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Off-tarp emissions, distribution, and efficacy of carbonated fumigants in a low permeability film tarped field

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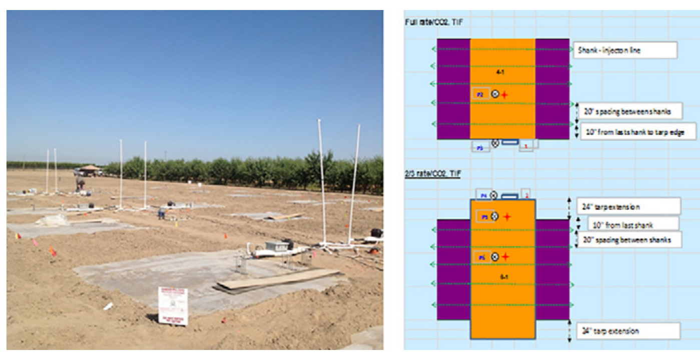
HIGHLIGHT

- Solutions to reduce emission and improve fumigant dispersion are needed in orchard.
- Low permeability films (TIF) improve fumigation efficacy than polyethylene film.
- Carbonation didn't show the improvement on fumigation efficacy in sandy loam soils
- Off-edge emissions were lower when fumigants are injected deeper than shallower.
- TIF film extension can be an effective solution to reduce off-tarp edge emissions.

GRAPHICAL ABSTRACT



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ABSTRACT

Carbonated fumigants have been shown to distribute quickly and uniformly in sandy soils and improve pest control efficacy for annual crops. Low permeability films, such as VaporSafe® (TIF), could further improve fumigant dispersion by effectively retaining the fumigant in soil; however, there is a concern that the TIF can lead to higher off-tarp edge emissions. An orchard field trial was conducted to determine the off-tarp emissions, distribution, efficacy, and fate of carbonated Telone® C35 [63.4% 1,3-dichloropropene (1,3-D), 34.7% chloropicrin (CP)] that was shank-injected at 46 cm soil depth. Treatments included carbonated fumigants at full- or 2/3 rates and a full rate of regular (nitrogen-pressurized) fumigants covered with standard polyethylene (PE) film, TIF, or no surface seal. Fumigant emissions at the regular tarp edge (25 cm from the shank line) peaked at 3.98 μg m^{-2} s^{-1} for 1,3-D and 0.05 μg m^{-2} s^{-1} for CP. The addition of a TIF tarp extension (to 85 cm from the shank line) reduce peak off-tarp emissions to <1 and <0.03 μg m^{-2} s^{-1} for 1,3-D and CP, respectively. Fumigant concentration under TIF was usually at least twice that under PE regardless of carbonation. Carbonation at 345 KPa with 1.5% of dissolved CO_2 did not significantly improve fumigant dispersion in soil profile compared to the conventional nitrogen pressurization. In a citrus nematode bioassay, only the 2/3 rate of carbonated fumigation treatment sealed with PE failed to control nematodes at 25 cm away from shank line. This research indicates that a 60-cm TIF extension can effectively reduce off-tarp edge emissions in strip fumigation treatments. While the adaptability of carbonation of fumigants is still questionable, further research efforts are needed in finding effective solutions to control plant parasitic nematodes, which remain a challenge in orchard fumigation.

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1. Introduction

California (CA) is the leading state for many tree fruits, tree nuts, and grapes in the USA (USDA-ERS, 2017). Orchards and vineyards typically have a limited productive lifespan, although this can vary among crops and regions of the state. When an orchard site is prepared for replanting, the major roots and larger root pieces of the old crops usually are picked up and removed from the field. However, many mid- and small-sized roots remaining in the field can be important sources of parasitic nematodes and pathogens that can affect the new crop (Doll, 2009). To ensure successful replanting, preplant soil fumigants often are applied to control parasitic nematodes or suppress the disease complex known as tree replant disorder (Browne et al., 2006).

In orchard replant situations in CA, fumigants are commonly applied at a 45 cm depth as either broadcast application or in strips centered on the locations of the future tree row. Since the phaseout of methyl bromide, a combination of 1,3-dichloropropene and chloropicrin (e.g. Telone C35) has been one of the major fumigants used for this purpose. However, these alternative fumigants diffuse more slowly than methyl bromide, which can result in non-uniform fumigant distribution that negatively affects pest control efficacy (Ajwa et al., 2010). This can be especially problematic in deep-rooted orchard crops which can have significant roots and root-associated pathogens at depths of 1.5 m or greater. Therefore, solutions that can facilitate fumigant distribution and movement in soil profile are important for improving fumigation efficacy.

Most shank-applied soil fumigants in CA are injected using a system that pressurizes the fumigant tank with nitrogen (N_2). Thomas et al. (2011) found that carbonating the fumigants for 18 h at 689 kPa and then injecting the carbonated fumigants using pressurized (1034 kPa) CO_2 instead of N_2, improved fumigant dispersion in raised-bed tomato production systems in sandy soils in Florida, USA. In their work, carbonated Telone® C35 at a 75% application rate provided better control of root-knot nematode and weeds than a full rate (430 kg ha^{-1}) of N_2-pressurized Telone® C35. However, in a CA perennial crop trial, carbonated Telone® C35 at 207 kPa did not improve nematode or weed compared to non-carbonated fumigants (Gao et al., 2016).

