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Emission and distribution of fumigants as affected by soil moistures in three different textured soils

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HIGHLIGHTS

- ▶ A rang of soil moisture levels were tested in three different textured soils.
- ▶ Soil columns were used under well controlled moisture conditions.
- ▶ High water content reduced and delayed emission peak flux in finer-textured soils.
- ▶ The wetter soils had higher fumigant concentrations than the drier soil.
- ▶ The air-filled porosity may serve as a good indicator for estimating emissions.

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ABSTRACT

Water application is a low-cost strategy to control emissions of soil fumigant to meet the requirements of the stringent environmental regulations and it is applicable for a wide range of commodity groups. Although it is known that an increase in soil moisture reduces emissions, the range of soil moisture for minimizing emissions without risking pest control, is not well defined for various types of soils. With two column studies, we determined the effect of different soil moisture levels on emission and distribution of 1,3-dichloropropene and chloropicrin in three different textured soils. Results on sandy loam and loam soils showed that by increasing soil moisture from 30% to 100% of field capacity (FC), peak fluxes were lowered by 77–88% and their occurrences were delayed 5–15 h, and cumulative emissions were reduced 24–49%. For the sandy soil, neither peak fluxes nor the cumulative emissions were significantly different when soil moisture increased from 30% to 100% FC. Compared to the drier soils, the wetter soils retained consistently higher fumigant concentrations in the gas-phase, suggesting efficacy may not be impacted in these soils. The air-filled porosity positively and linearly correlated with the cumulative emission loss across all soil types indicating that it may serve as a good indicator for estimating emissions. These laboratory findings can be further tested under field conditions to conclude what irrigation regime should be used for increasing soil water content before fumigant application that can achieve maximum emission reduction and uniform fumigant distribution with high exposure index values.

1. Introduction

Soil fumigation plays an important role in soil disinfestation or controlling soil-borne pests and replant diseases. With the phase-out of methyl bromide, 1,3-dichloropropene (1,3-D) and chloropicrin (CP) are being applied extensively. For example, in California, approximately 2.93 million kg of 1,3-D (21% of the total fumigant amount) and 2.51 million kg of CP (18% of the total fumigant amount), respectively, were applied in 2009, reflecting 7% and 6% increase from 2000 for 1,3-D and CP, respectively (Gao and Wilhoit, 2011). However, fumigant use is under stringent federal and state regulations because fumigant emissions increase exposure risks and contribute volatile organic compounds (VOCs) to air pollution (CDPR, 2009; USEPA, 2009). If the high fumigant emissions cannot be controlled effectively, growers may lose access to these alternatives and suffer enormous economic loss from insufficient pest control. Therefore, feasible techniques to minimize fumigant emissions are necessary for maintaining the availability of fumigants in agriculture.

Water treatment (irrigation with sprinklers after fumigant application) is an effective method to reduce fumigant emission by creating a near saturated surface soil layer that reduces the

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diffusion rate of fumigant gas, so less fumigant is being emitted into the air. It is a low-cost strategy, thus applicable to a wide range of commodity groups, especially those with low profit margins. Applying water was found to reduce 1,3-D and CP emissions even more effectively than the standard high density polyethylene (HDPE) tarp as well as reduce fumigation costs (Gao and Trout, 2007; Gao et al., 2008a). This regime, however, requires an irrigation system in the field following fumigant application, which may not be practical for many growers.

Irrigation to increase soil water content prior to fumigant application has also shown promising effects on reducing fumigant emissions by lowering the peak flux, delaying peak occurrence, and reducing cumulative emission losses of 1,3-D and CP (Thomas et al., 2003, 2004; Gao et al., 2008a,b). However, the benefit of increasing soil water content in emission reduction may be nullified by a concern that a too high soil moisture level can impede fumigant distribution in the soil profile (Thomas et al., 2003), especially in fine-textured soils (McKenry and Thomason, 1974). Non-uniform fumigant distribution and inadequate fumigant exposure index values throughout the soil profile can impact fumigation efficacy. Several field studies have shown that relatively high soil water content may not necessarily reduce fumigant distribution and concentration in the soil–gas phase (Wang et al., 1997; Thomas et al., 2003, 2004; Gao et al., 2008a). These studies indicate that an optimum soil water content that reduces emissions but does not reduce fumigant concentration or inhibit fumigant distribution can be identified for practical use.

In an earlier study on a sandy loam soil, increasing the soil water content (from 30% to 100% field capacity, FC) was found to negatively correlate with the emission peak flux of 1,3-D and CP while the fumigant concentration in the soil was not reduced (Qin et al., 2009). However, it is not clear if similar results are true for other types of soils. It is expected that the proper soil moisture condition for optimizing emission reduction and satisfactory pest control would vary strongly by soil texture, which is an important factor affecting water-holding capacity. The objective of this study was to determine the effect of different soil moisture levels on emission and distribution of 1,3-D and CP in three different textured soils. We utilized soil columns to produce a uniform soil water content profile at various moisture levels.

