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Fumigant persistence and emission from soil under multiple field application scenarios

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ABSTRACT

Chemical fumigants are routinely used for soil disinfestation of high value crops. Good agricultural practices (GAPs) are needed to reduce their human health risks, environmental impacts, and improve their cost-effectiveness. This study investigated the effect of fumigant application methods on soil persistence and emission of 1,3-dichloropropene (1,3-D) and chloropicrin (CP). Field experiments were conducted to measure the individual and combined effects of pre-application tillage practices, fumigant application technology, and plastic films on 1,3-D soil concentrations to obtain a numerical index (*CT* value) to estimate their potential for pest control efficacy and to compare soil persistence, atmospheric flux rate, and cumulative emission of CP and 1,3-D under two diverse application scenarios. Greater 1,3-D soil vapor concentrations were observed by combining a pre-application soil seal with low soil disturbance application technology when compared to pre-application soil tillage and the use of back-swept application shanks. Under high density polyethylene plastic, the low disturbance scenario resulted in time weighted exposure concentration (*CT*) values ranging from 6.8 to 12.2 $\mu g\ h\ cm^{-3}$ of soil as compared to *CT* values ranging from 2.9 to 5.4 $\mu g\ h\ cm^{-3}$ under the conventional application scenario. Cumulative atmospheric emission of 1,3-D was decreased by 18% under the low disturbance scenario and atmospheric emission of CP by 21% when compared to a conventional application scenario. This study identified GAPs that can be readily implemented in the field to reduce the human and environmental impacts of soil fumigants and improve their cost-effectiveness under solid-tarp (broadcast) applications.

1. Introduction

Agricultural fumigants are considered critical for control of soilborne pests in high value crop production systems of the United States (Geraldson, 1975; Wilhelm and Paulus, 1980). An impending phase-out of methyl bromide (MeBr) has led to increased use of alternative fumigants including 1,3-dichloropropene (1,3-D) and chloropicrin (CP). In 'raised bed-plastic mulched' crop production systems, fumigant combinations involving 1,3-D and CP can achieve pest control levels and marketable yields comparable to methyl bromide when good agricultural practices (GAPs) are followed during the application process (Ajwa et al., 2002; Chellemi and Mirusso, 2004, 2006; Gilreath et al., 1999, 2004; Locascio et al., 1997; Noling et al., 2010). In addition to improving fumigant efficacy, GAPs can extend the soil retention time of fumigants reducing their subsequent atmospheric emission (Chellemi et al., 2010). Key features of GAPs include reduced rate application technologies, improved plastic mulches, emission reduction technology, and optimization of soil environmental and edaphic conditions including moisture and compaction.

Soil porosity and the continuity of pore space are important factors affecting the movement of fumigants (Goring, 1962; Kolbezen et al., 1974; Lembright, 1990). A key feature of raised bed-plastic mulch cropping systems that promotes fumigant retention in soil is the compaction of soil into raised planting beds during the application process. Conversely, in broadcast (solid-tarp) applications, where the fumigant is applied to flat ground and covered with panels of high density polyethylene plastic glued together to

Abbreviations: CP, chloropicrin; *CT*, time weighted exposure concentration; GAP, good agricultural practices; HDPE, high density polyethylene; PID, photo-ionization detector; VIF, virtually impermeable film; VOC, volatile organic compound; 1,3-D, 1,3-dichloropropene.

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form a solid tarp, a surface tillage is typically performed prior to application to facilitate movement of the injection shanks through the soil profile and to facilitate fumigant dispersion when compaction or high clay levels are present. An unintended consequence of this process is the formation of vertical fissures or grooves in the soil profile as the shanks are dragged through the soil, facilitating transport of soil fumigants to the soil surface. A review of CP fumigant studies found that peak CP flux rates are lower under bedded shank applications than under broadcast applications at the same shank depth (Stanghellini et al., 2010).

Low soil disturbance application technology was first developed to minimize volatilization and grass contamination during the injection of liquid manure in grassland (Chen et al., 2001). The use of vertical coulters placed in front of narrow injection shanks to minimize disruption of the soil surface has been adapted for the application of soil fumigants and studies have indicated they can improve the efficacy of 1,3-D and CP (Dow AgroSciences, 2006; Gilreath et al., 2006; Hochmuth et al., 2004). However, quantitative assessment of their effects on retention of fumigants in soil and subsequent atmospheric emission are lacking under solid-tarp application scenarios. The objectives of the study were to: 1) measure the effects of soil preparation, fumigant application technology, and plastic film on 1,3-D concentrations in soil; 2) obtain a numerical index (*CT* value) to estimate their potential pest control efficacy; and, 3) compare soil persistence, flux rate, and cumulative emission of CP and 1,3-D under a conventional and low disturbance application scenario. Field experiments were conducted in association with the USDA-ARS Area-Wide Pest Management Project for Alternatives to Methyl Bromide (Chellemi and Browne, 2006).

