Soil Solarization as an Organic Pre-emergent Weed Management Tool on O'ahu

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Introduction

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 to a range of 38 to 50°C to a depth of about 10 to 20 cm (Gamliel and Katan, 2012) for soil pasteurization. Soil solarization has been studied as an alternative to chemical soil fumigant like methyl bromide, which sterilizes the soil and harms beneficial microorganisms like rhizobium for nitrogen fixing legumes and mycorrhizae for plant roots (Gamliel and Katan, 2012). In addition to pasteurization, it has been known to also control weeds as a pre-emergent control that terminate weeds seeds in the ground before and during germination.

Soil solarization for weed control can be dated back to the ancient Indian civilization that utilized radiation from the sun to expose weed seeds in a heat treatment (Gamliel and Katan, 2012). Some of the pioneering work done on soil solarization has been conducted in Hawaii. In 1933, Harold R. Hagan heated Hawaiian soils with cellophane to control nematodes in pineapple fields (Hagan, 1933). However, soil solarization did not become popular until S.E. Groshevoy in 1939, when he demonstrated that exposing soil to solar heat controlled soil-borne pathogens (Grooshevoy, 1939). In 1971, plant pathologist Peter B. Adams became the first to use polyethylene mulch to control a soil-born pathogen, black root rot (*Thielaviopsis basicola*) (Adams, 1971). Today, polyethylene is the standard mulch used for soil solarization. In 1977, American pathologist G. S. Pullman and J. E. Devay published work that indicated a wide application of soil solarization and later in 1981 coined the term "soil solarization" (Pullman and DeVay, 1977; Pullman et al., 1981). Today there are 74 countries that have adopted or are investigating soil solarization for weed management and soil pasteurization (Gamliel and Katan, 2012). Most recently, (Wang and Sipes, 2009) reported short-term weed suppressive effect of solarization in pineapple crop production.

Mechanism

Soil solarization is conduction of heat by entrapment of solar irradiation through the greenhouse effect. Very thin (25-50 µm) transparent polyethylene (PE) mulch is commonly used to trap solar heat because it is permeable to the short-wavelength solar radiation, but does not transmit longer-wavelength radiation (heat) from the ground back into the atmosphere (McGovern and McSorley, 1997). Solar radiation with short wavelengths (about 120 - 400 nanometers) carries higher amounts of energy than does radiation with longer wavelengths (infrared radiation). The transparent plastic tarp used in solarization transmits ultraviolet (UV) and visible light but not infrared radiation (IR) known as photoselective PE plastic (Chellemi, 2006). 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 that generate heat. This heat is trapped beneath the plastic where it warms the soil (Krueger and McSorley, 2009). Although the thin PE mulches are less durable and are susceptible to wind and animal damage, it is more effective in raising the soil temperature and controlling weeds than the thicker PE mulches of 50-100 μm (Rubin and Baruch, 2012). However, nut sedges commonly puncture the PE mulch thinner than 19 μm (Chase et al., 1998). Commercial soil solarization mulch is made with UV-stabilized materials so that it can be more durable.

The second mechanism of soil solarization is through a solar heating process by soil moisture. Soil moisture conducts heat, evaporates and increases the maximum soil temperature (Mahrer and Shilo, 2012). Water has the property to be a good absorber of infrared and ultraviolet 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. Also, heat as latent heat of vaporization is absorbed due to water vaporization and absorbing heat as it changes from liquid phase to a gas phase. Due to these properties of water, soil solarization is more effective on moist soil than dry soil. Soil moisture has also been reported to increase the thermal sensitivity of pathogens (McGovern and McSorley, 1997). Debris on the soil surface or uneven mulching will create air pockets that slow down solarization heating. Good contact between the mulch and the soil and an absence of air pockets is essential for thorough and effective solarization.

In addition, soil moisture combined with heat increase the metabolism of the weed seeds and reduces their viability to germinate (Rubin and Baruch, 2012). In some cases soil solarization can break the seed dormancy of weed seeds before killing them during germination (Rubin and Baruch, 2012). Due to the importance of soil moisture in soil solarization, solarized rows have been installed with drip irrigation to maintain an optimal soil moisture (Mahrer and Shilo, 2012).

