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Atmospheric flux of agricultural fumigants from raised-bed, plastic-mulch crop production systems

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A B S T R A C T

Atmospheric emission of methyl isothiocyanate (MITC), chloropicrin (CP), 1,3-dichloropropene (1,3-D), and dimethyl disulfide (DMDS) were measured in the field under fumigant application scenarios representative of raised bed–plastic-mulched crop production systems. For three fumigation sites located in Florida, cumulative emissions of 1,3-D, MITC and CP were less than 11%, 6% and 2%, respectively. For three fumigation sites in located in Georgia, cumulative emissions of MITC and CP were <13% and 12%, respectively while DMDS emissions varied from 37% to 95%. In the Florida sites, emission peak flux of CP occurred within the first 6 h after application. Peak emission of 1,3-D and MITC occurred between 100 and 144 h after application. In the Georgia sites where fumigated soil was covered by low density polyethylene (LDPE) plastic, emission peak flux of DMDS and MITC occurred between 12and 48 h after application. Key factors affecting atmospheric emissions were soil moisture, soil tilth and the resistance to fumigant diffusion of the plastic film used to cover soil following application. This study demonstrated reduced atmospheric emissions of agricultural fumigants under commercial production conditions when applied using good agricultural practices including soil water contents above field capacity, uniform soil tilth in the fumigation zone and the use of metalized or virtually impermeable films to further reduce fumigant emissions. The results of this study show a need for regional flux studies due to the various interactions of soil and climate with local agricultural land management practices.

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1. Introduction

Agricultural fumigants have been an essential component of high value crop production systems in the United States since the 1960's (Geraldson, 1975; Wilhelm and Paulus, 1980). An impending phase-out of the soil fumigant methyl bromide (MeBr) has led to increased use of alternative fumigants including 1,3-dichloropropene (1,3-D), chloropicrin (CP), dimethyl disulfide (DMDS) and the methyl isothiocyanate (MITC) generators, metam potassium and metam sodium (CDPR, 2009). When co-applied using good agricultural practices (GAPs), these fumigants can achieve a spectrum of pest control similar to methyl bromide while maintaining a high level of marketable yields (Ajwa et al., 2002; Chellemi and Mirusso, 2004, 2006; Gilreath et al., 1999; Locascio et al., 1997; MacRae et al., 2010; Noling and Gilreath, 2000). Key features of GAPs include the use of improved application methods and technology, reduced application rates, and selective inclusion of specific soil and environmental conditions.

Public concern regarding the acute toxicity and environmental impacts of soil fumigants has intensified the call for additional risk assessment and adoption of mitigation practices to ensure they meet current health and safety standards (Federal Registrar, 2008). The potential for farm worker and by-stander exposure to soil fumigant emissions is a critical area of concern. Volatilization and emission of fumigants have been studied under numerous application scenarios including many that fall under GAPs (Gan et al., 1998, 2000; Gao and Trout, 2007; Gao et al., 2008; Li et al., 2006; Qin et al., 2009; McDonald et al., 2009; Thomas et al., 2004; Wang et al., 2005; Yagi et al., 1993). From a regulatory perspective, risk assessment for fumigant emissions must take into account the dynamics of micro-scale meteorological conditions, with typical soil conditions and under the operational constraints of commercial agriculture production. Continuous and extensive air sampling of the near-surface atmosphere is essential for generating representative concentration profiles that can be used to estimate the

Abbreviations: LDPE, low density polyethylene; VIF, virtually impermeable film; MITC, methyl isothiocyanate; DMDS, dimethyl disulfide; 1,3-D, 1,3-dichloropropene; CP, chloropicrin.

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volatilization rate (Yates, 2009). This entails the simultaneous measurement of soil and ambient conditions combined with active (flow-through) air sampling methods across a vertical profile. Furthermore, fumigant applications must be made over areas large enough to generate sufficient fetch under conditions that are representative of commercial production practices. In California, large field studies were conducted to measure MITC emissions following application by chemigation and shank injection (Li et al., 2006; Sullivan et al., 2004). Emissions of 1,3-D were monitored following mechanical shank injections in agronomic field scale studies in Florida and California (Cryer et al., 2003).

Traditionally, fumigant flux studies conducted for regulatory purposes have followed techniques described in peer-reviewed literature including the Aerodynamic Method (Majewski, 1999), the Relaxed Eddy Accumulation Method (Majewski, 1999) or the Integrated Horizontal Flux Method (Wilson and Shum, 1992). These studies are expensive and site/GAPs specific. Efforts are underway to estimate fumigant emissions using limited field observations (Cryer and van Wesenbeeck, 2009; Yates, 2009). However, a minimum number of large-scale flux studies are necessary to provide the data for model validation. Raised bed–plastic mulch production systems are used extensively in the southeastern USA to produce high value vegetable and ornamental crops. Most systems rely upon shank injection of fumigants into the soil as it is gathered and pressed into planting beds (0.75–0.90 m wide by 15–20 cm high) that are immediately covered with polyethylene plastic (Cantliffe et al., 1995; Olson and Simonne, 2007). After fumigation, the plastic covering the raised beds is left in place to function as a mulch. There is a paucity of large-scale fumigant flux studies conducted under the unique application scenarios typical of vegetable production system particularly in the southeastern United States.

