Advances in Biosolarization Technology to Improve Soil Health and Organic Control of Soilborne Pests

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Abstract

Knowledge-based application of organic materials and passive solar heating can be useful as pre-plant, soil disinfestation treatments to eliminate soil pests, without using synthetic chemical applications. Solarization and biosolarization are specific, pseudo-soil fumigation techniques that are allowable under most organic certification programs. With the goal of making both of these approaches more effective, predictable and flexible for end users, we here review the principles, applications, and recent technological advances of soil solarization and biosolarization.

Introduction

This mini-review discusses two, related methods of pseudo-soil fumigation – solarization and biosolarization - that are organically acceptable. Knowing that there are many versions of what constitutes organic farming, this discussion will not consider the laws versus the philosophy of organic farming. We will simply lay out the science, applications, and certain historical aspects of these treatments for consideration by interested parties. It should be clarified that, although this discussion focuses on pest management for organic growers, solarization and biosolarization are techniques that can be useful to conventional growers, as well. These techniques can provide useful alternatives to chemical fumigation, which can be a continuing, and in some cases increasing problem to both human and environmental health. It is reasonable that most people would be interested in finding fumigation alternatives to avoid application of industrial toxicants into agricultural soils.

Review and Perspectives

Firstly, it is important to mention that there has been some incorrect information disseminated in certain organic circles that solarization destroys all life in the soil. Results from numerous bioindicators over the years show that fungi, bacteria, nematodes, and other biological activity are not eradicated when using solarization (Stapleton et al., 2000; Simmons et al., 2013; 2014). Solarization is a milder treatment than most chemical soil treatments. What occurs over time during the solarization process is a tendency to weaken and kill the plant parasitic organisms in soil. There is considerable information in the literature showing that, whenever stress (including heating) is applied to a soilborne community of organisms, many members that are phytoparasites tend to be more adapted to very close associations with the host plants, as opposed to survival in the open soil. On the other hand, organisms that are able to compete as soil inhabitants tend to be better able to tolerate adverse conditions (Kreutzer, 1965). By using the comparatively mild solarization treatment, numbers of phytoparasites often are greatly reduced, leaving populations, albeit reduced populations, of soil inhabiting organisms that are able to rapidly recolonize the treated soil (Stapleton et al., 2000). These surviving organisms are often antagonistic to phytoparasites. That being said, there have been a couple of cases that have been reported where, after solarization, there were some problems with either mycorrhizae or with *Rhizobium* bacteria that are needed for the bean

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family crops. In 30 to 40 years of solarization usage there have been less than a handful of such reports, but there should be awareness of the possibility.

Soil solarization is not a new technique - it's been around since the mid-1970s, and actually the concept of field soil heating for pest management is much older. For example, in the early days of the 20th century, farmers in the Imperial Valley of California knew that by doing a mid-summer cultivation of fallowed land and turning the soil over, they were able to knock out a lot of the soilborne disease and pest organisms, just by facilitating soil exposure to the very high summer temperatures (Newhall, 1955). Although the solarization concept is not new, it has been updated - nowadays plastic film mulch is used to trap and accumulate passive solar energy (Fig. 1). Solarization is allowed by USDA Organic and by most other organic certification standards. The bottom line is that if soilborne pest management is essential to a grower in a treatment-conducive area, solarization can make the difference between economic success and failure. There are certain cases in farming, especially in locations like California, where very high value crops are being grown or harvested in relay fashion. For example, in the Imperial Valley, solarization is used by organic growers producing leafy vegetables for bagged salad mixes. These crops are harvested by repeated mowing, and if weeds are present in the field, they could well wind up in the salad bags. So there's a zero tolerance for weeds. The alternative for getting around the problem is to frequently send in hand-weeding crews, which can be quite expensive. By using a pseudo-fumigation technique like solarization, the need for hand-weeding can be eliminated at a fraction of the cost. In California, commercial solarization usage is targeted mainly at weed control (Stapleton et al., 2005).