Addition of organic matter in the form of animal manure and plant residue from a cover crop can also greatly improve soil solarization. The organic matter additions can increase the soil moisture retention while fueling exothermic microorganism can raise the temperature up 1-3°C. Mineralization of organic matter also was accelerated by soil solarization. In addition, adding plant residues with allelopathic properties, biotoxins, can have also create a biofumigation effect with soil solarization (Rubin and Baruch, 2012).

Methods of solarization

Generally soil solarization is conducted over 4 to 6 weeks during the warmer time of a year with high solar irradiation and minimal cloud and precipitation, thus it is climate dependent (Gamliel and Katan, 2012). In Hawaii, the optimal time for soil solarization is during April to August to reach an optimal temperature range of 38 to 50°C (Fig. 1.).

Broadcast solarization and strip solarization are two main methods in conducting soil solarization. Broadcast solarization consists of covering a whole field with a continuous coverage of PE (Fig. 2A). This is performed by laying down strips of PE mulch with a tarp-laying machine

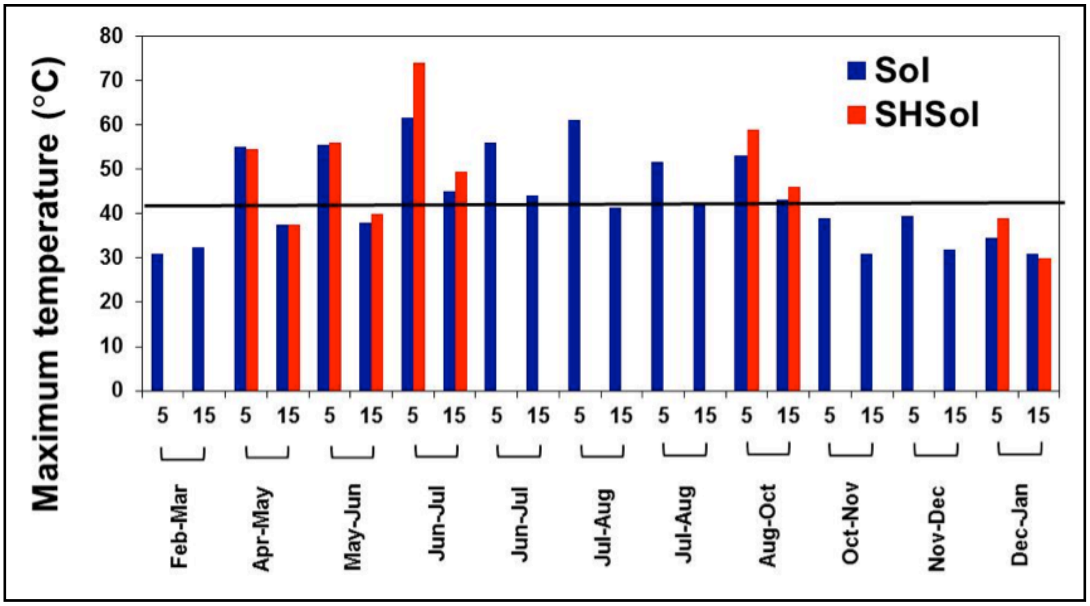

Fig. 1. Average of maximum daily temperatures recorded in each month under soil solarization mulch incorporated (SHSol) or not incorporated (Sol) with sunn hemp cover crop residues at 5- or 15-cm soil depth. Soil solarization was conducted on Oahu in 2010. Solid line represent 42°C which is a lethal temperature of many pests and pathogens.

and each adjacent sheet is overlapped and glued together. In Israel, a welding process was developed which is performed by emitting hot air from a combustion chamber on the PE sheets that overlap. The ends of the entire sheet are then anchored with narrow sand windrows that go across the PE mulch.

Strip solarization is simply applying the sheets of PE without attaching them. A mulch laying machine is commonly used to install 4-m wide PE sheets through strip solarization (Fig 2B). The machine creates two trenches for the ends of the sheet to be anchored to, and while the sheet is unrolled, a veering disc returns the soil back into the trench covering the ends of the sheet. This method is commonly used for raised beds as the PE mulch is used as a mulch for the crop after solarization (Gamliel, 2012).

