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Emission and crop response in almond orchards fumigated with reduced rates of Telone® C-35 and low permeability film for nematode control

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ABSTRACT

Many high-value tree crops are dependent on soil fumigation for control of plant-parasitic nematodes and diseases for successful orchard replanting. Due to detrimental impacts on the environment, fumigants are under stringent regulations. The study investigated if a commercially available totally impermeable film (TIF) such as VaporSafe® and reduced fumigant rates can achieve emission reduction while providing good control of plant-parasitic nematodes and improving tree establishment. Two field trials were conducted in almond orchards on a sandy soil or a sandy loam to test the effects of Telone® C-35 (containing 63% 1,3-dichloropropene and 35% chloropicrin) on fumigant movement, nematode survival, and tree performance. In the trials, Telone® C-35 was applied at various rates: 100% (610 kg ha^{-1}), 66%, or 33%; with three surface sealing methods: bare, standard polyethylene film (PE), and TIF. The TIF greatly reduced emissions compared to PE or bare soil with very low off-edge emissions. Both 100% and 66% rates of the fumigant promoted similar tree growth regardless of surface sealing methods. The 66% rate under TIF and PE also provided 100% control of resident nematodes as the 100% rate at or above 100 cm soil depth in both trials. Fumigation at the sandy soil site was able to reduce or eliminate the nematode population at the 120-150 cm soil depth. However, none of the treatments provided 100% control of nematodes at this depth in the sandy loam soil indicating the effects of soil texture on fumigation efficacy. Thus, TIF and reduced rates of Telone® C-35 can be used to reduce the environmental impacts of soil fumigation and fumigant expenses.

1. Introduction

In replanting situations many orchard crops, including almonds, rely on pre-plant fumigation to disinfest soil, especially in fields with soil-borne plant-parasitic nematodes or disease pathogens (Radewald et al., 1987; Browne et al., 2013). Since the gradual phase-out of methyl bromide (MeBr) began, the industry has been largely using alternative products such as Telone® C-35, a mixture of 1,3-dichloropropene (1,3-D) and chloropicrin (CP) (Dow AgroSciences, 2012). These alternative fumigants, however, are toxic materials and most of their ingredients are identified as air polluting volatile organic compounds (VOCs). Thus, their use has been highly regulated to minimize potential exposure risks to workers and nearby populations, and to reduce air pollution (CDPR, 2009). Both federal and state regulatory agencies continue to develop and amend existing regulations on soil fumigants (CDPR, 2015; USEPA, 2015) increasing the difficulty to apply these products in the Central Valley of California. An example of this is “township caps,” which refer to the California Department of Pesticide Regulation's *Permit Conditions* that allow only 90,250 pounds of 1,3-D be applied to any township (6 mi × 6 mi area defined by township and range designations) in a calendar year (Trout, 2003). To maintain the ability to use soil fumigants for orchard replanting, fumigation methods that lead to both satisfactory pest control and low environmental impact must be developed.

Research has shown that using low permeability tarps (e.g., VaporSafe® totally impermeable film or TIF) can effectively reduce emission by retaining more fumigant under the film. Better fumigant retention leads to longer residence time in soil improving fumigant distribution for increased efficacy (Qin et al., 2011; Gao et al., 2013). This provides the opportunity to reduce fumigant rates while maintaining efficacy when applied at 30 cm depth or shallower for annual crops. In fumigation of perennial crop sites, however, the benefits observed in shallow-rooted crops were less conclusive because the

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survival of plant-parasitic nematodes within greater soil depths was observed (Cabrera et al., 2015; Gao et al., 2016). The nematodes can be present at 1.5 m or deeper and fumigants are often injected at a deeper depth, ~45–50 cm (18–20 in) within California orchard and vineyard replant situations. For comparison, within annual crops, fumigants are commonly injected at 25-30 cm (10-12 in) depth (Qin et al., 2011; Gao et al., 2013). A field study conducted following removal of a vineyard indicated that TIF retained higher fumigant concentrations immediately under the film and showed some improvement on fumigant dispersion in the surface soil compared to PE (Gao et al., 2016). In the same study, TIF effectively reduced emissions and reduced rates of Telone® C-35 provided similar pest control as the 100% rate near the surface. However, high nematode survival was observed below 1 m depth in all treatments including the TIF covered at the 100% rate. None of the previous studies was able to monitor the crop response to fumigation treatments after planting.

The ability of TIF to retain fumigants and improve fumigant distribution in soil offers the potential for reducing rates to achieve similar efficacy as the current standard maximum rate with either no plastic film or standard polyethylene (PE) films. Reducing fumigant rates provide immediate environmental benefits by reducing chemical input and corresponding emissions. A drawback of using 100% fumigant rates with highly retentive TIF is the observed surge in emissions upon film-cutting for planting (Qin et al., 2011). One solution to this problem is to extend covering time until the fumigants degrade to a level low enough to minimize emissions (i.e., exposure risks) and reduce potential crop phytotoxicity (Ajwa et al., 2013). However, extending the covering period may delay planting or other field operations. There is also concern of the high emission rates immediately off the tarp edge from shallow injected fumigants (Gao et al., 2013), which is unknown from the deeper injection for perennials. The objective of this study was to test if a commercially available totally impermeable film (TIF, VaporSafe®) and reduced fumigant rates can achieve emission reduction while providing good control of plant-parasitic nematodes and improving tree establishment.

