Environment & Ecology 29 (2) : 529—535, 2011
 ISSN 0970-0420

Soil Solarization : An Emerging Technique for Weed and Pest Control—A Review

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Abstract

The review paper aimed to analyze the, application, effectiveness, importance, limitation and constraints of the soil solarization technique as a method for pest and weed control. Soil solarization had a tremendous effect on soil-borne pathogens, nematodes and weeds and it enabled the crop to grow and yield better as compared to non-solarized fields. The magnitude of increase depends upon the type of pest problem and the degree of control. The technique was found to be simple and easy to use by farmers and its immediate application can be in nursery areas in high value crop, such as in vegetables growing, and floriculture. With regard to its application in India almost every area is climatically suitable for soil solarization.
Key words : Soil, Solarization, Weed, Pests, Pathogens.

About 8000 BC, man learned how to cultivate grain crops and also how to protect them. Through trails and errors of the centuries, many cultural and physical practices evolved for protecting crops from plant pest. Such measures as burning or ploughing under crop refuse, rotating crops, planting in the most favorable season, using healthy seeds, isolating crops, pruning and managing water and fertilizer, have been used for hundreds of years to improve the chances of making a good crop (1). The discovery in 1882 of the bordeaux mixture encouraged many scientists to look for other chemicals that could kill pests (2). Pesticides are increasingly being used to keep the level of crop production high. The world pesticide market is valued at 26 billion US dollars with herbicides accounting for the largest share (47%) followed by insecticides (29%) and fungicides (18%). Although, pesticides have helped in increasing crop productivity to a great extent, their limitation can not be ignored. Environmental pollution, toxicity to non-target organisms, pesticide residues in food chain, evolution of tolerance among pests etc. are some of the issues of great concern associated with use of pesticides. This calls for a socially acceptable and ecologically sustainable method of pest control. Pest control through soil solarization is an attempt towards this direction.

Soil solarization, the covering of most soil with transparent polyethylene sheets during the hot months, is a relatively new method for controlling soil borne pathogens, fungi, nematodes, weeds and mites. This method was initially developed and improved in Israel (3). Currently, it is investigated in more than 25 countries including USA, Greece, Morocco, Iraq, Australia, Jordan and others (4, 5). This method has the advantage of being simple, relatively cheap, safe and does not involve the use of toxic material (6, 7). Results obtained by various workers from different countries have repeatedly shown that in many cases plant growth and yield (IGR—phenomena) were improved (3, 8, 9). In the present paper, an attempt was made to collect the information on the effect of soil solarization on pest management and on growth and yield of crops.

Concept of Soil Solarization

Soil solarization involves the use of heat as a lethal agent for pest control through the use of traps for capturing solar energy by means of transparent polyethylene. The energy from the sun is received in the form of electro-magnetic short waves, which are permeable through transparent PE films used in solarization treatment. The TPE films, however, do not

Table 1. Maximum soil temperature at different depths in solarized and non-solarized soils of some selected places. S : Solarized, NS : Non-solarized.

Place / country	Temperature (C) S	NS	Depth (cm)	References
Nedlands, Australia	46, 37	38, 29	10, 30	Kaeuwruang et al. (28)
Jodhpur, India	58 (wet) 69 (dry)	53 (wet) 63 (dry)	5	Lodha and Solanki (26)
New Delhi, India	54, 47, 44	46, 40, 37	5, 10, 15	Kumar and Yaduraju (1992)
Varanasi, India	50, 40, 38	41, 33, 29	5, 15, 30	Arora and Pandey (1989)
Jordan Valley, Israel	51, 41	38, 32	5, 15	Katan et al. (3)
Karachi, Pakistan	52, 39 (dry) 48, 38 (wet)	44, 35 (dry) 36, 32 (wet)	5, 20	Usmani and Ghaffar (14)
Lincoln, New Zealar	55, 51, 47, 43	NA	1, 4, 6, 9	–
Abohar, India	57, 49, 44	47, 41, 38	5, 10, 15	Singh (36)
California, USA	61, 47, 42, 36 49, 36, 33, 27		2, 10, 20, 30	Elmore et al. (19)
Los Angles, USA	56, 54, 52, 49	46, 43, 41, 39	1, 2, 4, 6	Standifer et al. (24)
Stone Ville, USA	65—69	43—50	1, 3	–

allow the re-radiation from the earth, which is normally in the from of long waves, to escape. This selective permeability traps the heat within the mulch resulting in effective heating of the soil. This is some sort of a greenhouse effect operating at a micro-level. The increase in temperature is also due to the elimination of heat loss by evaporation and heat convection during day time. The data on soil temperature with and without solarization for different places in some countries are given in Table 1.

