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Effects of emission reduction surface seal treatments on pest control with shank-injected 1,3-dichloropropene and chloropicrin

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ABSTRACT

The phase-out of methyl bromide for preplant soil fumigation has resulted in an increased reliance on combinations of 1,3-dichloropropene and chloropicrin in many annual and perennial cropping systems in California. However, these fumigants also can have negative environmental and human health consequences and considerable research has been conducted on methods to minimize emission of these products from the soil to the atmosphere. To ensure that pest control efficacy is not compromised by emission reduction techniques, this research was conducted to simultaneously evaluate the effects of several surface seal techniques on fumigant emissions and the efficacy of soil-borne pest control with a mixture of 1,3-dichloropropene + chloropicrin. Results indicated that the interaction between emission reduction techniques and pest control efficacy can be complicated. For example in the 2006 trial, some surviving nematodes were observed in plots with both high (manure plus high density polyethylene film) and intermediate (pre-irrigation) 1,3-D cumulative emissions which suggested that emission loses are not solely responsible for some pest control failures. Weed control tended to be better with plastic film treatments and worse with pre-fumigation soil moisture manipulations but was affected less than expected by intermittent water seals. Although pest control clearly was affected by surface seal techniques, especially in shallow soil layers, some differences in nematode and weed control could not be explained solely by surface seals. These results underline the complex interactions among soil moisture and other environmental factors, application techniques, and emission reducing surface seal treatments. As new techniques and technologies become available to reduce fumigant emissions, we recommend that research include pest control efficacy evaluations before any emerging techniques are required by regulators or implemented by growers.

1. Introduction

Soil fumigation is commonly used in high value annual, perennial and nursery cropping systems for preplant control of a broad spectrum of soil-borne pests including weeds, plant parasitic nematodes, and disease pathogens. In California, commercially available fumigants include methyl bromide (MB), 1,3-dichloropropene (1,3-D), chloropicrin (Pic) and metam sodium/metam potassium (Trout, 2006). Of these, MB and 1,3-D alone or in combinations with Pic are the most widely used for orchard and vineyard replanting and perennial crop nursery production. MB has been identified as a contributor to the depletion of stratospheric ozone and is being phased out of many common uses (UNEP, 2006). In California, the phase-out of MB has resulted in increasing dependence upon 1,3-D and Pic combinations. Although these compounds do not deplete stratospheric ozone, they can have negative human health and environmental consequences related to worker and bystander safety and release of volatile organic compounds (VOC) that contribute to air pollution (CDPR, 2009). Controlling fumigant emissions has become an important goal of regulatory agencies in California and has spurred research on techniques to effectively keep fumigants in the soil and/or to rapidly degrade the compounds before they are released into the atmosphere. Gao et al. (in press) recently reviewed established and experimental techniques for reducing soil fumigant emissions including plastic films, water seals and chemical or organic soil amendments. Technological advances in plastic barrier films such as virtually impermeable film (VIF) and totally impermeable films (TIF) can reduce emissions tremendously compared to conventional high density or low density polyethylene (HDPE or LDPE)

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films and bare soil applications (Gao and Trout, 2007; Ntow et al., 2009; Wang and Yates, 1998). However, these methods are prohibitively costly for some fumigant-dependant commodities and generate a considerable waste disposal issue once the plastic is removed from the field. Post-fumigation soil moisture management can be used to reduce emissions of some MB alternatives by creating a water-saturated layer at the soil surface (Ashworth and Yates, 2007; Gan et al., 1996; Gao and Trout, 2007; Thomas et al., 2003). In addition to physical barriers such as plastic film or saturated soil, adding chemical or organic amendments to surface soils has been shown to reduce emission of 1,3-D and Pic in laboratory and field experiments due to more rapid degradation of the fumigants (Gao et al., 2009; Qin et al., 2009; Zheng et al., 2006). It is clear that fumigant emissions can be reduced using these techniques alone or in various combinations. However, before regulators require and before growers adopt these emission mitigation practices, more data are needed on the effects of these techniques on the primary goal of soil fumigation, namely pest management.

The objectives of this research were to simultaneously evaluate 1) the effects of surface sealing techniques on emissions of 1,3-D and Pic from the soil to the atmosphere and 2) the impacts of the surface treatments on control of soil-borne pests. Because the emission results have been previously reported (Gao et al., 2008, 2009), this paper is focused on the pest control evaluations.

2. Materials and methods

Two field trials were conducted in 2006–07 and 2007–08 to determine the effects of surface seal treatments on fumigant emissions and on control of soil-borne pests. The two trials were conducted in different areas of the same field at the U.S. Department of Agriculture-Agricultural Research Service (USDA-ARS), San Joaquin Valley Agricultural Sciences Center near Parlier, California (36° 35′ 36.7″ North latitude; 119° 30′ 48.7″ West longitude). The soil type was a Hanford sandy loam (coarse-loamy, mixed superactive, non-acid, thermic Typic Xerorthents) with pH 7.2, 0.9% organic matter, and 60% sand:32% silt:8% clay.

A split-block experimental design with a two by six factorial treatment structure and three replicates was used in both trials. The main plots were fumigant treatment (treated vs untreated) and the subplots included six surface seal treatments. Surface seal subplots were randomized within each block; however, main plots were not randomized in order to minimize fumigant rate variations due to starting and stopping of the application rig.

