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Research article

Deep injection and the potential of biochar to reduce fumigant emissions and effects on nematode control

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ABSTRACT

Reducing fumigant emissions is essential for minimizing the environmental impacts of pre-plant soil fumigation. Low permeability plastic films are effective at reducing emissions but have high initial purchase, installation, and disposal costs. The objective of this study was to evaluate if deep fumigant injection and biochar soil amendments can reduce emissions, improve fumigant distribution in soil, and provide acceptable control of plant parasitic nematodes. A pre-plant soil fumigation trial was conducted in a commercial orchard in the San Joaquin Valley, CA, USA. Treatments included two rates of Telone® C-35 (a mixture of 1,3-dichloropropene and chloropicrin) under totally impermeable film or with no surface seal, two injection depths (45 or 65 cm), and two biochar rates (20 or 40 ton ha^{-1}). Emission rates were generally low due to rain events encountered during the trial, but data clearly showed that the deep injection enhanced fumigant delivery to depths below 60 cm and resulted in significantly lower peak emission compared to the standard injection depth. Biochar applied at 40 ton ha^{-1} had the lowest emission rates during 1-month monitoring period. Although variability in nematode survival was high, tarped, deep injection, and biochar treatment showed lower survival of nematodes at various depths. Increase in fumigant persistence, especially chloropicrin, was observed in this study, likely due to the high soil moisture and low temperature. All data indicate that biochar amendments can help reduce fumigant emissions without reducing nematode control; however, additional research is needed to optimize treatments, determine the affordability of various biochar materials, and validate results under a range of field conditions.

1. Introduction

Soil fumigation continues to play a critical role in orchard replanting, primarily due to vigorous and uniform tree establishment when plant-parasitic nematodes and replanting disease is managed (Radewald et al., 1987; Browne et al., 2006; Gao et al., 2015). The phase-out of methyl bromide (MeBr), due to its contribution to the depletion of the stratosphere ozone, has resulted in wide use of other pre-plant soil fumigants in California, such as 1,3-dichloropropene (1,3-D) and chloropicrin (CP). These alternative fumigants, however, are highly regulated due to their contributions to air quality degradation after emission from the soil to the atmosphere. Federal and state regulatory agencies in the USA continue to develop and amend fumigant regulations to protect people and the environment (CDPR, 2013, 2015; USEPA, 2015), so techniques that reduce fumigant emissions from soil could determine the availability of these pest management options for growers.

Previous studies have shown that low permeability or high-barrier plastic films such as virtually impermeable film (VIF) (Qin et al., 2011; Gao et al., 2014) or totally impermeable film (TIF) (Wang and Yates, 1998) can significantly reduce emission loss, increase fumigant concentrations or residence time in soil, and improve fumigant distribution. As a result, reduced rates (1/2 rate for annual crop such as strawberry and 2/3 rate for perennials such as almonds) can be used to achieve the same efficacy as the full rate applied under standard polyethylene (PE) film or no barrier film (Fennimore and Ajwa, 2011; Gao et al., 2014, 2015). MeBr emissions were managed using relatively inexpensive PE films; however, this material is not as effective for the

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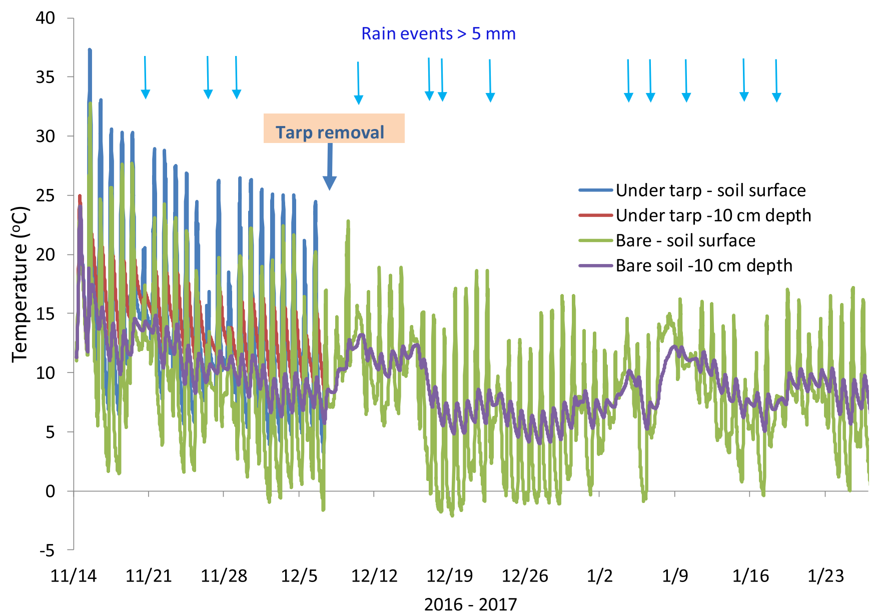

Fig. 1. Soil temperature at 10 cm in a bare plot and a TIF tarped plot during a fumigation trial conducted in fall 2016 near Hughson, CA.

alternative fumigants (Gao et al., 2011). TIF is effective in reducing emissions of 1,3-D and chloropicrin, but is 1.5–2.0 times more expensive than PE film. Recently, soil amended with biochar has shown the potential to reduce fumigant emissions (Wang et al., 2014, 2016) while also eliminating the initial purchase, installation, and disposal costs of plastic films.