Fumigant emissions that contribute to air pollution or pose exposure risks are highly regulated (CDPR, 2013; USEPA, 2009). Five regions in CA have been listed as air quality nonattainment areas (NAAs) (CDPR, 2009) where low emission fumigation methods must be implemented between May 1 and October 31 each year in order to reduce air pollution. Currently, the most effective fumigant emission reduction strategy involves covering the soil surface with low permeability film, such as VaporSafe® totally impermeable film (TIF). These films can retain fumigants much more effectively than the standard polyethylene film (PE) and improve pest control efficacy (Qin et al., 2011; Gao et al., 2013a; Cabrera et al., 2015).

Extremely high emission flux from just outside the TIF tarp edge was measured in a large scale demonstration of trial. This raised great concerns about how highly retentive films influence lateral fumigant movement and off-tarp edge emissions which would be of even greater concern in strip-fumigated orchard sites with a high proportion of edges relative to a whole field fumigation. With carbonated fumigants to enhance dispersion in soil, there is a potential that fumigant emissions past the edge of the TIF-tarped area could be even more significant. Under current practices, the barrier films extend 25 cm past the outer shank-lines on a multi-shank application rig. To minimize off-edge emissions, one simple option would be to extend the tarped area further outside the fumigated area; however, no field research has been conducted to validate this idea. Therefore, we conducted a field trial to evaluate the effects of carbonated fumigants and TIF tarping in strip fumigant applications commonly used in California perennial crops. The objectives were 1) to determine fumigant emission from the edge of TIF tarped area and evaluate if an extended tarp width can reduce the off-edge emissions, and 2) to evaluate whether the distribution, efficacy, and fate of 1,3-D and CP are affected by carbonation and TIF covering.

2. Materials and methods

2.1. Chemicals and plastic materials

For laboratory analysis, all organic chemicals used were pesticide-grade. 1,3-Dichloropropene (1,3-D) ($C_3H_4Cl_2$; purity of 99.9%) containing 52.5% cis-1,3-D and 47.5% trans-1,3-D was provided by Dow AgroSciences (Indianapolis, IN). Chloropicrin (CP) (Cl_3CNO_2) was provided by Niklor Chemicals (Mojave, CA). For the field applications, Telone® C35 (63% 1,3-D, 35% CP, and 2% other ingredients) was provided by TriCal, Inc., Hollister, CA. Standard PE film (0.038-mm thickness, clear) was provided by PolyPak, Los Angeles, CA. The TIF (VaporSafe™, 0.025-mm thickness, clear) was provided by Raven Industry, Sioux Falls, SD.

2.2. Field trial and treatment

The field trial was conducted at the USDA-ARS-San Joaquin Valley Agricultural Sciences Center (Parlier, CA, USA) in a Hanford sandy loam soil (coarse-loamy, mixed, superactive, nonacid, thermic Typic Xerorthents) during May 16–June 19, 2013. Before fumigation, the field was ripped to 90 cm depth, disked in surface, and irrigated one week early to achieve proper soil moisture. Ten treatments were applied in the trial including three non-fumigated controls (PE, TIF, and bare soil), three full-rate regular N_2 pressurized Telone® C35 (PE, TIF, and bare soil), two full-rate and two 2/3 rate carbonated Telone® C35 (PE and TIF). The full rate fumigant, 690 kg ha^{-1}, was the maximum rate of 1,3-D used in CA. The 2/3 rate was 460 kg ha^{-1}. The carbonated Telone® C35 was prepared by TriCal, Inc. (Hollister, CA) by saturating the fumigant with CO_2 at 345 kPa overnight, which was about half of the 689 kPa used by Thomas et al. (2011). The lower pressure was used because of the safety concerns for the pressurized fumigant tank during transportation to the field. The final amount of CO_2 added to the fumigants was 1.51% (w/w). The carbonation pressure, was higher than 207 kPa tested earlier (Gao et al., 2016) when no significant carbonation effects were observed, but the final added CO_2 was similar for unknown reasons, possibly caused by different size of cylinders used and carbonation time etc. During application, both the carbonated and non-carbonated fumigants were applied using N_2 which differed from Thomas et al. (2011) who also used pressurized CO_2 to inject the carbonated fumigants.

Telone® C35 was shank-injected at a 46 cm soil depth using a conventional Telone® rig with five shanks and the spacing between neighboring shanks was 51 cm apart. Immediately after application, the surface soil was compressed by disks and rollers following the label requirement and then left bare or immediately tarped with PE or TIF. Individual plots were 4.6 m long and the width between the outer fumigation shanks was 2 m. In the conventionally-tarped plots, the film extended approximately 25 cm beyond the outer shank-line for a 2.5 m wide plot. In the plots with carbonated fumigant at 2/3 rate, an additional 60 cm of film was added so that the tarped width was 3.7 m and extended 85 cm beyond the outer shank-line on each side. There was at least a 2.4 m non-fumigated buffer between fumigation blocks or plots and each treatment was replicated three times in a randomized complete block design.

2.3. Sampling and measurement

Fumigant concentrations in soil profile were monitored at 15, 30, 45, 60, 75, and 100 cm depth using soil gas probes that were installed immediately after fumigation and tarping. The monitoring focused on TIF-tarped plots including full rate regular N_2 pressurized fumigant (Full-N_2-TIF), full rate carbonated fumigant (Full-CO_2-TIF), and 2/3 rate carbonated fumigant (2/3-CO_2-TIF). To monitor fumigant lateral movement in soil profile, there were two sampling locations in the Full-CO_2-TIF plots: at the center of the plot and at the plot/edge. There