In California, most conventional solarization treatments are applied as row applications, rather than broadcast coverage over the entire field (Stapleton et al., 2005). In the Central Valley, at the present time, solarization procedures include tilling and furrowing of soil, followed by bed-shaping, laying of drip tape, and plastic film application, which may all be done in one tractor-pass. Solarization is scheduled around the month of July, the warmest time of the year. After plastic film application, the drip irrigation system is turned on to moisten the soil, which is then allowed to accumulate passive solar heating for a period of four to six weeks. Of course, treatment for that period of time in mid-summer can be a limiting factor for farming operations. Another limiting factor can be the dependence on passive heating. In growing areas that do not get high summer temperatures, or in those subject to local weather conditions which are not conducive (e.g., foggy) at that period of time, less than desirable pest management efficacy may result. As an idealized estimate of solar heating during July in the Central Valley of California, soil heating may peak at 60 ºC at 5 cm depth (2 inches), 45 ºC at 15 cm (6 inches), and 42 ºC at 30 cm (12 inches). There are very high daytime peak temperatures near the soil surface; as soil depth increases to 15 cm and 30 cm the heating is less. At greater soil depths, the extent of night-time cooling is less, as well (Fig. 2; Stapleton et al., 2000). The energy source for soil heating by solarization is a point source, the sun; therefore the heating is top-down. The surface layer of the soil receives the greatest heating, and deeper into the soil, the heating decreases (Marshall et al., 2013). However, it is important to note that the process of solarization is not strictly a physical heating phenomenon - chemical and biological changes occurring in soil also are very important to the pest management mechanisms (Stapleton et al., 2000).

In California, solarization is most commonly practiced in the Central Valley and in the lower desert (Imperial Valley), where summer solar heating is maximal, solarization has worked best, and comparatively more growers have adopted the technique. We have determined the thermal inactivation kinetics of quite a few different pests, describing the dosage required for inactivation of the important weeds, and phytopathogenic nematodes, fungi, and bacteria (Stapleton, 2000; Dahlquist et al., 2007). The information is available to the public on the UC Solarization website (Stapleton, 2016) for reference. When using solarization, it is important to consider temperature constraints. If solarization is attempted during a time period or at a location where the weather is not conducive, the treatment may not be effective. This is one limitation of conducting solarization without additional treatment components.

The primary focus of this brief report is on biosolarization, and the alternative soil disinfestation treatment which is a "close cousin" to solarization. The main principle of biosolarization is adding organic material into soil prior to the passive solar heating process. As the moist soil is heated, the organic material begins to decompose and free up allelochemicals and other biotoxic decomposition products which then briefly appear in the soil. The combination of soil heating, organic material decomposition and ample soil moisture produce an enhanced pseudo-fumigation effect, which can increase soil disinfestation efficacy (Gamliel and Stapleton, 1993) over solarized, non-amended soil. An additional advantage of using biosolarization is in combining two different modes of pesticidal activity - soil heating and organic material decomposition - in order to eliminate the past organisms while retaining at least low numbers of the beneficial biotic community. During solarization, we aim to maintain at least a partially aerobic process, with a portion of the soil microbial community respiring and undergoing normal metabolism, which can lead to additional biological heating of the soil on top of that achieved through solar energy accumulation (Simmons et al., 2013). However, it is important to remember that field soil is not necessarily a homogeneous medium. There are widespread instances where microaerobic and/or anaerobic conditions prevail under saturated conditions, deeper in soil, in conjunction with compacted soil layers restricting water percolation, etc.

The soil treatment known as anaerobic soil disinfestation (ASD) may be considered as a "close cousin" to biosolarization. This soilborne pest management approach currently is used by some organic growers of high value crops (particularly strawberries) in coastal areas of California, which are less conducive to soil heating than more inland areas. Plastic mulch is used to maintain very high moisture levels in soil containing organic amendments (Butler et al., 2012). The objective is to promote and maintain reductive and fermentative soil conditions to inactivate the pest organisms. One of the modes of action of ASD has been shown to be the production of biotoxic, organic acids in soil. The ASD technique can be used where the temperatures are low or where the weather conditions are not conducive to predictable biosolarization treatment

In terms of organic amendments for use in biosolarization, we prefer to use finished, plant-based composts, and crop and fruit processing solid wastes. We tend to stay away from animal-based materials (Stapleton et al., 2016). We have used animal by-products in the past (Gamliel and Stapleton, 1993), but with the risk of contamination with human pathogens, we currently find no reason to use them. Another advantage of staying with the plant-based amendments is the avoidance of restrictions associated with use of animal-based materials. Recently, we have been trying to get some of the solid waste materials from the food processing industry into our treatments. We have been testing incorporation of mixtures of greenwaste compost, along with pomaces of processing tomatoes, white wine grapes, and/or red wine grapes. Initial results indicated that the processing tomato pomace was the superior material among the three tested (Achmon et al., 2015).