Biochar (charcoal produced via pyrolysis of various biomass material) when applied to or incorporated into the soil has been shown to improve soil properties (Glaser et al., 2002; Lehmann and Joseph, 2009), remove or reduce the toxicity of many contaminants including pesticides (Ahmad et al., 2014; Miles et al., 2016), and suppress plant-parasitic nematodes (Huang et al., 2015; George et al., 2016; Cao et al., 2018). Biochar has also been reported to reduce fumigant emissions in lab soil column studies (Wang et al., 2014; Ashworth et al., 2017); however, no information is available on the effects of biochar on fumigant emissions under field conditions. Adsorption and degradation have been determined to be the mechanisms for fumigant dissipation by biochar (Wang et al., 2016).

Surface soils amended with biochar in which soil fumigants are injected below the amended level might simultaneously reduce emissions and increase fumigant residence time in soil due to the greater adsorption than degradation (Wang et al., 2016). Additionally, as a soil amendment, biochar has been shown to improve soil physio/chemical properties such as increased soil cation exchange capacity (CEC) (Glaser et al., 2002), improved soil hydraulic conductivity or soil water holding capacity (Guo, 2016), and improved soil fertility (Igalavithana et al., 2016). Thus in addition to reducing fumigant emission, biochar could provide a number of agricultural and environmental benefits.

A second challenge for the alternative fumigants in orchard replant situations is related to poor distribution deep in the soil profile due to relatively low vapor pressure compared to MeBr (Ajwa et al., 2010). Due to the deep rooting system of trees and vines, plant-parasitic nematodes may be present below 1.5 m or deeper in soil. In California orchard sites, soil fumigants typically are applied at 45 cm depth via straight or winged shanks. However, poor pest control efficacy has been observed below 1 m soil depth (Gao et al., 2014, 2015) due to the much lower concentrations or non-uniform distribution at those depths. Fumigant application to soil depths deeper than 45 cm could increase concentrations below 1 m depth and improve nematode control (Gao et al., 2018). The objective of this study was to evaluate if deep fumigant injection and biochar soil amendments can reduce emissions, improve fumigant distribution in soil, and provide acceptable control of plant parasitic nematodes. This research was conducted to provide additional management practices to complement those in the literature and answer the important question if biochar amendment can be an emission reduction strategy in soil fumigation.

2. Materials and methods

2.1. Fumigation trial

A fumigation trial was carried out in late fall of 2016 in an orchard located in Hughson, Stanislaus County, CA after removal of a mature almond orchard. The soil was Hanford sandy loam (Mixed, superactive, nonacid, thermic Typic Xerorthents), with 0–3% slope in the field. More information about the soil type is available at Natural Resources Conservation Service (NRCS) website (https://soilseries.sc.egov.usda.gov/OSD_Docs/H/HANFORD.html). Average daily temperature, humidity, and wind speed were 8.9 °C, 82.5%, and 1.3 m s^{-1}, respectively.

The cooperating grower removed the old orchard and prepared the site for fumigation and replanting of the orchard using standard practices for the region. After the site was prepared, several Telone® C-35 (34.7% CP, 63.4% 1,3-D, and 1.9% other ingredients) treatment combinations were applied. Properties of 1,3-D and CP, and factors or processes affecting their fate in soil can be found in Ajwa et al. (2010). Treatments included two fumigant injection depths: regular (45 cm) injection depth or a deeper (65 cm) injection depth, two application rates (100% or ~66% of current maximum rate, which is 610 kg ha^{-1}), two rates of biochar amendment (20 and 40 ton ha^{-1}) at 66% fumigant rate and injected to 65 cm depth, and two surface sealing methods (no tarp or TIF), plus a non-fumigated control. These treatments were tested in two different settings. The injection depths and rate treatments were investigated in large plots with each plot 34.0 m long and 6.4 m wide for planting 8 trees. Limited by the available amount of biochar product, testing the biochar treatment effects were carried out in small plots within the large field with each plot occupying the area of one tree (3.05 m × 3.05 m). The TIF was VaporSafe® (1-mil thickness, clear, Raven Industries, Sioux Falls, SD, USA). CoolTerra® biochar (Cool Planet, Camarillo, CA, USA), was derived 100% from coconut shell feedstock, pyrolyzed at 550 °C, and subjected to a proprietary post-production treatment to neutralize the pH and remove some residual elements. All treatment combinations were tested in a randomized