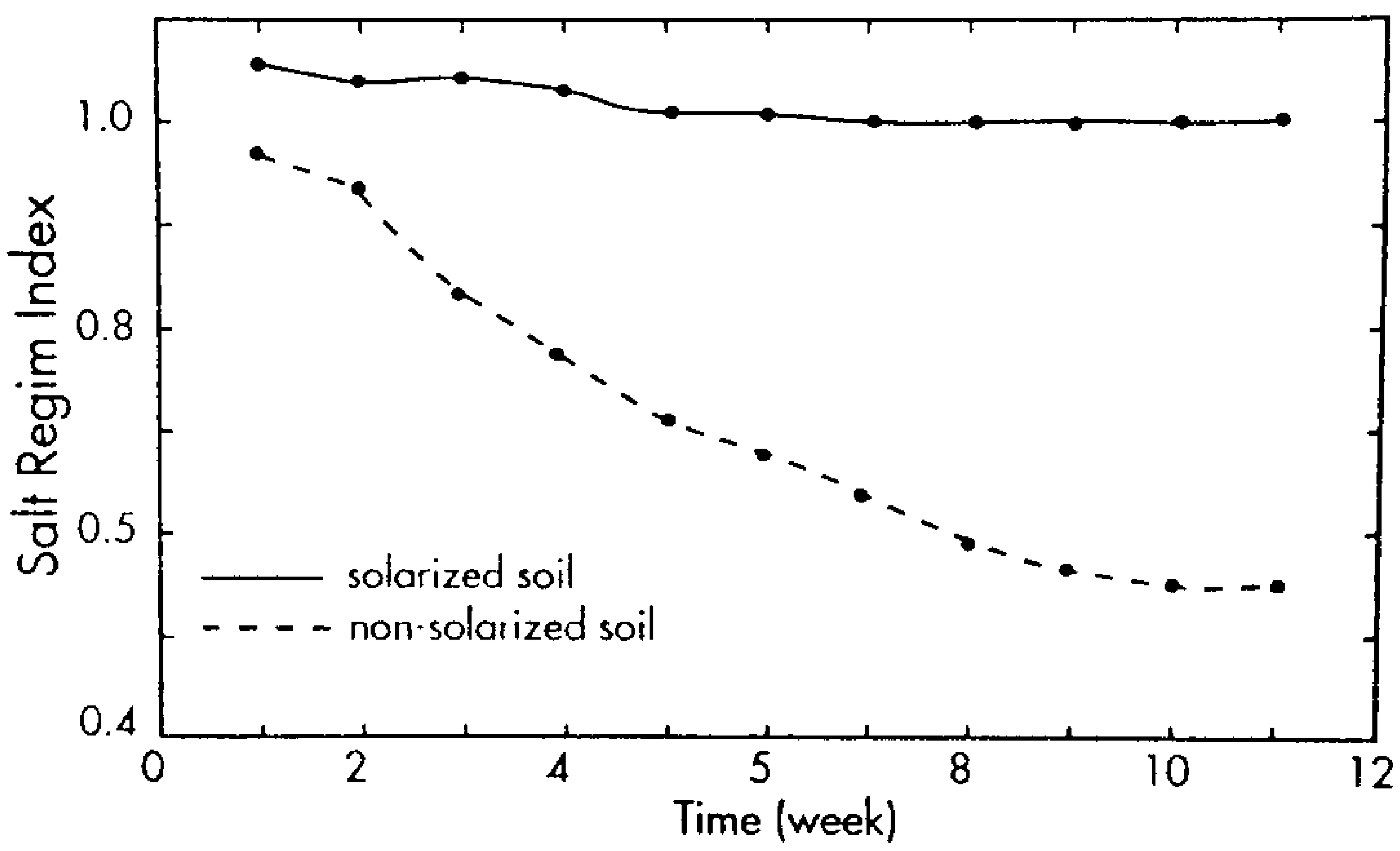

Figure 1. Variation in the salinity index of the top layer of soil (0-30 cm.). Salt Regim Index= ground water $ClSO_4$/ surface soil $ClSO_4$. From Reference 3.

In contrast to the effect of solarization on fungi, the populations of *Bacillus* spp. in soil were not significantly reduced (14). Moreover, the number of *Bacillus* bacteria (colony forming units) that colonized the roots of lettuce plants following solarization were significantly higher than the number on plant roots in nonsolarized plots (14). Numbers of fluorescent pseudomonads also increased rapidly in soil following solarization (13, 14, 27) and the number of colony forming units in the rhizosphere of lettuce roots in solarized soil were six to 10 times higher than the number found on lettuce roots in nonsolarized soil (14).

Among the *Bacillus* spp., those that exhibited antibiosis to *Geotrichum candidum* had increased nearly 20-fold in solarized soil in comparison with nonsolarized soil (27), a possible factor in the suppression of plant pathogens and the biological control of plant diseases that is often associated with soil solarization.