The bottom line to our recent biosolarization experimental work is the field testing for improved biocidal effects on soilborne pest organisms (Fernández-Bayo et al., 2016). This past season, we used black mustard (*Brassica nigra*) and black nightshade (*Solanum nigrum*) weed seeds as our test organisms. The black mustard is more adapted to cool season conditions, while the black nightshade is more adapted to warmer conditions. We found that after eight days of biosolarization in July, seeds of both species were approaching 100% mortality, as determined both with a thirty-day germination test, and subsequent testing of the non-germinated seeds with tetrazolium vital stain. The confirmatory stain testing is because, when organic materials are added to soil or the chemical composition or microbial composition of the soil is altered, plant seeds and survival structures of fungi, nematodes, and bacteria can be driven into secondary dormancy (Stapleton et al., 2016).

Conclusions

We have initial indications that, instead of the 4-6 weeks treatment period we currently estimate for conventional solarization, we may now look at a 1-1.5 week treatment, which will make routine use of biosolarization a far more attractive and versatile option for growers. Not only will it permit a shorter treatment period, it may allow growers to treat during periods of time that are not as heat-conducive as mid-summer. Also, it may allow growers to treat in geographic and climatic locations that are more marginally heat-conducive. Consequently, there can be some real advantages with using biosolarization, as opposed to solarization of non-amended soil. As a final word of advice, as with all treatments which include soil amendment with organic materials, be aware of possible phytotoxicity to the subsequent crop. Start using biosolarization on a small scale, and take the time to develop guidelines for using it optimally on your own farm.

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Appendix:

Fig. 1. Transparent polyethylene film is applied to solarize a field on an organic vegetable farm in the San Joaquin Valley. (From Stapleton et al., 2000).

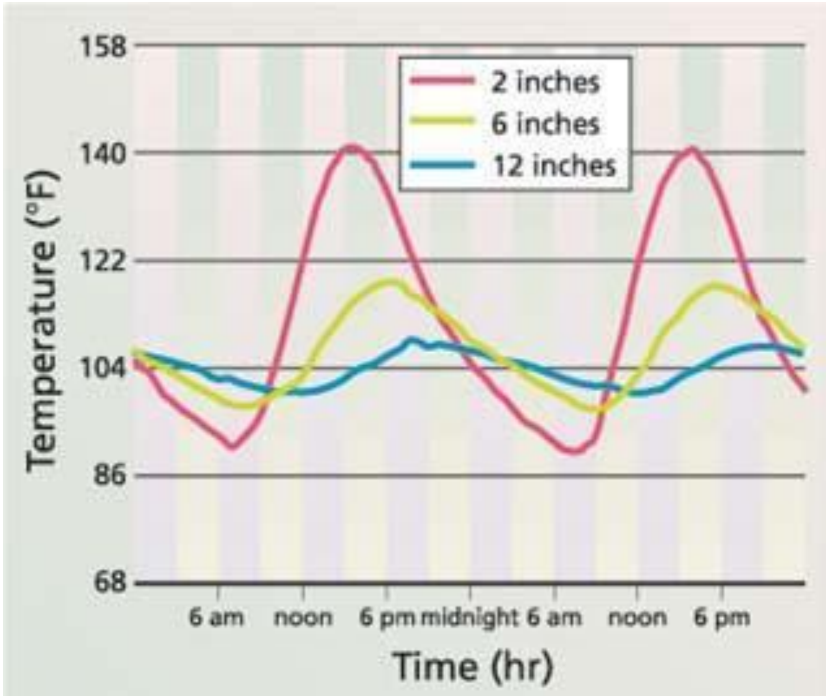

Fig. 2. Typical diurnal soil-temperature curves during solarization in the San Joaquin Valley, at three depths. (From Stapleton et al., 2005).