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Soil Solarization as an Organic Pre-Emergent Weed-Management Tactic

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Soil solarization is a non-chemical soil treatment that utilizes solar radiation and a thin film of transparent mulch, usually of polyethylene, to heat the soil so that it reaches temperatures (usually ranging from 38 to 50°C to a depth of about 10 to 20 cm) detrimental to soil-borne pests (Gamliel and Katan 2012). Soil solarization has been studied as an alternative to chemical soil fumigants like methyl bromide or 1,3-dichloropropane, which disinfect the top soil layer but are also harmful to non-target organisms (Gamliel and Katan 2012). Some of the pioneering work done on soil solarization has been conducted in Hawai‘i. In 1933, Hagan heated Hawaiian soils with cellophane to control nematodes in pineapple fields (Hagan 1933). However, soil solarization did not become popular until six years later, when Groshevoy (1939) demonstrated that exposing soil to solar heat controlled soil-borne pathogens. In 1971, plant pathologist Adams became the first to use polyethylene mulch to control a soil-borne pathogen, black root rot (*Thielaviopsis basicola*), on sesame (Adams 1971). In 1977, American pathologists Pullman and Devay (1977) published work that indicated there were wide applications for soil solarization, and later, in 1981, they, with Weinhold, coined the term "soil solarization" (Pullman et al. 1981). Since then, many have demonstrated the use of soil solarization for the management of nematodes and other soil-borne pathogens (Chellemi et al. 1993, McGovern and McSorley 1997, McSorley and McGovern 2000). However, this article will focus on soil solarization for weed management.

Soil solarization for weed management can be dated back to ancient India, where weed seeds were exposed to radiation and heat treatment from the sun (Gamliel and Katan 2012). Today there are 74 countries that have adopted or investigated soil solarization for weed management and soil pasteurization. Although pioneering work on soil solarization was conducted in Hawai‘i, this practice lost its popularity after the introduction of soil fumigants soon after World War II. The rising concern about environmental hazards imposed by soil fumigation, increasing restrictions and bans on many effective soil fumigants, and ever-rising interest of organic farming have led to revisiting soil solarization technology. In Hawai‘i,

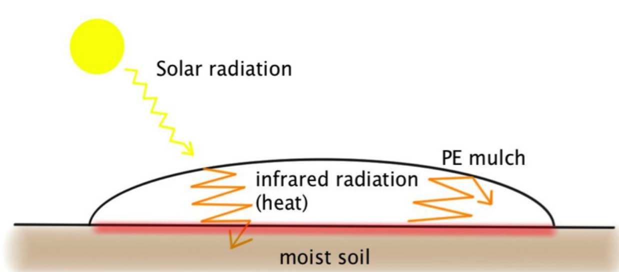

Fig. 1. The transparent plastic tarp used in solarization, known as photoselective polyethylene (PE) plastic (Chellemi 2006), transmits ultraviolet (UV) and visible lights but not infrared radiation (IR). As the short-wavelength solar radiation passes through the plastic layer, it loses energy; the wavelengths increase in length and the radiation essentially becomes infrared radiation, which generates heat.

Wang and coworkers (2009) reported a short-term (up to 3 months) weed-suppressive effect of solarization in pineapple crop production. While this practice might not be an economically viable option for a long-term crop such as pineapple, it is a good alternative approach for managing weeds in short-term vegetable crops. The efficacy of soil solarization for soil-borne pest control relies on proper installation of solarization mulch. This article reviews multiple criteria for proper mulch installation for soil solarization.

Solarization Mulch

Soil solarization is performed by covering the soil with transparent, 25 μm-thick, UV-stabilized, low-density polyethylene mulch (Fig. 1). The soil is generally covered by the solarization mulch over a 6–8-week period for soil-borne pest management.

It is critical that very thin (25–50 μm) transparent polyethylene (PE) mulch be used to trap solar heat, because it is permeable to short-wavelength solar radiation but does not transmit longer-wavelength radiation (heat) from the ground back into the atmosphere (McGovern and McSorley 1997), as illustrated in Fig. 1. Solar radiation with short wavelengths (about 120–400 nm) carries higher amounts of energy than does radiation with longer wavelengths (infrared radiation, > 750 nm). When the short wavelengths of light penetrate the solarization mulch, they lose some energy and convert to longer wavelengths of infrared radiation that generate heat. This heat is trapped beneath the plastic tarp, where it heats up the soil (Krueger and McSorley 2009), much like the greenhouse effect.

