Soil & Tillage Research 124 (2012) 1–7

Contents lists available at SciVerse ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Methane emission from soil under long-term no-till cropping systems

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ARTICLE INFO

Article history:
Received 9 November 2011
Received in revised form 14 March 2012
Accepted 15 March 2012

Keywords:
Global warming
Agricultural soils
Methane uptake
Subtropical climate

ABSTRACT

Methane (CH_4) emission from agricultural soils increases dramatically as a result of deleterious effect of soil disturbance and nitrogen fertilization on methanotrophic organisms; however, few studies have attempted to evaluate the potential of long-term conservation management systems to mitigate CH_4 emissions in tropical and subtropical soils. This study aimed to evaluate the long-term effect (>19 years) of no-till grass- and legume-based cropping systems on annual soil CH_4 fluxes in a formerly degraded Acrisol in Southern Brazil. Air sampling was carried out using static chambers and CH_4 analysis by gas chromatography. Analysis of historical data set of the experiment evidenced a remarkable effect of high C- and N-input cropping systems on the improvement of biological, chemical, and physical characteristics of this no-tilled soil. Soil CH_4 fluxes, which represent a net balance between consumption (−) and production (+) of CH_4 in soil, varied from -40 ± 2 to $+62 \pm 78$ μg C m^{-2} h^{-1}. Mean weighted contents of ammonium (NH_4^+–N) and dissolved organic carbon (DOC) in soil had a positive relationship with accumulated soil CH_4 fluxes in the post-management period ($r^2 = 0.95$, $p = 0.05$), suggesting an additive effect of these nutrients in suppressing CH_4 oxidation and stimulating methanogenesis, respectively, in legume-based cropping systems with high biomass input. Annual CH_4 fluxes ranged from -50 ± 610 to $+994 \pm 105$ g C ha^{-1}, which were inversely related to annual biomass-C input ($r^2 = 0.99$, $p = 0.003$), with the exception of the cropping system containing pigeon pea, a summer legume that had the highest biologically fixed N input (>300 kg ha^{-1} yr^{-1}). Our results evidenced a small effect of conservation management systems on decreasing CH_4 emissions from soil, despite their significant effect restoring soil quality. We hypothesized that soil CH_4 uptake strength has been off-set by an injurious effect of biologically fixed N in legume-based cropping systems on soil methanotrophic microbiota, and by the methanogenesis increase as a result of the O_2 depletion in niches of high biological activity in the surface layer of the no-tillage soil.

1. Introduction

Methane (CH_4) is one of the main anthropogenic greenhouse gases, which contribution to global warming is estimated in 20% (IPCC, 2007). Soil CH_4 fluxes are a net result of the CH_4 production (+) by methanogenesis and CH_4 oxidation (−) by methanotrophy processes (Ball et al., 1999; Baggs et al., 2006). Usually, undisturbed soils act as a net CH_4 sink, but a dramatic decrease on the CH_4 oxidation rates is experienced when soils are converted to agriculture, which effect has been mainly related to the soil disturbance and to the ammonium-based N fertilization (Baggs and Blum, 2004; Hutsch, 1998a,b; Mojeremane et al., 2011; Powlson et al., 1997; Suwanwaree and Robertson, 2005). Tillage creates an inhospitable environment to methanotrophic organisms (Hutsch, 1998a; Willison et al., 1995), while increased soil NH_4^+ contents compete with CH_4 for the methane mono-oxygenase enzyme (Acton and Baggs, 2011; Bender and Conrad, 1992; Hutsch, 2001; Knief et al., 2005). As a result of the decrease on soil CH_4 sink to the increase of anthropogenic CH_4 sources, a net significant amount of 32 Tg of CH_4 has been annually increased in the atmosphere (UNEP, 1993).