2. Materials and methods

2.1. Fumigation trials and treatments

Two fumigation trials were conducted in late 2012 near Merced and late 2014 near Delhi in the San Joaquin Valley of California (SJV, CA). The soil was Snelling sandy loam at Merced and Delhi sand at Delhi. The Snelling series consists of deep and well drained soils formed in alluvium from predominantly granitic rock sources and typically on terraces. Detailed information on the soil type can be found at https://soilseries.sc.egov.usda.gov/OSD_Docs/S/SNELLING.html. The Delhi series are very deep and somewhat excessively drained soils, formed in wind modified material weathered from granitic rock sources, and located on floodplains, alluvial fans, and terraces (https://soilseries.sc.egov.usda.gov/OSD_Docs/D/DELHI.html). In the studied region, crop production is dominated by orchards for stone fruits and nuts. The climate of SJV is Mediterranean type, i.e., with hot dry summers and cool wet winters. Both trials were conducted during the cool and usually rainy season of the year. The old orchards were removed after harvest in the fall. The field was prepared by the grower for fumigation and replanting was done within several months following fumigation. This is a typical pattern for growers when replanting to maximize their field production in the region. Specific information about the field location, soil, fumigation date, treatments, plot size, and field monitoring for both trials are summarized in Table 1. With the same climate and fumigation season, the key difference between the two trials is the soil type.

The trials were to evaluate the effects of three surface sealing methods (bare, standard PE, and TIF) and application rates: 100%, 66%, 33% (in Merced trial only), and 0 rates of Telone® C-35 (35% CP, 63% 1,3-D, and 2% other ingredients) on fumigant movement, control of plant-parasitic nematodes, and tree response to the pre-plant fumigation treatments. The 100% rate refers to the maximum rate of 1,3-D allowed in CA, which is 610 kg ha^{-1} (48 gallons or 540 lb/ac) of Telone® C-35. The targeted reduced rates were 407 kg ha^{-1} and 204 kg ha^{-1} for the 66% and 33% rates, respectively, and were applied by a commercial applicator (TriCal, Inc., Hollister, CA). Application rates in all plots were monitored and achieved 91-102% of the target value. The TIF used in the study was VaporSafe® (1-mil thickness, clear, Raven Industries, Sioux Falls, SD, USA). Standard PE (1-mil thickness) was provided by TriCal, Inc. (Hollister, CA, USA). Both films were 4 m wide. With ten trees per plot, treatments were tested in six (Merced trial) or four (Delhi trial) replicates with a randomized complete block design. Fumigant monitoring and pest control efficacy data were collected in three replicates, but tree growth was measured in all replicates.

Telone® C-35 was shank-applied in both trials at a 46 cm (18 in) plus a 71 cm (28 in) depth at Delhi. Fumigant treatments were applied to 3.56 m wide strips spaced 4.9 m apart on center; this arrangement corresponded to the spacing of the planned orchard rows covering about 54% of the orchard area. After fumigant injection, the soil was disked and rolled for compaction according to the label requirement (Dow AgroSciences, 2012) before plastic films were installed.

2.2. Field sampling and monitoring on fumigant movement

Field sampling included measurement of emissions and fumigant concentration changes under the film and in soil profile as well as fumigant residue at the end of monitoring period. Passive flux chambers, an apparatus for sampling air under the plastic film, and soil gas sampling probes were installed immediately after film installation.

In the Merced trial the three treatments monitored for emissions were: 100% rate sealed with PE, 66% rate sealed with PE, and the 66% rate sealed with TIF. For the 66% rate sealed with TIF, emissions immediately off the film edges and 50 cm outside of the film-edge were also monitored. The 100% rate with TIF was tested to observe effects on tree growth but it is not expected to be recommended to or adopted by growers due to increased fumigation costs; thus, emissions were not determined. Fumigant concentration under the films was monitored for all tarped treatments. Fumigant concentration through the soil profile over time was monitored for six treatments: 100% rate with no film, 100% rate sealed with PE, 66% rate with no film, 66% rate sealed with PE, 66% rate sealed with TIF, and the 33% rate sealed with TIF. The 33% rate with PE covering was not tested because of known poor efficacy due to low fumigant concentrations in soil or high emissions (Gao et al., 2016).

In the Delhi trial, the sampling plan was similar to that at Merced. Emissions were measured from the 100% rate at both injection depths (46 and 71 cm) with bare and PE surface treatment as well as a 66% rate with TIF. The 33% rate with TIF was excluded in the Delhi trial after the Merced trial showed poor efficacy.

All tarped treatment plots were monitored for fumigant concentration changes under the film. Soil gas sampling was conducted for all surface and injection depth treatments at 100% rate to compare with 66% rate with TIF at regular injection depth. In both trials, soil gas sampling probes were installed at 15, 30, 45, 60, 75, and 100 cm depths, plus 125 cm depth at Delhi. Sample collection, storage, and processing followed previously developed protocols (Gao et al., 2009).

Based on gaseous 1,3-D and CP concentrations in soil, the concentration-time exposure index (CT) was calculated [Σ(concentration × time). The index values were calculated for individual compounds and the sum was used for data reporting and discussion. The CT index is an indicator of pest control efficacy (Wang and Yates, 1999). The CT was calculated for 96 h and end of the monitoring period (35 d or 28 d for Merced or Delhi trial, respectively) following fumigant application.