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Assessment of tomato and wine processing solid wastes as soil amendments for biosolarization

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ABSTRACT

Pomaces from tomato paste and wine production are the most abundant fruit processing residues in California. These residues were examined as soil amendments for solarization to promote conditions conducive to soil disinfestation (biosolarization). Simulated biosolarization studies were performed in both aerobic and anaerobic soil environments and soil temperature elevation, pH, and evolution of CO_2, H_2 and CH_4 gases were measured as metrics of soil microbial activity. Tomato pomace amendment induced conditions associated with soil pest inactivation, including elevation of soil temperature by up to 2 °C for a duration of 4 days under aerobic conditions and a reduction of soil pH from 6.5 to 4.68 under anaerobic conditions. White wine grape pomace amendment showed similar trends but to a lesser extent. Red wine grape pomace was generally less suitable for biosolarization due to significantly lower soil temperature elevations, reduced acidification relative to the other pomaces and induction of methanogenesis in the soil.

1. Introduction

Soil treatment to inactivate soil-borne pathogens and pests is an important practice in modern agriculture (Popp et al., 2013). Most pest management soil treatments use synthetic chemicals to destroy pathogens and weeds pre- or post-emergence (Lichtfouse et al., 2009). However, soil fumigants, such as methyl bromide, can have a deleterious effect on the environment (Maione et al., 2013). In contrast, alternative and sustainable integrated pest management strategies can be both environmentally friendly and cost effective (Lichtfouse et al., 2009). One such practice that has already seen practical application is solarization (Katan and DeVay, 1991), which employs solar heating to inactivate soil-borne pathogens, nematodes, and weed propagules. During solarization, moist soil is covered with transparent plastic tarp to induce passive solar heating of the soil and thermal inactivation of pests. Solarization has been successfully implemented in strawberry cultivation (Yildiz et al., 2010) and in smaller farming operations (Stapleton et al., 2005). Hurdles preventing widespread use of solarization include a strict scheduling requirement to coincide with the warmest period of the year and the variable efficacy of inactivation (Stapleton, 2000).

To address these issues, soil microbial activity enhanced by organic soil amendments has been combined with solarization, in a process termed biosolarization, to increase heat accumulation in the soil and produce chemical factors, including organic acids and other decomposition products, for pathogen and weed seed inactivation (Gamliel and Stapleton, 1993a; Huang et al., 2014; Momma et al., 2006). It is thought that the combination of multiple inactivation mechanisms during biosolarization may enhance pest inactivation and compensate for suboptimal climates that are not ideal for passive solar heating alone (Butler et al., 2014; Lamers et al., 2014). Biosolarization has been effective in controlling nematodes and other soil-borne pathogens in Japan, the Netherlands, and the US (Lamers et al., 2014).

Biological contributions to pest inactivation during biosolarization depend, in part, on the ability of soil microbial communities to convert soil organic matter into relevant biotoxic end products. Green waste compost has been demonstrated as an effective inoculum for introducing thermophilic bacteria to the soil that remain active under the extreme conditions encountered during biosolarization (Simmons et al., 2013). Additionally, some organic matter sources have already been shown to be compatible with biosolarization, such as chicken manure (López-Pérez et al., 2005), cruciferous,

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alliaceous, and poaceous crop residues (Gamliel and Stapleton, 1993a; Mallek et al., 2007; Stapleton et al., 2010), wheat bran (Simmons et al., 2014), and others. However, these amendments represent only a narrow fraction of the potential organic matter sources that might be used for biosolarization. As a result, there is a need to assess the biosolarization potential of a broad range of organic amendments, particularly abundant, low-value organic waste streams that could enable widespread adoption of biosolarization.

Solid residues from fruit processing are promising biosolarization soil amendments due to the fact that many of them are rich in organic compounds and have few alternate uses. As a major agricultural and food processing hub for the USA and the world, California produces large quantities of fruit processing residues and also requires soil pest management in high-value, horticultural crops. The most abundant fruit processing solid residues in California are pomaces from tomato paste and wine production (Matteson and Jenkins, 2007). Pomace consists primarily of skins and seeds that remain after the fruit has been disrupted and pressed. For grape pomace, pomace comes from both white wine production, where the juice is separated from the pomace ahead of fermentation, and red wine production, where the pomace is separated from juice after fermentation. As tomato and grape pomaces contain appreciable levels of carbohydrates (Del Valle et al., 2006; Valiente et al., 1995), they justify investigation as possible substrates for soil microogranisms during biosolarization.