Implementation of conservation tillage systems has been suggested as a key strategy to decrease CH_4 emissions to atmosphere by restoring CH_4 sink strength in agricultural soils (Hutsch, 1998a; Kessavalou et al., 1998; Ussiri et al., 2009), which effect is attributed to the more favorable biological, chemical, and physical soil environments to microorganisms in general, as well as to methanotrophic bacteria (Hutsch, 2001, 1998a). However, most studies have evidenced a little effect of soil management on soil CH_4 emissions evidencing that the recovery of methanotrophic activity in agricultural soils is a very slow process, and several

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http://dx.doi.org/10.1016/j.still.2012.03.006

decades may be required for providing a significant effect of the conservation tillage systems on soil CH_4 sink strength (Jacinthe and Lal, 2005, 2006; Ojima et al., 1993; Priemé et al., 1997; Regina and Alakukku, 2010; Suwanwaree and Robertson, 2005).

Grass and legume cover crops-based cropping systems have profound impact on soil quality, but their potential effect on CH_4 emissions in no-tillage soils is unknown. High biomass input by legume cover crops-based cropping systems increases the soil organic matter content and lability, aggregation, and microbial biomass and activity (Amado et al., 2006; Bayer et al., 2000; Kong et al., 2005; Vieira et al., 2007, 2008), which changes may be potentially favorable to methanotrophic bacteria as evidenced for organically fertilized soils (Seghers et al., 2003). However, biological oxidation of large quantity of labile C, as from narrow C:N crop residues, may result in an intense O_2 consumption, mostly in niches of high biological activity in soil, creating favorable conditions to methanogenesis (Baggs et al., 2006; Topp and Pattey, 1997). Thus, the net effect of this practice on CH_4 fluxes will be dependent on the balance between these opposite effects.

Smaller requirements of mineral N fertilizer by the cash crop in legume cover crops-based cropping systems (Fontoura and Bayer, 2009) may also have a benefic effect on soil CH_4 oxidation; nevertheless, no information is available regarding the injurious effect of long-term biologically fixed N input on methanotrophic population. Only the immediate or short-term deleterious effect of increased ammonium (NH_4^+) soil content on CH_4 oxidation capacity of legume crop residues-amended soils has been characterized (Boeckx and Van Cleemput, 1996; Tlustos et al., 1998), which is related to competitive enzymatic process between methanotrophy and nitrification in soils (Baggs and Blum, 2004; Bender and Conrad, 1992; Hutsch, 2001). The long-term effect of N input for several decades on soil CH_4 oxidation is probably a slow and not fully reversible process in agricultural soils (Chan and Parkin, 2001; Hutsch, 2001; Suwanwaree and Robertson, 2005), and might be related to changes in the microbial community structure (Suwanwaree and Robertson, 2005).

Based on scarce information available in literature concerning the effect of cropping systems on CH_4 emissions in tropical and subtropical soils, this study was developed in two long-term experiments (>19 years) aiming to evaluate the potential of high biomass-C and biologically fixed N inputs by no-till cropping systems for decreasing CH_4 emissions from a previously degraded South Brazilian Acrisol. Historical data concerning the influence of cropping systems on soil quality were also analyzed.

2. Material and methods

2.1. Long-term experiments and historical data set of soil quality

The study was carried out in two adjacent long-term experiments initiated in 1983 (Exp. I) and 1985 (Exp. II), at a formerly degraded Aluminic Acrisol (220 clay kg^{-1}) in subtropical climate (annual mean temperature and rainfall of 19.4 °C and 1440 mm, respectively) from Southern Brazil (30°06′S; 51°41′W, about 45 m altitude). Previous soil degradation was caused by the intense plowing and erosion due to the conventional tillage adopted over almost two decades.