2. Materials and methods

2.1. Soils and chemicals

Three soils used in the study were Delhi sand (mixed, thermic Typic Xeropsamments), Hanford sandy loam (coarse-loamy, mixed, superactive, nonacid, thermic Typic Xerorthents), and Madera loam (fine, smectite, thermic Abruptic Durixeralfs). These soils were collected from the surface soils (0–30 cm) in agricultural fields in the San Joaquin Valley of California. Delhi sand and Madera loam were collected from Merced County, CA, and Hanford sandy loam was collected from Fresno County, CA. The soils were air-dried, passed through a 4-mm sieve, and homogenized before use. Selected soil properties are shown in Table 1. Soil bulk density was measured by core method (Blake and Hartge, 1986a). Soil texture was determined by hydrometer method (Sheldrick and Wang, 1993). Field capacity, the water content at 33 kPa suction, was measured by the method of Klute (1986). Soil organic matter content was measured by the combustion method (AOAC Official Method, 1997). The cation exchange capacity (CEC) of soil was measured by the method of Rible and Quick (1960).

Fumigant 1,3-D containing two isomers (50.7% *cis*-1,3-D and 46.6% *trans*-1,3-D) was obtained from Dow AgroSciences (Indianapolis, IN). Chloropicrin (purity of 99.9%) was provided by Niklor Chemical Co., Inc. (Mojave, CA). Ethyl acetate (pesticide grade), hexane (pesticide grade), and sodium sulfate anhydrous (Na_2SO_4, 10–60 mesh, ACS grade) were obtained from Fisher Scientific (Fair Lawn, NJ).

Table 1
Selected properties of soils used in this research.

Soil properties	Delhi sand	Hanford sandy loam	Madera loam
Bulk density (g cm^{-3})	1.5	1.4	1.3
Sand (%)	95.0	54.8	40.4
Silt (g kg^{-1})	5.0	39.6	34.4
Clay (g kg^{-1})	0	5.6	25.2
Water content at 33 kPa suction (%, w/w)	5.0	17.0	23.0
Organic matter content (%)	0.87	0.74	1.12
Cation exchange capacity ($cmol_c$ kg^{-1})	3.8	6.8	20.0

2.2. Packing of soil column

Soil was packed to a depth of 23 cm in closed-bottomed stainless steel columns (25-cm height and 15.5-cm i.d) at a bulk density of 1.5, 1.4, and 1.3 g cm^{-3} for the sand, sandy loam, and loam, respectively. Details about procedures in packing the column are described in Qin et al. (2009). Duplicate columns were used for each treatment. For the Madera loam, the treatments included soil water content at 30%, 45%, 60%, 75%, 90% and 100% (w/w) of FC, represented as treatments L-W30, L-W45, L-W60, L-W75, L-W90 and L-W100, respectively. The six water content treatments for Madera loam were designed to establish the correlation of soil water content with flux and total emissions. For comparison purposes among soil texture, fewer water content levels were tested for the other two soils. For the Hanford sandy loam, the treatments included soil water content at 30%, 60%, and 100% (w/w) of FC, represented as SL-W30, SL-W60, and SL-W100, respectively. For the Delhi sand, the target soil water contents were chosen as 30%, 60%, and 100% (w/w) of FC, represented as S-W30, S-W60, and S-W100.

In the study, the moisture in the air-dried soils was generally lower than the lowest target soil water content W30. For the treatment with the lowest soil water content for the loam and sandy loam soils and all treatments for Delhi sand, a small amount of water was added to the soil to increase the soil moisture up to the target level. Then the soils were well-mixed and remained in plastic bags for 24 h to homogenize the soil water content before packing columns. This procedure is effective for preparing a soil column with relatively low soil water content. For other treatments which have higher soil water contents, after the soil columns with air-dried soils were packed, the calculated amounts of water were added to the soil surface to allow water infiltrate or distribute overtime to achieve the uniform water content. The columns were sealed immediately with aluminum foil and set aside for 6–8 weeks. Relatively uniform soil water content throughout the column was achieved for each treatment measured at the end of experiments (Fig. 1). The average soil water content ranged from 1.3% (w/w) for W30 to 4.9% (w/w) for W100 in the columns packed with sandy soil, from 4.4% (w/w) for W30 to 15.5% (w/w) for W100 in the columns packed with sandy loam, and from 6.1% (w/w) for W30 to 21.9% (w/w) for W100 in the columns packed with loam soil at the end of the experiment. The water content of these treatments was in a range of 77–98% of the target water content.

2.3. Fumigant application, sampling, and analysis

Before fumigant injection, the aluminum foil cover was removed from the soil columns. A flow-through gas sampling