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The role of organic matter amendment level on soil heating, organic acid accumulation, and development of bacterial communities in solarized soil

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ABSTRACT

In light of the negative environmental impacts of soil fumigants such as methyl bromide, soil solarization, the treatment of soil using passive solar heating, has emerged as an environmentally friendly approach to soil pest suppression. Unfortunately, traditional solarization processes remove land from cultivation for 4–6 weeks during the peak of the growing season, limiting economic practicality. Biosolarization, where soil is amended with organic residues prior to solarization, can accelerate pest suppression, compress the solarization timetable, and facilitate effective treatment in shorter time periods. A combination of laboratory experiments and a field trial were employed in this study to examine the effects of organic matter amendment on soil heating, organic acid accumulation, and microbial community dynamics during biosolarization. Provision of organic matter resulted in robust metabolic activity, boosting peak soil temperatures by up to 2 °C beyond what could be achieved without an organic amendment. In the deep soil layers, organic matter amendment led to significant accumulation of acetic, *iso*-butyric, and butyric acids; increasing organic matter from 0% to 5% yielded 352–1271 fold increases in organic acid accumulation. The relative abundance of several organisms belonging to the phylum Firmicutes also increased with increasing organic matter amendment. The organic acid levels observed in this study (1–7 mg g^{-1} soil) would result in soil suppressive to a variety of fungal and nematode plant pathogens. Moreover, results suggest that suppression could be achieved within 2 weeks, potentially making biosolarization a more attractive alternative to chemical fumigation.

1. Introduction

Soil fumigation with synthetic chemicals is a common and effective agricultural practice for economic control of soilborne pathogens, nematodes, and weeds. Methyl bromide is one fumigant that has been used for maximizing production of high-value specialty crops, however, its use contributes to significant stratospheric ozone depletion and it has been largely phased out of routine usage (USEPA, 2011). The alternatives adopted by many growers have been other synthetic toxicants, including 1,3-dichloropropene, chloropicrin, metam sodium, metam potassium, dazomet, and sodium tetrathiocarbonate. These toxicants have significant problems of their own, including release of volatile organic compounds (VOCs) into the atmosphere, acute mammalian toxicity, and potential for ground and surface water contamination, which has led to usage caps and other governmental regulatory actions (EPA, 2012).

Soil solarization is a safe and effective, non-chemical alternative to fumigation. During soil solarization, moist soil is covered with a transparent plastic tarp, resulting in passive solar heating of the soil and a pasteurization effect that reduces pathogen populations.

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Despite this benefit, solarization is only applied commercially to a limited extent, because the recommended solarization duration is 4–6 weeks during the warmest period of summer (Elmore et al., 1997) and most growers cannot justify taking cropland out of production for that length of time.

Researchers have shown that solarization effectiveness can be increased, thereby decreasing treatment duration, if solarization is combined with other plant disease control techniques, such as incorporation of cruciferous residues (Ramirez-Villapudua and Munnecke, 1988), or application of compost (Gamliel and Stapleton, 1993). Soil organic matter amendment may improve the efficacy of solarization by increasing soil temperatures during solarization; soil temperatures have been reported to be 2–3 °C higher during solarization with compost than without compost (Gamliel and Stapleton, 1993), as a result of exothermic microbial activity stimulated by organic matter application (Simmons et al., 2013).

While addition of organic matter improves soil heating, organic matter decomposition during the solarization process is poorly understood. For example, there is little information on the evolution and accumulation of organic acids during the solarization process and the impact of changes in organic matter composition on microbial community structure. This information is important in order to best manage organic matter amendment and solarization conditions to achieve rapid soil heating while minimizing potential phytotoxic effects of residual organic acids on solarized soil.

In this study we examined the effect of amended organic matter level on organic acid accumulation, soil heating, and microbial community structure during soil solarization. Laboratory studies were conducted in temperature-controlled incubators to determine stable compost and organic matter amendment levels needed to achieve elevated biological activity. These studies were followed by a field experiment to evaluate laboratory observations. Soil biological activity and compost stability were characterized by measuring respiration and organic acid accumulation while microbial community structure was analyzed by high-throughput 16S rRNA gene sequencing. The results demonstrate the role organic matter management plays on temperature elevation and organic acid accumulation, potential key factors involved with soil disinfestation.