Selected cropping systems involving grass and legume cover-crops [Exp. I: black oat (*Avena strigosa* Schreb) + vetch (*Vigna sativa* L.)/maize (*Zea mays* L.) + cowpea (*Vigna unguiculata* Walp)-O + V/M + C, pigeon pea (*Cajanus cajan* L.) + maize-P + M, and lablab (*Dolichos lablab*) + maize-L + M; Exp. II: black oat/maize-O/M and vetch/maize-(V/M)] were evaluated. All cropping systems were conducted under no-tillage system, where crop residues of winter and summer cover-crops and of maize were maintained on soil surface, and no mineral N fertilizer was applied in any treatment for 20 (Exp. I) and 19 years (Exp. II). Phosphorus and potassium were applied annually for maize at rates of 60 kg ha^{-1} of P_2O_5 and K_2O.

Winter cover-crops were sown in April (autumn in the South Hemisphere) and maize in September or October (spring in the South Hemisphere). A seed rate of 60–80 kg ha^{-1} was used for winter cover-crops, while maize was sown at 50,000–70,000 seeds ha^{-1}. In the first 7 (Exp. I) and 5 years (Exp. II), all crops were sown manually, and a mechanical sowing of winter cover-crops and maize was performed in the subsequent period. Summer cover-crops were intercropped with maize; they were manually sown in spring–summer at the maize inter-rows, with an average of three seeds per hole and distance of 40–50 cm between holes. No pesticides were applied in any cropping system, excepting the glyphosate-based herbicide applied every spring season for the winter cover-crops management, followed by roller-cutter in about 1 week later. Additional information concerning the experiments is available in Zanatta et al. (2007) and Vieira et al. (2008).

Historical data regarding annual biomass-C and -N inputs, and the influence of long-term cropping systems on biological, chemical and physical soil quality indicators are summarized in Table 1.

2.2. Air sampling and CH_4 flux calculation

In Oct 30th 2003, after the management of cover-crops, a 2 m × 2 m area was defined in one plot of each treatment, and two aluminum-made bases were fixed in the soil. Air sampling was performed for a period of 344 days (from Nov 5th 2003 to Oct 13th 2004), in weekly intervals in the first 45 days after the management of cover crops, and intervals varying from 15 to 60 days in the later period (Fig. 1).

Air samples were manually taken from closed flux chambers (0.25 m diameter × 0.20 m height) composed of a PVC-cylinder with the top border hermetically closed. At the time of the gas measurement this chamber was fitted on to an aluminum base (0.0346 m^2) equipped at the top with a circular channel (diameter of 0.21 and 0.28 m of inner and outer ring, respectively, and height of 0.05 m) inserted 5 cm into the soil, which was only removed from the field at the sowing and harvesting events. To ensure a good seal between the base and the PVC chamber, water was added to the channel in the lower base. The chambers had a thermometer with outside display for monitoring the temperature of the inward air, and an internal fan for homogenizing the chamber atmosphere before the sampling. In the top, the chambers were equipped with a rubber septum for sampling the air. This apparatus is similar to that used by Gomes et al. (2009) and Zanatta et al. (2010).

Air samples were taken simultaneously in all treatments, beginning at 9 a.m. and taking samples at 0, 15, 30 and 45 min after closing the chamber. The syringes (polypropylene, 20 mL) were closed and immediately disposed in a cooler box, where they were kept at low temperature, and dispatched by express mail to the Environmental Biogeochemical Lab (Nuclear Energy Centre, University of Sao Paulo) for analysis of CH_4 concentration by gas chromatography (GC-Shimadzu 14A), within 24 h of sampling. The chromatograph was equipped with a Porapak-Q column set at 30 °C temperature, N_2 as carrier gas in flow of 30 mL min^{-1}, injector temperature of 50 °C, and FID detector at temperature of 320 °C.

The CH_4 fluxes were calculated using the following equation by Hutchinson and Livingston (1993): $f = (\Delta C/\Delta t) \times (V/A) \times (m/V_m)$; where: f is the flux of soil CH_4 gas (μg C m^{-2} h^{-1}), $\Delta C/\Delta t$ is the rate of change for the gas concentration inside the measuring chamber (μg C h^{-1}), V is the headspace volume of the chamber (0.00982 m^3), A is the circular area of the bases (0.0346 m^2),