The goal of this study was to determine the effects of application practices and soil factors on fumigant flux under commercial application scenarios, including those incorporating GAPs. Sites with uniform soil properties were chosen to minimize “fate and transport” effects (i.e., differences in degradation, diffusion/dispersion, and volatilization) across sites allowing the effect of soil water, tilth, etc. to be revealed. The specific objective was to quantify atmospheric concentrations of MITC, CP, 1,3-D, and DMDS under a range of commercial application scenarios representative of raised bed, plastic-mulched vegetable production systems in the Southeastern United States. DMDS is currently undergoing registration as a soil fumigant in the United States. Data were collected from six field trials affiliated with the USDA-ARS Area-Wide Pest Management Project for Alternatives to Methyl Bromide (Chellemi and Browne, 2006) conducted in Florida and Georgia to ensure representative participation by growers and industry professionals.

2. Materials and methods

2.1. Site characterization

Three field sites were selected on a commercial tomato production farm in the Palmetto–Ruskin tomato production region of Florida (ManateeCounty). Sites were representative of Florida raised bed–plastic mulch vegetable production including a characteristic soil type, typical land preparation and season for fumigant application. Each 0.4 ha site was in close proximity but separated by a minimum distance of 600 m. Soil type at the three sites was Myakka fine sand (sandy, siliceous, hypothermic Aeric Haplaquods) with 0–2% slope, and a Spodic horizon that is typical of fumigated vegetable production fields in the area. Three field sites were located on or near the University of Georgia Tifton Research facility. Each 0.4 ha site was in close proximity but separated by a minimum distance of 600 m. Sites were representative of Georgia raised bed–plastic mulch vegetable production including a characteristic soil type, land preparation and season for fumigant application. The soil type for Sites 1 and 2 was Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults). The soil type for Site 3 was a Dothan sandy loam (fine-loamy, kaolinitic, thermic Plinthic Kandiudults).

Soil conditions at application were characterized by collecting 8 samples along a transect line that bisected each treated area diagonally. Samples consisted of multiple 15 cm × 2 cm cores. 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 (−0.033 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). 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. A small hole was dug to a depth of 45.0 cm in two locations across each field and soil density changes through the profile observed and noted.

2.2. Application scenarios – Florida trials

In Site 1, a three-way combination of 1,3-D (Telone II, Dow AgroSciences, Midland, MI), CP (Metapicrin, HyYield Bromine, Inc., Palmetto, FL), and metam potassium (KPAM, AMVAC Chemical Corp., Los Angeles, CA) was applied under a 30-μm thick, silver metalized film (Canslit Inc., Quebec, Canada). Fumigant applications were made sequentially in rapid succession with the plastic placed onto beds immediately after the final fumigant was applied. Three different implements were used to complete the application procedure. First, 1,3-D and CP were applied through separate lines using back-swept shanks spaced 30 cm apart at 20 cm depths. Behind the application shanks, beds (81 cm wide × 25 cm high) were immediately formed and pressed using a pan attached to the same implement. Second, metam potassium was injected into the pressed beds at a 10 cm depth using 25 cm vertical cultures spaced 10 cm apart. Third, beds were pressed again with the second implement and then immediately covered with metalized plastic film using a third implement. The application in Site 2 was identical to the application in Site 1 except that a 30-μm thick virtually impermeable film (VIF) (Guardian, Grupo Olefinas, Villa Nueva, Guatemala) was used to cover the fumigated beds. The application in Site 3 was identical to the application in Site 1 except that the 1,3-D was omitted from the procedure. Applications were made on 14 Jan, 2009. The application in Site 1 took place between 10:43 and 11:49 AM. The application in Site 2 took place between 1:22 PM and 2:37 PM. The application in Site 3 took place between 4:03 and 4:51 PM. Fumigant cylinders were weighed before and after application on certified scales and the application rates are provided in Table 1.

Table 1
Fumigant application rates at the Florida and Georgia trials.

Fumigant	Site 1	Site 2	Site 3
Florida trials			
1,3-dichloropropene, kg ha^{-1}	142	145	0.00
Chloropicrin, kg ha^{-1}	192	198	184
Metam potassium, kg ha^{-1}	348	336	342
Georgia trials			
Dimethyl disulfide, kg ha^{-1}	612	603	637
Chloropicrin, kg ha^{-1}	162	160	169
Metam sodium, kg ha^{-1}	335	343	331