Soil Solarization Techniques

The technique of solarization would include the thermal chemical and biological changes soil caused by soil radiation when covered by clear plastic film, especially when the soil has high moisture content. As the purpose of solarization is to trap maximum solar radiation transparent films are more efficient than black film as the increase is temperature is maximum at soil surface and it decreases with increasing depth. Thinner films (19—25 micron) are more effective for solar heating than thicker films (50—100 micron) and are proportionally less expensive (10). However, thickness of film did not significantly alter pest control as much as duration of solarization did (11). It was found that the higher soil temperatures were recorded with red PE followed by transparent, green, blue, yellow and black films the plastic film reduces heat loss from soil by preventing evaporation and heat conversion (12). Adsorption of radiation by the soil and therefore, heating of soil is best when the plastic film is laid close to the soil with a minimum of air space to reduce the insulating effect of air layer. Hence, good land preparation is essential to provide a smooth even surface. Moist soil either irrigated before mulching or irrigated under the plastic film increases the thermal sensitivity of soil borne micro flora and fauna as well as heat transfer or conduction in the soil (13).

The techniques best practiced in warmest summer months and plastic sheeting left in place for as long as practical. However, duration of 4—6 weeks would be adequate under many situations. Shorter

Table 2. Weeds not controlled by solarization.

Weeds	References
Ammaranthus spp.	*Angadi et al*., 1992
Astragalus sp.	*Rubin and Benjamin*, (16)
Conyza canadensis	*Horowitz et al*., 1983
Cynodon dactylon	*Chauhan* 1988
Cyperus sp., *C. rotundus*, *C. esculenturs*	*Abdel et al*., (36) ; *Binod Kumar et al*., 1993 ;
Digitaria carginata	*Habeeburranhman*, 1992
Desmodium spp.	*Angadi et al*., 1992
Melilotus sp., *M. Indica*, *M. sulcatus*	*Katan*, (30), *Rubin and Benjamin*, (16) ; *Binod Kumar*, 1991 ; *Abdel et al*., 1988

Table 3. Effect of heating loamy sand soil for 30 min on the viability of vegetative parts of perennial weeds (% of control).

Name of Weeds	Soil temperature (C) 30	40	50	60	70	80	90
Cynodon dactylon (Rhizome)	90	10	0	0	0	0	0
Sorghum halepnense (Rhizome)	100	5	0	0	0	0	0
Cyperus rotundus (Tubers)	100	95	90	80	45	25	0

duration may often be sufficient in tropical countries. In India, April-May in south and May-June in northern parts experience intense radiation and are best suited for solarization. As solarization effect is restricted to surface soil only (0—10 cm), pest control at greater depths may be achieved, some times, with extended period of PE mulching.

Maximum temperatures in upper soil layers under ideal conditions are achieved within 3—4 days after solarization begins (14). The upper 15—30 cm of soil show diurnal temperature changes influenced by day and night air temperature. Typical maximum soil temperatures in solarization plots are 8 to 12 C higher than in corresponding non-solarization plots (7). Temperatures of 53.9, 46.6 and 38.3 C at 5, 10 and 15 cm were recorded at ICRISAT Center at Hyderabad under solarized as compared to 43.7, 37.6 and 32.4 C in control plots (14). Experiments carried out at Dharwad, Varanasi and Jodhpur, similarly showed an increase of 7—14 C in solarized plots. In Dhrawad, while the increase with 100 μm films was 9.7 C, it was 13.8 C with 50 μm films.

Effect of Solarization on Weeds

Several workers have observed that most of the annual and perennial weeds were effectively controlled by solarization. However, weed flora are diverse in nature that may differ in heat sensitive thus variable control is likely to occur with weeds compared to other pests. In thermal death studies in vitro, it has shown that the survival of various microorganisms and weeds at or above 50 C is limited to a maximum of few hours (15, 16). From a field at ICARDA, Syria, Linke (17) reported that soil solarization reduced the population of 46 out of 57 weed species. While populations of five species increased in number, six species were unaffected by the treatment. Most annual weeds and especially *Sinapis arvensis* were almost completely controlled. Low to zero control or even stimulation occurred with weed species which have bulbs, deep lying root system or other perennial organs. Poor control of *Cyperus rotundus,* which is mainly propagated by tubers has been reported by many workers (16, 18). Bulbs and tubers are known to put up growth from deeper layers where soils may not be sufficiently heated to affect their growth. Some species with hard seed coat may also escape the lethal effect of soil solarization. *Melilotus indica* consistently showed tolerance to solarization treatment. There are instances where solarization stimulated more emergence of *M. indica*. In general, perennial weeds are difficult to control in a cropping situation. Table 2 gives the list of weed species which are not controlled by solarization. However, solarization gave well to excellent control of *Cynodon dactylon* and *Sorghum halepense* in California (19). The control of *Convolvulus arvensis,* however, was not satisfactory. While the viabilily of rhizomes of *C. dactylon* and *S. halepense* was lost substantially at 40 C (Table 3) the tubers of *C. rotundus* tolerated temperatures well above 60 C (16, 18).