2. Materials and methods

2.1. Soil and compost preparation

Dry topsoil (Hanford sandy loam) was collected July 2011 from the 0–15 cm depth range at UC Kearney Agricultural Research and Extension Center (KARE) in Parlier, CA (36.6 °N; 119.5 °W; elevation 97 m a.s.l.), sieved through a 3.18 mm screen, and stored at room temperature. The soil was classified as Hanford fine sandy loam and the contents of organic matter, sand, silt, and clay were 0.0151 g (dry g)$^{-1}$, 0.41 g (dry g)$^{-1}$, 0.37 g (dry g)$^{-1}$ and 0.22 g (dry g)$^{-1}$, respectively (Marshall et al., 2013). Varying levels of compost stability were achieved by preparing compost mixtures containing stable green waste compost, and varying amounts of autoclaved wheat bran (Simmons et al., 2013). This was done to maintain a consistent microbial inoculum associated with the compost while enabling control of organic matter level and the potential for biological activity in the amended soil. Wheat bran was selected because its composition is similar to agricultural residues and municipal solid waste. Green waste compost was collected in May 2012 from Northern Recycling in Yolo County, CA. Compost was air dried under ambient conditions to a moisture content of 30.2% (dry weight basis), sealed in plastic bins, and stored at room temperature (ca. 21–28 °C). Food grade wheat bran ('Giusto's Vita Grain,' South San Francisco, CA) was autoclaved dry at 121 °C for 20 min. The sterile wheat bran (11.7% moisture content, dry basis) was then sealed in plastic bags and stored at room temperature.

2.2. Microcosm preparation

To prepare soil mixtures for field trial microcosms, soil wetted to field capacity was collected from the trial site and sieved through a 3.18 mm screen, and compost and wheat bran were wetted separately to 80% of field capacity the day prior to solarization. Field capacities for soil, compost, and wheat bran were 12% dry basis, 87% dry basis, and 172% dry basis, respectively. Wetted soil, compost, and wheat bran were combined to achieve the three following soil mixtures: (1) 98% soil and 2% compost (dry weight basis), (2) 96% soil, 2% compost, and 2% wheat bran, and (3) 93% soil, 2% compost, and 5% wheat bran. Soil mixtures were allowed to equilibrate for approximately 12 h under ambient conditions. Equilibrated soil mixtures were packed into 3.8 l black plastic Grow Bags with drainage holes to facilitate moisture and gas exchange (neHydro, Southampton, MA) to form microcosms. Temperature sensors (model 1922L, iButtonlink, Whitewater, WI) were embedded in the center of each microcosm at a depth 12.7 cm. The diameter and height of filled microcosms were 17.8 cm and 17.4 cm, respectively.

2.3. Solarization

The KARE field site used for soil collection was also used for conducting the field experiment. The field site was summer-cropped with sunflower in 2007, left fallow in 2008, and cropped with a winter forage mix (approximately 50% oats, 25% beardless barley, and 25% beardless wheat) in 2009 and 2010. Cool-season weed covers were present during portions of each year. To prepare for the solarization experiment, the field was plowed in May 2011 to incorporate the remains of the forage mix. The field was then irrigated, dried down, disced twice, then rotovated to bring soil to seedbed texture. Finally, an orchard float was passed over the soil to smooth the soil surface sufficiently for plastic film application. Solid-set sprinklers were placed around the plot and the site was irrigated five, three, and one day prior, as well as immediately before the initiation of the experiment. Pre-experiment water application totaled approximately 6.5 cm, which was sufficient to bring the soil to above field capacity at depths sampled in this study.

The experimental design for field plots followed those from prior field trials (Simmons et al., 2013). The field site was arranged into 5 plots. Each plot contained each of the three microcosms with soil amended with compost and wheat bran. Microcosms were buried within plots such that the top of the microcosm was flush with the soil line. Microcosms were buried 0.6 m apart from each other with a 0.9 m buffer between microcosms and plot borders. Microcosms were arranged randomly within each plot. Plots were covered with 0.7 mil transparent plastic sheets ('Husky Film Sheeting,' Poly-America, Inc., Grand Prairie, TX) and sheet edges were embedded in soil along plot borders to begin solarization. Temperature was logged every 15 min during solarization. After 15 days of solarization, microcosms were exhumed from field plots at 06:00–07:00 h, and were immediately transported at ambient conditions for approximately 3 h from the field site to the laboratory. Upon arrival, microcosms were cut into three 5.8 cm sections to isolate soil samples from various depths. Soil sections were sealed in plastic bags and stored at −20 °C until analysis of residual respiration, organic acid concentration and 16S rRNA gene sequencing