The experimental site was prepared each year following harvest of the preceding wheat (*Triticum aestivum* L.) crop by cultivation to a depth of 75 cm. To ensure that soil moisture was adequate to meet label requirements (Anonymous, 2004), the site was sprinkler irrigated approximately two weeks prior to fumigation. Soil moisture in the top 50 cm one day prior to fumigation was about 8 and 12% v/v (30 and 45% of field capacity) and soil temperature at 25 cm was 18.1 and 15.9 °C in 2006 and 2007, respectively.

On 17 October 2006 and 12 November 2007, a commercial premix of 1,3-D and Pic (Telone C35™ = 61% 1,3-D, 35% Pic, 4% inert) was applied using commercial shank-application equipment (Tri-Cal, Inc.; Hollister, CA). The fumigants were injected at a 45 cm depth through eight or nine shanks spaced 50 cm apart at a rate of 500 kg ha^{-1} in 2006 and 553 kg ha^{-1} in 2007 (the target rate was 584 kg ha^{-1} in both years). After fumigant injection, the soil was compacted and shank traces were closed using a spring-tooth harrow and ring roller (2006) or a disk and ring roller (2007) in a single-pass operation. Following the tillage operation, six surface seal treatments were imposed over the fumigated and unfumigated main plots including: 1) control, 2) composted manure (12.4 Mg/ha) + HDPE film, 3) potassium thiosulfate (KTS) + HDPE film, 4) pre-irrigation, 5) intermittent water seals and 6) intermittent KTS seals.

The control treatment was bare soil with no plastic film, manure or additional irrigation treatments. Composted manure was spread over the surface of the soil after fumigant application and the plots were covered with a single sheet of 0.025 mm HDPE film. KTS (1000 kg ha^{-1}) was applied in 4 mm water using a high-volume, low-pressure spray rig and the plots were subsequently covered with HDPE film. The pre-irrigation treatment consisted of an additional 34 mm irrigation applied 4 days prior to fumigation to increase soil moisture to 60% of field capacity. The intermittent water seals and intermittent KTS seals were applied using sprinkler systems installed after the post-fumigation tillage operation and were initiated within 3 h of fumigant injection. The intermittent water seal treatment included 13 mm of water applied immediately after fumigation followed by additional 4 mm water applications 12, 24 and 48 h after fumigation. The intermittent KTS treatment involved application of 1000 kg ha^{-1} KTS in 13 mm water following fumigation, 500 kg ha^{-1} KTS in 4 mm water 12 h after fumigation, and 4 mm water applied 24 and 48 h post-fumigation. In the 2007 trial, four additional manure treatments were added to the treatment structure as part of the emission reduction research (Gao et al., 2009); however, pest control data from those treatments are not included here. Individual surface seal plots were 3 × 9 m (untreated and HDPE tarped plots) or 9 × 9 m (sprinkler irrigation treatments).

Efficacy of fumigation treatments was evaluated by determining nematode survival in a bioassay, soil pathogen populations, viability of weed seed buried in each plot, weed emergence counts, visual weed control evaluations and weed biomass production. Soil samples tested prior to initiation of the trial showed insufficient populations of plant parasitic nematodes at the site; thus a nematode bioassay was conducted to allow a relative comparison of nematode control among surface seal treatments. In this bioassay, muslin bags containing 100 g of soil infested with citrus nematode (*Tylenchulus semipenetrans* Cobb) were buried in the center of each plot prior to fumigation. Soil used in the bioassay was collected from a commercial citrus orchard and contained 3848 and 4086 citrus nematodes per 100 g of soil in 2006 and 2007, respectively. In the fumigated main plot, bioassay samples were placed 15, 30, 60 and 90 cm below the soil surface whereas in the unfumigated plots samples were placed only at the 15 and 30 cm depths. Nematode bags were recovered one month after fumigation and processed using the sieving/Baermann funnel protocol and surviving nematodes were counted (Barker, 1985).

A weed seed bioassay was conducted in each trial using procedures adapted from Haar et al. (2002). Briefly, sachets of unimbibed field bindweed (*Convolvulus arvensis* L.) and little mallow (*Malva parviflora* L.) seed were buried 7.5 cm deep in each main plot after fumigation and tillage but before surface seal treatments were imposed. Seed packets were recovered two weeks after fumigation and seed was removed from the bags and sorted by species, germinated seeds were counted and ungerminated seeds were allowed to air dry for storage. Seeds were imbibed on blotter paper moistened with deionized water in 100 mm Petri dishes for 24 h. Once imbibed, 50 seeds were cut with a scalpel, transferred to another Petri dish and placed cut side down on Whatman no. 1 filter paper moistened with 1 ml of 0.1% (w/v) 2,3,5-tetrazolium chloride solution. Petri dishes were sealed and placed in the dark at 20 °C for 24 h and then the seeds were evaluated under a microscope for staining of the embryo.

Although not included in 2006, analyses for the effect of surface seals on soil fungal pathogens were conducted in the 2007 trial to broaden the applicability of the research. Soil cores were collected two weeks after fumigation from the upper 25 cm of soil near the