Some weeds are more sensitive and studies re-

Table 4. Effect of solarization and Rhizobium inoculation on seed yield (kg/ha) of some legumes.

Yield (kg/ha)	Solairzed Inoculation (–)	Solairzed Inoculation (+)	Non-solarized Inoculation (–)	Non-solarized Inoculation (+)
Soybean	1833	2683	717	1383
Groundnut	1489	1756	844	1112
Mungbean	1191	1315	547	556

vealed that many rainy and winter season annuals are susceptible to soil solarization. For instance. *Phalaris minor* and *Avenal ludoiciana*—the major grass weeds in winter in India were completely controlled by 10-day solarization treatment (20). Similarly, a 7-day treatment resulted in complete loss in the germinability of seeds of *Orobanche cernua* and *Striga hermomhica* (21)—the most serious parasitic weeds of the world. Excellent field control of *Orobanche* has been reported in many crops (22). Studies carried out at Dharwad, India have confirmed earlier investigations in Israel and Syria (23) about the excellent control of *Orobanche* spp. in different host plants. This is particularly advantageous, as broomrape control has been a challenge at least in some crop plants such as tobacco. Abu-Iramaileh (22), however, found that BPE lasted longer, gave excellent control of *Orobanche* and gave higher crop yield when the crops were planted in the same mulch after making holes.

The possible mechanisms of weed control are direct killing of weed seeds by heat, indirect microbial killing of seeds weakened by sub-lethal heating, killing of weeds stimulated to germinate in the moistened mulched soil and killing of germinating seeds whose dormancy is broken in the heated soil. Volatile may also play a role in weed control. The effect of solarization is limited to seeds located in the surface soil only (24). Any soil disturbance either before or after planting is, therefore, bound to nullify the effect. Direct seedling in solarized soil is desirable. The overall effect is best in crops, which form quick canopy cover. Otherwise, slow growth of crop plants may give way for weed seeds which have escaped solarization treatment. Although the density of weeds is substantially reduced due to solarization, their increased biomass may seriously interfere with crop growth and yield. Under such circumstances, a low energy input manual weeding or chemical one would prove highly beneficial and cost effective. Chemicals due to their selectively, can control a narrow spectrum of weeds, whereas solarization takes care of a wide spectrum of seeds. Vizantiopolos and Katranis (25) reported that solarization gave better weed control than pre-emergence pendimethalin and atrazine, imazaquin and metolachlor, metribuzin and alachlor or acetachlor and atrazine at their recommended rates in maize in Greece. Similarly, experiments with soybean have shown that herbicides such as alachlor, metolachlor, metribuzin, pendimethalin or chlorimuron were inferior in controlling weeds and enhancing soybean yield than soil solarization treatment (20).

Solarization effect with regard to weed control often extended for more than one season. It has been reported that solarization in summer took care of weeds in both crops in soybean-wheat system, provided the soil was not disturbed. The productivity of both crops was, therefore, superior with solarization than with either manual weeding or chemical treatments (20).

Effect on Pathogens

Soil solarization was found to be effective against many soil borne pathogens under varying conditions. The effect often persisted for more than one growing season (11). According to Katen et al. (3) there are at least three ways by which solarization can affect control of pathogens : Fungiistasis, which keeps the fungus propagules at a positive resistant stage, is partially nullified at 45—50 C. Thus the sensitive germinating prop gules are exposed to the action of lytic micro-organisms and to other detrimental factors existing in the soil, sub-lethal structures may weaken the resting structures rendering them more vulnerable to the antagonistic microflora, creation of a shift in microbial population in the soil in favor of heat resistant saprophyles. This is expected as most pathogens are less resistant to heat than many saprophytes.

Verticillum and *Fusarium* welts of several crops have been successfully controlled by solarization, and diseases caused by *Bipolaris sorokiniana, Phytophthora cinnamomi, Plasmodiophora brassicae, Pythium myrothecium, Rhizoctonia solani.* In India, too attempts have been made to use solarization for the successful control of *fusarium* wilt of chickpea, dry rot of clusterbean tomato wilt (26). Excellent control of several soils–borne diseases has been reported from different places of Australia (27, 28). However, certain pathogens such as *Fusarium Oxysporum, Macrophomina Phaseolina and Plasmodiophora brassicae* are reported to be tolerant to solorization (5, 10). Actinomycetes and *Bacillus* spp., many of which are thermotolerant, were sometimes reduced to much lesser extent (45—58%) or even increased (26—158%) following solarization (29). Population of *Rhizobium* spp., sufficient to cause heavy nodulation to bean roots, survived solarization in Israel (30).