Although the thin solarization mulches are less durable and are susceptible to wind and animal damage, they are more effective in raising the soil temperature and controlling weeds than the thicker PE mulches of 50–100 μm (Rubin 2012). However, nutsedges (Cyperaceae) commonly puncture PE mulch thinner than 19 μm (Chase et al. 1998), making the control of this type of weed difficult.

Soil Moisture

Another important factor affecting soil solarization is solar heat absorption and retention by soil moisture. Soil moisture conducts heat, evaporates, and increases the maximum soil temperature (Mahrer and Shilo 2012). Water is a good absorber of infrared radiation. This is because water has a high specific heat capacity (capacity to absorb heat), allowing it to contain a great amount of thermal energy. Due to this physical property of water, soil solarization is more effective in moist soil than in dry soil (Fig 2). Soil moisture has also been reported to increase the thermal sensitivity of pathogens (McGovern and McSorley 1997). In addition, soil moisture, combined with heat, increases the metabolism of the weed seeds and reduces their viability to germinate

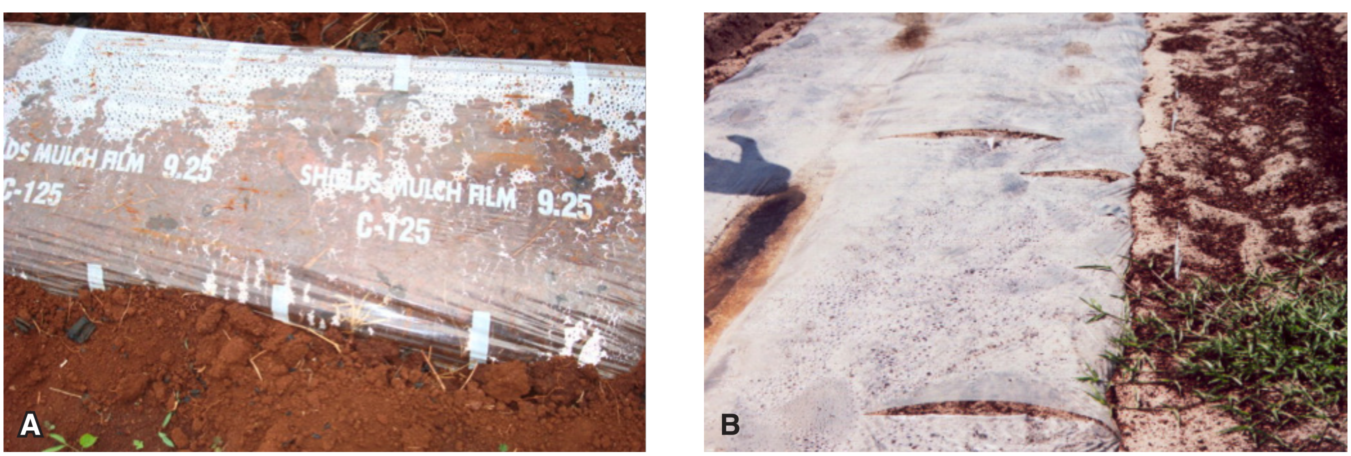

Fig. 2 A) Solarization mulch is accumulating water vapor under the polyethylene (PE) mulch and suppressing weed germination as compared to non-solarized soil outside of the plastic. Picture was taken 3 weeks after the initiation of soil solarization. B) Non-UV-light-protected PE mulch tears easily before the termination of the solarization period. Pictures by K.-H. Wang.

(Rubin and Baruch 2012). In some cases, soil solarization can break the seed dormancy of weeds before killing them during germination (Rubin and Baruch 2012). Due to the importance of soil moisture in soil solarization, one could install drip irrigation in the soil prior to covering the soil with solarization mulch (Mahrer and Shilo 2012).