Effects of soil solarization on plant growth and development

The cumulative effects of soil solarization are manifested in the increased growth and yield responses of plants compared to those growing in nonsolarized soil, even in the absence of known major pathogens (8, 15, 27). The bases for these responses are complex and not clearly understood; however, the increased availability of mineral nutrients and beneficial changes in populations of growth-promoting bacteria which colonize plant roots are considered as major contributors to the increased growth response (27, 30). The persistence and duration of the increased growth response in growing seasons following soil solarization is believed to be due in part to the suppression and biological control of pathogens and also to the persistence of plant growth promoting species of *Pseudomonas and Bacillus* bacteria (13, 26, 27). In a recent study of the physiological and developmental aspects of increased growth response resulting from soil solarization (15), a comparison of five plant species (tomato, maize, cucumber, sorghum, and tobacco) showed that increases in leaf area and shoot fresh and dry weights, were significantly larger in solarized soils compared to controls from nonsolarized soils. Surprisingly, during the first 25 days after planting, tomato plants in solarized and control soils had similar root fresh and dry weights. It was apparent that changes in soil properties caused by soil solarization did not have an immediate effect on root biomass or surface area, whereas, the increased growth response of the shoot was evident in young seedlings (15). No disease symptoms were visible on the plants in these experiments.

Post-plant soil solarization and moisture conservation

Most examples of soil solarization as an environment-friendly technology are drawn from preplant applications. However, experiments with fruit tree crops, especially in semi-arid climates, have shown the effectiveness of soil solarization to not only control plant pathogens and pests, but also to conserve soil moisture for extended periods (approximately five months) during the growing season.

Young orchards, including peach, almond, apricot, and pistachio, varying in age from the first year to about the sixth year (for olive, up to 10-15 year-old trees) have been successfully solarized for the control of Verticillium wilt (4, 11, 25, 29, 31). The use of clear (transparent) polyethylene films have been most successful in older orchards but first year trees are more sensitive to solar heating of soil and may not survive. However, for the younger trees, black polyethylene film is much more satisfactory, and in addition can remain in place for at least five months, providing excellent weed control and conservation of moisture during the growing season (29).

In a study (29) comparing transparent and black polyethylene films for solarization of an almond and apricot orchard on Panoche clay loam, maximum soil temperatures under transparent plastic at 18 cm depth reached 46° C. while under black film, the temperatures reached 41° C. and the nonsolarized control soil reached 33° C. At 30 cm depth, the temperatures for transparent and black films reached 41 and 37° C., respectively, while the control reached 32° C. Daily air temperatures were in the range of 32 to 41° C and under these relatively high temperatures, newly planted bare root trees mulched with transparent plastic were severely stressed and 76% of the almond trees and 22% of the apricot trees collapsed. In contrast, and at the same time, only 3% and 6% of the black-mulched almond and apricot trees, respectively, were dead, not statistically different from the nonmulched trees. In this study, 21% less water was used to drip irrigate the trees during the solarization period. However, in other studies (11), the solarized trees required less than 25% of the irrigation water applied to nonsolarized control trees. These results demonstrated that mulching with black film is an effective horticultural and pest management practice while conserving significant amounts of irrigation water.

Conclusions

Among the various technologies useful for disinfesting soil, soil solarization is recognized as being both user-friendly and environment-friendly. Moreover, the results of soil solarization are often of long duration (19, 32). The complex of soil changes which occur during soil solarization involve improved soil texture, increased availability of mineral nutrients, reduced salt accumulation in the upper soil layer, and beneficial shifts in microbial populations that effect not only disease and pest control, but in the absence of disease, cause an increase in plant growth and crop yields. Thus, the advantages and effectiveness of this simple technology which is nonchemical and nonhazardous to use, emphasize the importance of soil solarization as an environment-friendly technology for soil disinfestation.

الملخص

دو فاي، جيمس. 1995. التشميس: تقنية سليمة بيئياً لادارة الآفات الزراعية. مجلة وقاية النبات العربية. 13(2): 97 - 102

التشميس هي طريقة لتعقيم التربة الرطبة المغطاة بغطاء بلاستيكي والمعرضة لأشعة الشمس وبخاصة خلال أشهر الصيف. ويمكن بهذه الطريقة رفع درجة حرارة التربة لدرجة كافية لقتل غالبية العوامل الممرضة للنبات.ويصاحب عملية التشميس تغيرات معقدة في الصفات البيولوجية والكيميائية والفيزيائية للتربة. وتشمل هذه التغيرات انخفاضاً كبيراً لأعداد الكائنات الممرضة للنبات المنقولة مع التربة وزيادة في أعداد البكتيريا والفطور النافعة. كما يرافق تحسن بنية التربة، وزيادة توافر العناصر الغذائية (خاصة الآزوت)، وزيادة أعداد البكتيريا التي تفرز مواد مساعدة للنمو في التربة المشمسة وزيادة في نمو النبات وغلته. ويعتبر التشميس عملية غير كيميائية وتتماشى مع المبادئ الرئيسية للمكافحة المتكاملة؛ فهي بديل كفء للتعقيم الكيميائي للتربة وتسهم في بناء نظام طبيعي للمكافحة الأحيائية لأمراض النباتات. وعلى نقيض المدخنات الكيميائية المستخدمة في تعقيم التربة مثل بروميد الميثايل، يعتبر التشميس تقنية أمينة بيئياً. وقد تم استخدام هذه الطريقة بشكل مكثف داخل الدفيئات البلاستيكية، كما أن التطبيق الحقلي لها كان ناجحاً في بعض المناطق الزراعية.

كلمات مفتاحية: تشميس، أعشاب، ممرضات، مكافحة متكاملة.

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