Effect on Nematodes

Soil solarization is an effective method of multiple pest control has been reported to reduce the population and densities of several plant parasitic nematodes. These include species of *Meloidogyne, Pratylenchus, Rotylenchulus, Tylenchulus, Heterodera, Globodera, Tylenchrohynchus, Ditylenchus* (31). The solarization gave better results than Carbofuran 1.5 kg/ha in tobacco new series (11). Solarization for 15 days with 100 gauge TPE film gave b : c ratio of 2 : 6.93 and enabled the film to be used in another site. Similarly, Kamra and Gaur (32) reported that 1 - 2 kg of soil root-knot infested soil if placed in sealed polythen bags under for 5 days resulted into 100% mortality of *Meloidogyne* juveniles. This method can be utilized for raising nematodes free seedlings of vegetables, ornamentals, horticultural and plantation crops.

Effect of Solarization on Crop Growth and Yield

As soil solarization has tremendous effect on soil-borne pathogens, nematodes and weeds, the treatment enables the crop to grow and yield better as compared to non-solarized fields. The magnitude of increase depends upon the type of pest problem and the degree of control. Control of weeds alone due to solarization increased the yield of onion by 100—125%, groundnut by 52%, sesamum by 72% and 78% in soybean. Solarization is effective in controlling parasitic weed, *Orobanche,* and a yield of 78 t/ha of carrot was reported from solarized plot, while the non-solarized plot did not yield of bean due to *Orobanche* control by solarization (23).

Even in places where there was no infestation of either soil-borne pathogens, nematodes or weeds, solarization has been found to enhance growth and yield of crop plants, which would be attributed to several chemical and biological changes in soil caused by solarization when covered by clear plastic film especially when the soil has a high moisture content. Table 4 shows that with adequate control of weeds and nematodes though chemical or mechanical methods, soil solarization still enhanced the yield of soybean.

Chemical Changes

Soil mulched with transparent plastic films has frequently been reported to contain higher levels of soluble mineral nutrients (33). Significant increases in ammonium-nitrogen, nitrate-nitrogen, Ca^{+2}, Mg^{+2} and electrical conductivity were consistently found. Phosphorus, K^{+} and Cl increased in some soils. Other micronutrients Fe^{+2} Mn^{+1}, Zn^{+2} and Cu^{+2} were not increased (28, 33, 34).

However, extensive studies in different soils types and nutrient sources, it has been shown that the increases in levels of soil nutrients are transient and do not persist long. Therefore, the increases growth response (IGR), following soil solarization is likely to result from reduction of major factors limiting plant growth such as fungal or bacterial pathogens, nematodes, soil borne insects or weeds rather than increased mineral nutrient availability.

Biological Changes

In comparison with most other methods of soil disinfestations, the effects of solarization are selective on micro-organisms (35, 36). Detailed discussion on this however, is outside the scope of this review, but it is sufficient to mention that the shift in the micro biota of the soil following solarization is in favour of antagonists. These organisms are usually saprophytes rather than phytopathogens which may subsequently inactivate surviving phytopathogeic fungi, bacteria, and nematodes and weed seeds that are damaged or weakened by solarization. These effects may persist for several seasons. Several investigations have been made on the effect of solarization on native inoculated *Rhizobium*. The native population in pigeonpea and chickpea was decreases with soil solarization (17, 37, 38). However, in unirrigated soil, solarization did not alter *Rhizobium* population. Population of *Rhizobium*, sufficient to cause heavy nodulation of bean roots survived solarization in Israel (37). Better response of mungbean, soybean and groundnut to seed inoculation of *Rhizobium* (Table 5) was observed in New Delhi. In most cases the negative effect appeared to be short lived and recolonization took place rapidly (39, 40).

Conclusion

Soil solarization as a method of pest control is unique. It is non-hazardous, user-friendly and environmentally benign, effective on a wide variety of pests and effective for more than one season or a year. Solarization involves limitation and difficulties also. It can only be used in regions where the climate is suitable and the land is free of crops for about a month or more at the time of mulching. The major constraint is the high cost of the treatment as the cost of PE films is high in India.

The solarization technique is simple and easy to use by farmers. However, its immediate application appears to be more promising in nursery areas in high value crop, such as in vegetables growing, floriculture. In addition, pre-plant solarization film may be left in place, after plant emergence, as post-plant mulch. Soil solarization has been shown to enhance degradation of pesticide residues in soil, hence could be employed for decontamination of polluted soil.

As far as its application in India is concerned almost every area is climatically suitable for soil solarization. Vast majority of the area experiences mean daily maximum temperature in excess of 40 C in the months of April to June. It is also the time when the land is fallow enabling farmers to practice this technique without sacrificing his land/crop.

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