Soil Organic Matter

The addition of organic matter in the form of animal manure and plant residue from a cover crop can also greatly improve soil solarization. The addition of organic matter can increase soil moisture retention, while fueling exothermic biochemical reactions from the microorganisms, thus raising the temperature 1–3°C higher than without the organic amendment. Mineralization of organic matter also can be accelerated by soil solarization. Furthermore, the addition of plant residues containing allelopathic compounds or biotoxins can have a biofumigation effect when it is integrated with soil solarization (Rubin 2012). For example, in controlling soil pathogens, rapeseed (*Brassica napus*) is commonly recommended as a green manure cover crop prior to soil solarization to obtain a biofumigation effect against *Fusarium oxysporum* infestation in the soil (Fig. 3). As the rapeseed biomass is incorporated into soil, its glucosinolates will break down into isothiocynite, which acts as a soil fumigant.

In another study, the maximum daily soil temperatures achieved in soil solarization conducted with and without prior planting of sunn hemp (*Crotalaria juncea*) as a green manure crop were compared. In most cases, soil that had received sunn hemp green manure reached higher maximum soil temperatures compared with that which had received no sunn hemp amendment prior to soil solarization (Fig. 4).

Time of Solarization

Generally, soil solarization is conducted for a minimum of 4 to 6 weeks during the warmer time of year, when there is high solar irradiation and minimal cloud and precipitation, thus its effect is climate dependent (Gamliel and Katan 2012). A survey on soil solarization conducted during different months of the year in Hawai'i revealed that April to August is the optimal time for soil solarization if the soil is to reach the lethal temperature (42°C for most soil-borne pests and pathogens) in at least the top 10 cm of soil layer (Fig. 4). In addition, depending on soil texture, solarization heat penetrates to different soil depths.

Methods of Mulching

Broadcast solarization and *strip solarization* are the two main methods of soil solarization. Broadcast solarization consists of completely covering a whole field with

Fig. 3 A) Rapeseed is planted as a cover crop for 4 weeks prior to soil incorporation and B) tarping with solarization mulch for biofumigation effect. Pictures by K.-H. Wang.

PE (Fig. 5A). This is performed by laying down strips of PE mulch with a tarp-laying machine, with each adjacent sheet overlapping and fastened to the previous one. A welding process was developed which emitted hot air from a combustion chamber on the overlapping edges of the PE sheets, fusing them together. The ends of the entire sheet are then anchored with a narrow strip of soil (Gamliel 2012).

Strip solarization is simply applying the sheets of PE without attaching them together. A mulch-laying machine is commonly used to install 4 m-wide PE sheets (Fig 5B). The machine creates two trenches for the sides of the sheet to be anchored into soil, and as the sheet is unrolled, a veering disc returns the soil to the trench, covering the edges of the sheet. This method is commonly used for raised beds, where the PE sheet is used as a mulch for the crop after solarization (Gamliel 2012).

Other Strategies to Overcome Challenges of Soil Solarization

While soil moisture is a benefit to soil solarization, precipitation from rainfall is not. It accumulates in water puddles on top of the mulch; then, when water evaporates from the outside surface of the mulch, it lowers the temperature of the soil. In humid areas of Hawai‘i, especially on the windward side, this may be a major problem. Strategies to overcome this obstacle include increasing the time of solarization from the standard 4–6 weeks to 10–14 weeks.

Another technique, known as double-layer (DL) soil solarization (Fig. 6), can be implemented to increase the efficiency of solarization in wet climates. Here a second layer of clear PE mulch creates a layer of air that becomes an insulator (Stevens et al. 2012). As shown in Fig. 6, DL soil solarization mulches can overcome the heavy pressure of nutsedges as compared to a planting strip covered by a regular opague PE mulch.

