ELSEVIER

Soil Biology & Biochemistry 37 (2005) 475–485

Soil Biology & Biochemistry

www.elsevier.com/locate/soilbio

Greenhouse gas production and emission from a forest nursery soil following fumigation with chloropicrin and methyl isothiocyanate

Kurt Spokas[a,*], Dong Wang[a], Rodney Venterea[b]

[a]*Department of Soil, Water, and Climate, University of Minnesota, 1991 Upper Buford Circle, 439 Borlaug Hall, St Paul, MN 55108, USA*
[b]*USDA-ARS, Soil and Water Management Unit, University of Minnesota, St Paul, MN 55108, USA*

Received 17 March 2004; received in revised form 16 August 2004; accepted 21 August 2004

Abstract

Soil fumigation is commonly used to control soil-borne pathogens and weeds. Our aim was to examine the effects of soil fumigation with chloropicrin (CP) and methyl isothiocyanate (MITC) on CH_4, N_2O and CO_2 production and emission. These effects on a SE USA forest nursery soil were examined in field and laboratory experiments. Following field fumigation, CH_4 surface emissions and concentrations in the soil atmosphere were unaffected. Both fumigants increased N_2O emissions rates significantly compared to non-fumigated controls, and the effects were still evident after 48 d. These findings are in contrast to fertilizer-induced N_2O emissions, which generally return to background within 2 wk after application. Depths of N_2O production were different for the two fumigants as determined by soil gas sampling, suggesting fumigant-specific stimulation mechanisms. CO_2 emissions (0–15 d) were not altered significantly, although sub-surface CO_2 concentrations did increase following fumigation with CP or MITC and remained elevated for CP treatment on d 48. CP-induced N_2O production was also stimulated in aerobic laboratory incubation studies, with surface soils exhibiting 10 to 100-fold greater production rates. MITC and a combination of CP/MITC also stimulated N_2O production, but the effect was significantly less than for CP alone. MITC suppressed and CP did not effect CO_2 production in the laboratory incubation. By comparing sterilized to non-sterile soils, $>95\%$ of these effects appear to be of biotic origin.

Keywords: Soil fumigation; Trichloronitromethane; Nitrous oxide; Methane; Carbon dioxide; Methyl isothiocyanate

1. Introduction

Forest nurseries in the southern US are producing approximately 1.2×10^9 seedlings per year with 89% of the nurseries relying on chemical fumigation to control soil pathogens and weeds (Lantz, 1997). Methyl bromide (MeBr) has been the primary soil fumigant. As a result of the Montreal Protocol of 1995, the use of MeBr for fumigation is being curtailed and will eventually be eliminated. Therefore, other fumigants are being investigated to replace MeBr and are selected based on their efficacy toward a particular weed, insect, fungi, or pathogen at a site. However, the fumigant does not act solely on its target and can affect the entire soil microbial community.

The effects of fumigation on the soil microbial community are specific to the particular fumigant. Fumigation with MeBr reduces the aerobic bacterial population (Ridge, 1976) and substrate induced respiration (SIR) (Parthipan and Mahadevan, 1995; Lin and Brookes, 1999). Similar decreases in SIR have been observed with 1,3-dichloropropene and propargyl bromide, which are two potential MeBr replacements (Dungan et al., 2003). SIR rates are correlated with microbial counts and biomass for a specific soil type (Anderson and Domsch, 1978; Harden et al., 1993). There was no shift observed in proportions of Gram-negative and Gram-positive bacteria following MeBr fumigation (Ridge and Theodorou, 1972; Ridge, 1976).

Dazomet, a methyl isothiocyanate (MITC) precursor, caused a 50% reduction in total bacterial numbers in soil for at least 15 wk (Parthipan and Mahadevan, 1995; Charbol et al., 1988) and a reduction in nitrification rates (Lebbink and Kolenbrander, 1974). In contrast, chloropicrin (CP)

* Corresponding author. Tel.: +1 612 625 1798; fax: +1 612 625 2208.
E-mail address: kspokas@umn.edu (K. Spokas).

0038-0717/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.soilbio.2004.08.010

increased the aerobic-Gram negative bacterial population 10-fold within 10 d following fumigation (Ridge, 1976; Kakie et al., 1978). In particular, *Pseudomonas fluoroscenes* flourished following CP fumigation, comprising over 70% of the aerobic population, compared to $<10\%$ in non-fumigated controls (Ridge, 1976; Rovira, 1976). This is of particular importance since some *Pseudomonas* spp have been shown to degrade CP (Castro et al., 1983). CP also increases the denitrifying bacteria population (Ishizawa and Matsuguchi, 1966) as well as reduces nitrification rates in soils (Kakie et al., 1978). It has been suggested by Dungan et al. (2003) that organic amendments reduce fumigant impacts on microbial population and diversity. However, decreased microbial population and diversity does not always affect soil functionality (Degens, 1998).