In this study, the biosolarization potential of tomato pomace and red- and white-wine grape pomaces were investigated using a bioreactor-based, simulated biosolarization approach. Metrics relevant to pest inactivation, such as soil heating and acidification, were measured under aerobic and anaerobic soil conditions. Additionally, evolution of carbon dioxide, hydrogen, and methane gases were measured as indicators of microbial activity, substrate utilization, and potential greenhouse gas emissions. This simulated solarization technique has been shown to yield estimations of microbial soil activity that translate well to biosolarization field trials (Simmons et al., 2013). Relative to field conditions, simulated biosolarization in a laboratory setting permits finer control of process variables for comparing the biosolarization potential of different materials under varying conditions. Furthermore, it can serve as a decision making tool for identifying soil organic amendments, such as organic wastes from agriculture and food processing, that warrant further study in more resource-intensive field trials.

2. Materials and methods

2.1. Soil and soil amendments

Soil was collected from the Kearney Agriculture Research and Extension Center located in Parlier, CA in September, 2014 (36.6°N; 119.5°W; elevation 97 m). Mature green waste compost (from composting of lawn clippings, branches, and leaves) was obtained from a commercial facility in Zamora, CA in 2011. Tomato pomace was collected from a commercial tomato paste production facility in California in September, 2014. Red- and white-wine grape pomaces were obtained from the teaching winery at the University of California, Davis, in October, 2014. Properties of each material are given (Table 1). All pomaces were initially solar dried and then dried to their final storage moisture content in a drying oven (55 °C for 3–5 days). Each pomace was ground in a laboratory blender to achieve particle sizes <1 mm prior to analysis. Moisture content were determined gravimetrically (Pansu and Gautheyrou, 2007). Briefly, samples of tomato pomace, grape pomace, compost, and soil were weighed prior to and following drying in a vacuum oven once the dry weight for each stabilized. Determination of water holding capacity (WHC) was performed as previously described (McConnell et al., 1974) with several modifications. Samples of pomace and compost weighing 3–5 g were placed in 15 mL plastic centrifuge tubes. An excess of distilled water was added to the samples and they were allowed to equilibrate for 24 h. After reaching saturation, solids were isolated by centrifugation for 10 min at 9000 rpm. The supernatant was decanted and residual water was removed by gently blotting with tissue to avoid loss of solids. The weight of the saturated material was used in conjunction with the dry weight to calculate WHC. Soil WHC was determined by wetting 3 g of soil on filter paper to saturation with distilled water, allowing excess water to drain over 48 h, and then comparing wet and dry sample weights as described previously. Ash content was determined as the mass that remained following incineration of soil or biomass samples at 550 °C for 7 h and was expressed as a fraction of the original sample dry weight. The volatile solids content of each sample was calculated as a measure of organic matter content by subtracting the mass of ash from the initial sample dry weight. Values of pH were measured on mixtures of soil, compost, or pomace combined with distilled water at a 1:1 ratio. Bulk density was determined by weighing 5-mL samples of dried material and calculating the weight to volume ratio.

To prepare amended soil for bioreactor experiments, soil aliquots were combined with compost and pomace to achieve 2% and 5% loading (dry weight basis), respectively. Four soil amendment treatments were considered: soil containing 2% green waste compost and 5% tomato pomace, soil containing 2% green waste compost and 5% white wine grape pomace, soil containing 2% green waste compost and 5% red wine grape pomace, and a negative control consisting of soil containing 2% compost without pomace amendment. Dry soil and amendment materials were thoroughly mixed and then wetted with distilled water to achieve 80% WHC to represent the near-saturation conditions in field soil during biosolarization. Properties of soil mixtures are provided (Table 2).

2.2. Simulated biosolarization

Two bioreactor systems were established to broadly represent the aeration extremes that may be encountered in soil during biosolarization (Fig. 1). These include an anaerobic system to simulate conditions that may occur deeper in the soil or in those with high clay and/or moisture contents where oxygen diffusion is low, and an aerobic system to replicate soil conditions that could occur near the soil surface or in sandier soils as a result of oxygen diffusion from untarped border regions or through the tarp itself. For the anaerobic system, 250 mL glass media bottles with lids modified to accept a check valve (catalog #80103, Qosina, Edgewood, NY) were used as bioreactors. These reactors allowed evolved gases to escape the reactor headspace while preventing oxygen contamination. Tubing attached to the check valve and connected to a separate 250 mL bottle served as a gas collector (Fig. 1). Gas collectors for each reactor were connected to a MicroOxymax respirometry system (Columbus Instruments, Columbus, OH) equipped with infrared absorbance sensors for measurement of methane and carbon dioxide and an electrochemical fuel cell sensor for hydrogen detection. Sampling and measurement of gases in collectors occurred every two hours.

For the aerobic system, 250-mL aerated bioreactors described previously (Simmons et al., 2013) were used with several modifications. To reduce cooling and drying of the soil, air was heated and humidified to saturation by bubbling it through a series of three 1 L glass bottles upstream of the bioreactors containing distilled water at 55 °C. Effluent gas from each bioreactor was fed through glass bottles at room temperature to condense moisture and protect sensors downstream. During operation, reactors were supplied with air at a rate of 20 mL/min. Carbon dioxide concentrations in