Another dilemma of soil solarization for weed management is the edge effect (Fig. 7). This is especially problematic when strip solarization is used and the bed is not evenly exposed to sunlight throughout the day due to its orientation. Planting rows running north to south heat up significantly higher than planting rows running east to west. This is due to the angle of solar radiation during sunrise and sunset and its intense contact with the bed edges (McGovern et al. 2004). Although bed edges are rarely if ever shaded

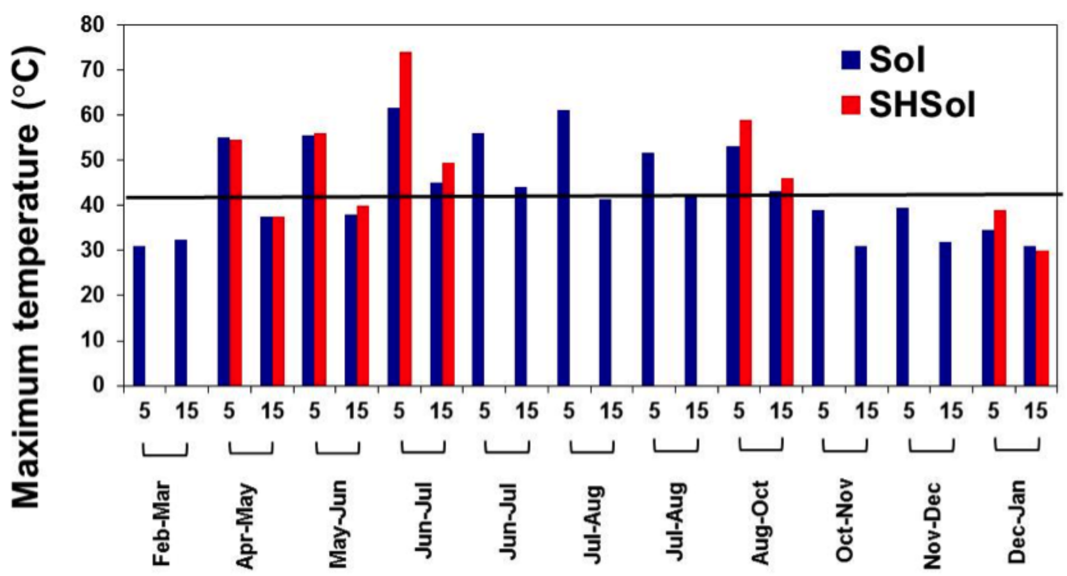

Fig. 4. Average of maximum soil temperatures recorded daily under soil solarization mulch combined (SHSol) or not combined (Sol) with sunn hemp cover crop residues at 5- or 15-cm soil depth. Soil solarization treatments were initiated at different months on O‘ahu (x-axis) in 2010. The solid line represents 42°C, which is a lethal temperature to many soil-borne pests and pathogens.

when they coincide with the path of the sun (north–south-oriented beds), east–west-oriented beds do not get the intense radiation required to sufficiently raise soil temperature due to shading of the bed edges. In addition, heat units are usually accumulated to a higher level at the west end of the bed, due to greater light intensity in the afternoon. Stevens et al. (2012) recommended expanding narrow sheet solarization beds from 1 m wide to 3–4 m wide to reduce the percentage of coverage with edge effect.

In addition, debris on the soil surface or uneven mulching will create air pockets that slow down solarization heating. Thus, good contact between the mulch and the soil and an absence of air pockets are essential for thorough and effective solarization.

Summary

To date, organic farmers still do not have effective OMRI-certified herbicides for weed management. In addition, frequent soil tillage is destructive to soil health. Thus, soil solarization offers a viable weed-management strategy. Although farmers still need to till and rotorvate the soil prior to soil solarization, the weed seed bank suppression subsequent to a proper soil solarization practice is substantial (Fig. 8). Soil solarization would help organic farmers to reduce the need to rely on frequent mechanical weed management at post-plant, thus reducing gasoline costs for machinery.

Fig. 5 A) Broadcast (flat-bed) solarization, and B) strip (raised-bed) solarization (pictures by K.-H. Wang).

Fig. 6. Double-layer soil solarization (right two rows) vs. non-solarized opaque plastic mulch (left 3 rows) with heavy pressure of purple nutsedge. Double-layer soil solarization is installed by laying a second layer of solarization mulch on top of the first, held up by wire hoops.

Fig. 7. The edge effect of soil solarization, where weeds are not exposed to intense sunlight on one side of the solarization strip, resulted in favorable conditions for weeds to grow under the mulch. Pictures by K.-H. Wang.