In addition to microbial community changes, there are also alterations in soil inorganic-N concentrations following fumigation. Soil ammonium (NH_4^+) concentrations have increased 10-fold following soil fumigation with CP (Winfree and Cox, 1958; Rovira, 1976), MITC (Hansen et al., 1990), or MeBr (Winfree and Cox, 1958). Increases in nitrate (NO_3^-) following application of CP and MITC have been observed to be soil type dependent (Ebbels, 1971; Hansen et al., 1990). Typically, these higher levels are assumed the mineralization of N from biomass killed by the fumigation (Jenkinson et al., 1972; Ridge and Theodorou, 1972; Hansen et al., 1990). The typical gain in inorganic-N from fumigation ranges from 5 to 10 kg N ha^{-1} (Lebbink and Kolenbrander, 1974). These nutrient increases have been postulated to cause increases in plant yield (e.g. Jenkinson et al., 1972) and vigour of conifer seedlings (e.g. Benzian, 1965). Soil nutrients could also be used as precursors in the complex cycles of greenhouse gas formation.

Flux of reactive trace gases from soil is the resulting balance of microbial consumption and production reactions (Hutchinson and Davidson, 1993). Alterations in microbial structure and diversity play an important role in the balance of greenhouse gas exchange, especially for CH_4 and N_2O fluxes (Kravchenko et al., 2002). Effects of soil fumigation on greenhouse gas exchange have only recently been addressed by Spokas and Wang (2003) who observed a 7-fold increase in N_2O emissions over 20 d following CP fumigation of a northern US nursery soil. To our knowledge, there have been no other studies on the effect of MeBr alternatives on greenhouse gas exchange. Our purpose of this study was to examine the effect of MITC and CP on the production and emission of N_2O, CO_2, and CH_4 in a southeastern US nursery soil using field and laboratory measurements.

2. Materials and methods

2.1. Experimental site

The field experiment was conducted at the Flint River State Nursery in Byromville, GA (32.169° N; 83.974° W), which was established in 1987 and is capable of producing 5×10^7 seedlings per year (Georgia Forestry Commission, 2003). The soil at the experimental site is a loamy sand of the Eustis series (siliceous, thermic psammentic paleudult). The experimental area was divided into 12 plots each measuring 9.1 m $\times$ 3.0 m with a minimum buffer zone of 1.5 m between plots. A randomized block design was used to position four replicates of three treatments dazomet (DAZ), chloropicrin/metam sodium (CPMS), and control. Dazomet and metam sodium are two field-applied fumigants that decompose rapidly in soil to MITC (Dungan and Yates, 2003) which is the active fumigant ingredient. Irrigation was applied for the first week ($\approx$1 cm d^{-1}) to provide a surface seal to reduce volatilization loss of fumigants.

2.2. Soil physical properties

Unfumigated soil was sampled at 15 cm intervals from 0 to 60 cm depth from random locations across the experimental area (Table 1). Soils were sieved (2 mm), homogenized by depth interval, and stored in a humidified and dark environment at 22 °C ($\pm$2 °C) until incubations could be performed (maximum 3 d of storage). Bulk density was determined using the core method (Blake and Hartge, 1986). Soil water content was determined by oven drying 10 g sub-samples at 105 °C for 24 h. Soil pH was measured in a 1:1 (v:v) slurry of soil and deionized water using a Hanna Instrument (Ann Arbor, MI) portable pH/EC/TDS/temperature probe. TOC was determined from loss on ignition (Nelson and Sommers, 1996). Soil texture was determined by the University of Minnesota Soil and Plant Testing Laboratory using the hydrometer method.

Table 1
Summary of soil physical properties at various depths sampled at the nursery site

Depth (cm)	ρ_b (g cm^{-3})	pH	θ_v (%)	Sand (%)	Clay (%)	Silt (%)	TOC (%)
0–15	1.26 $\pm$ 0.12	5.6	10.0 $\pm$ 1.9 a	86.2	7.3	6.5	1.37 $\pm$ 0.01 a
15–30	1.46 $\pm$ 0.27	5.9	14.6 $\pm$ 1.5 a	85.9	6.8	7.3	1.39 $\pm$ 0.01 a
30–45	1.63 $\pm$ 0.04	6.0	16.1 $\pm$ 0.6 b	86.2	6.5	7.3	1.39 $\pm$ 0.01 a
45–60	1.62 $\pm$ 0.01	5.0	11.0 $\pm$ 0.3 a	83.9	7.8	8.3	1.11 $\pm$ 0.01 b

ρ_b, soil bulk density; θ_v, Soil volumetric water content; and TOC, total organic C. Data are shown as the arithmetic means with the standard deviation ($n=3$); different letters indicate significant differences in the depth intervals ($P<0.05$), if no letters are present the data have are not significantly different for the different depth intervals.