2. Materials and methods

Experiments were conducted on a commercial sod farm in St. Lucie County, Florida, U.S.A. The soil type was a Nettles sand (sandy, siliceous, hypothermic, ortstein, Alfic, Arenic Haplaquods) with 0–2% slope and a spodic horizon at 25–40 cm deep. Soil preparation was typical for fumigated agricultural production fields in the area. Experiments measuring the effect of soil preparation, application equipment, plastic film types on soil concentration of 1,3-D were conducted on 21 March 2008 and on 4 December 2008. A field experiment to quantify soil persistence, flux rate, and atmospheric emission of CP and 1,3-D under two application scenarios was conducted on 17 November 2009.

Soil chemical and physical parameters at application were documented by collecting 8 samples along a diagonal transect line bisecting each treated area. Samples consisted of 5 cores (15 cm × 2 cm) bulked together. Soil bulk density was determined using the core method (Blake and Hartge, 1986). Soil moisture was determined gravimetrically (Gardener, 1986). Water content at field capacity (−0.03 MPa pressure) was determined using ceramic pressure plate moisture extractors (Soil Moisture Equipment Corp., Santa Barbara, CA). Soil texture was determined by the Bouyoucos Hydrometer Method (Bouyoucos, 1936) Soil organic matter was determined by the dichromate reduction method (Walkley and Black, 1934). Soil structure and profile discrepancies, such as plow pans, presence of clods, stones, and crop residue were recorded in the field.

2.1. Fumigant application methods

Soil preparation consisted of surface tillage or a surface seal. Surface tillage was performed using a field cultivator equipped with rolling basket attachments. A surface seal was implemented with a single drum smooth roller. Application technology included conventional back-swept shanks spaced 30 cm apart and 20 cm deep with a fumigant delivery tube welded to the back of the shank and a low disturbance implement. The low disturbance implement was comprised of 0.75 m diameter vertical coulters, spaced 30 cm apart, with steel tubes behind the coulter to deliver fumigants to a 20 cm depth. A 5 cm horizontal steel wing was welded to the delivery tube above the injection point to promote lateral diffusion of the fumigants and a spring-loaded Teflon™ press pan was used to seal the soil surface above the injection points. Plastic film types included a 25 μm thick, clear, high density polyethylene plastic (HDPE, Cadillac Produces, distributed by TriCal, Inc., Hollister, CA) and a 25 μm thick, clear, virtually impermeable film (VIF, Bromostop, Industria Plastica Monregalese, Mondovi, Italy). Samples of each plastic film were collected prior to- and after application and their resistance to fumigant diffusion was determined (Scott Yates, USDA-ARS U.S. Salinity Laboratory in Riverside CA). Details of the procedures of the static chamber procedure are provided elsewhere by Papiernik et al. (2001, 2002). An analytical model was fitted to the data to obtain the mass diffusion coefficient (h). The resistance to diffusion (R) was calculated as the inverse of h following procedures outlined by Papiernik et al. (2010). For the HDPE, R values of 0.2 and 0.1 cm h^{-1} were obtained from cis and trans 1,3-D, respectively. For the VIF, R values of 526 and 208 cm h^{-1} were obtained from cis and trans 1,3-D, respectively.

For the 21 March 2008 and 4 December 2008 application methods study, a factorial design was employed to examine the individual and combined effect of soil preparation, application technology and plastic film. Treatment combinations were replicated 5 times and arranged in a randomized complete block design. Replicate plot were 3 m wide and 30 m long. The fumigant 1,3-D (Dow AgroSciences, Midland, MI, USA) was applied at 226 kg ha^{-1}.

For the 17 November 2009 flux study, two application scenarios were implemented. A conventional scenario consisted of field cultivation followed by fumigant application with back-swept shanks. A low disturbance scenario consisted of a soil surface seal followed by fumigant application using the low disturbance apparatus. Both application combinations were covered by HDPE immediately after application by gluing together panels every 3 m to form a solid tarp. Each application site measured 36 m by 54 m (0.2 ha) and was separated by 600 m. This configuration is considered sufficient in scope and scale for the determination of fumigant flux rates using the Integrated Horizontal Flux Method (Sullivan, D.A., and Ajwa, H.A., 2010). A 60:40 mixture of 1,3-D and CP (Pic-Clor 60, Cardinal Professional Products, Hollister, CA) was applied to both fields. Fumigant cylinders were weighed before and after application on certified scales to facilitate calculation of fumigant mass balance and emission rates. Application rates were 441 kg ha^{-1} for the soil seal-low disturbance combination and 420 kg ha^{-1} for the cultivation-back swept shank combination. Applications were made between 8:00 and 9:00 AM for the low disturbance method and between 10:00 and 11:00 AM for the conventional method.

2.2. Measurement of 1,3-D and CP in soil and soil vapor

A hand-held photoionization detector (PID) (MiniRae 2000, Rae Systems, San Jose, CA) was used to measure 1,3-D soil vapor concentrations in the 21 March and 4 December 2008 methods experiments. The primary use of a PID is to generate real-time quantitative measurements of organic vapors when the identity of the compound is known and its ionization potential is near to or less than that of the ionizing lamp (USEPA, 1994). The PID was used in the 21 March and 4 December 2008 field experiments where only 1,3-D was applied. The PID was not used in the 17 November 2009 flux study, where a mixture of 1,3-D and CP was applied,