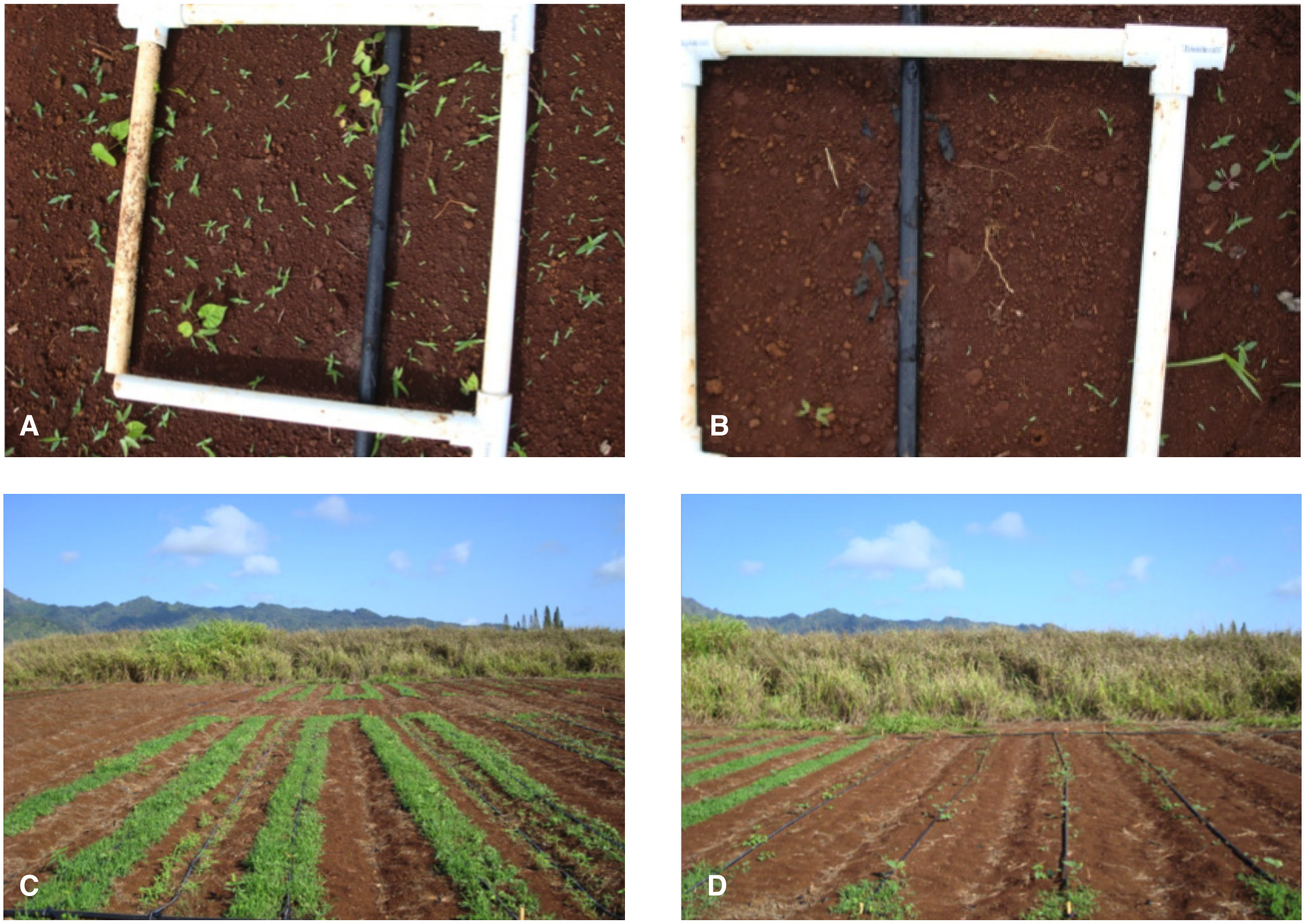

Fig. 8. Weed-suppressive effect of soil solarization. Weeds are flushed by irrigation in A) non-solarized control vs. B) solarized plots at 1 week; and in C) non-solarized control vs. D) solarized plots at 3 weeks after removal of solarization mulch.

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