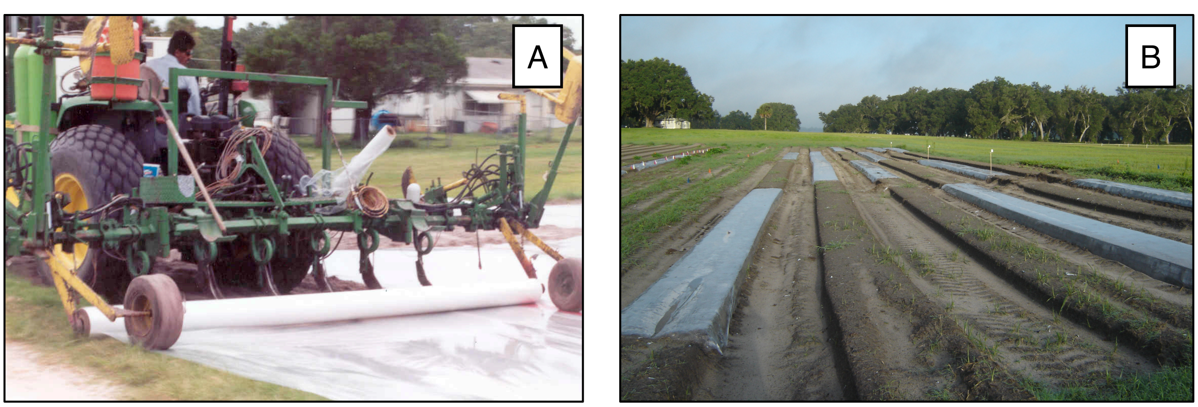

Fig. 2 A) Broadcast (flat bed) solarization, and B) strip (raised bed) solarization (pictured by Koon-Hui Wang).

Overcoming challenges of solarization in the humid tropics

While soil moisture is a benefit to soil solarization, precipitation is a hinder for soil solarization as it lowers the temperature of the soil. In the humid tropics of Hawaii, this may be a problem. Strategies to overcome this obstacle include increasing the duration of solarization from the standard 4-6 weeks to 10-14 weeks. Another technique known as double-layer (DL) soil solarization (Fig. 3). It can be implemented to increase the efficiency of solarization in wet climates as a second layer of clear PE mulch maintaining a layer of air that becomes an insulator (Stevens et al., 2012). As shown in Fig. 3, DL soil solarization can overcome the heavy pressure of nutsedges in a field that is normally out grown by this noxious weed despite covering the soil with regular opaque PE mulch.

Fig. 3. Double layer soil solarization (right two rows) vs non-solarized opague plastic mulch (left 3 rows) with heavy pressure of purple nutsedge. Double layer soil solarization is installed by laying a layer of solarization mulch on top of another holding up by wire hoops (picture by K.-H. Wang).

Another dilemma of soil solarization for weed management is the edge effect (Fig. 4). This is especially problematic if strip solarization is used and the bed orientation is not exposed to sunlight relatively evenly throughout the day. Soil temperatures with rows running north to south heat to a significantly greater level than 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 never (or rarely) shaded when they coincide with the path of the sun (north-south oriented beds), east-west oriented beds do not get the intense radiation needed to sufficiently raise soil temperature due to shading of the bed edges. Heat units are usually accumulated to a higher level at the west end of the bed due to stronger light intensity in the afternoon. Stevens (2013) recommended expanding narrow sheet solarization bed of 1-m wide to 3-4 m wide to reduce the percentage of coverage with edge effect.

Fig. 4. Edge effect of soil solarization where weeds are not exposed to intense sunlight on one side of the solarization strip resulted in favorable condition for weeds to grow (pictured by Koon-Hui Wang).

Conclusion

Due to high dependency on herbicides, growers have unintentionally created selective pressure on weeds to develop resistance against some herbicides. Soil solarization offers a new tool for weed management and is a viable weed management strategy for organic farmers.

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