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),

Table 1
Summary of historical soil quality data set from the two long-term experiments in Southern Brazil.

Soil quality indicator[a]	Time[b] (years)	Depth (cm)	Cropping systems[c]					Reference[d]
			O/M	V/M	O+V/M+C	L+M	P+M	
Mean annual C input (Mg ha^{-1})	19	–	4.00	5.75	6.60	6.27	7.84	1, 2
Annual N input by cover crops (kg ha^{-1})	19	–	40	114	140	128	327	4
Biological								
Microbial biomass (mg C kg^{-1} soil)	17	0–10.0	410	–	469	–	428	3
Microbial activity (mg C kg^{-1} soil)	17	0–10.0	100	–	135	–	154	3
β-Glucosidade (μg p-nitrophenol g^{-1} soil)	17	0–10.0	97	–	135	–	146	3
Amidase (μg NH_4^+–N g^{-1} soil)	17	0–10.0	199	–	228	–	267	3
Chemical								
SOC (g C kg^{-1} soil)	19	0–12.5	10.88	12.79	12.68	17.15	14.69	1, 2
Total soil N (g N kg^{-1} soil)	19	0–12.5	1.07	1.16	1.94	1.37	1.40	4, 5
Labile-C (g C kg^{-1} soil)	19	0–12.5	0.48	–	0.82	–	1.45	1
CEC at pH 7.0 ($cmol_c$ kg^{-1} soil)	19	0–12.5	7.20	11.30	9.98	11.62	10.53	4, 5
Physical								
MWD wet (mm)	21	0–10.0	2.80	–	2.90	3.70	–	6
Total soil porosity (m^3 m^{-3} soil)	18	0–10.0	0.40	–	0.38	–	0.38	2, 6

[a] SOC: soil organic carbon; CEC: cation exchange capacity; MWD: mean weight diameter.
[b] Time of the experiment when soil variable was evaluated.
[c] Exp. I: O+V/M+C = black oat (*Avena strigosa* Schreb) + vetch (*Vigna sativa* L.)/maize (*Zea mays* L.) + cowpea (*Vigna unguiculata* Walp); P+M = pigeon pea (*Cajanus cajan* L.) + maize; L+M = lablab (*Dolichos lablab*) + maize; Exp. II: O/M = black oat/maize; V/M = vetch/maize.
[d] (1) Vieira et al. (2007); (2) Zanatta et al. (2007); (3) Schmitz (2003); (4) Vieira (2007); (5) Zanatta (2006); (6) Vieira et al. (2008).

m is the molecular weight of the gas (16 g mol^{-1}), and V_m is the molar volume of gas (m^3 mol^{-1}) corrected for the air temperature (K) in the headspace chamber, measured at the sampling time.

Mean CH_4 fluxes (μg C m^{-2} h^{-1}) and respective standard deviations were calculated from the fluxes measured in the two chambers per treatment. Daily CH_4–C fluxes were estimated by linear interpolation assuming that the 9:00–10 a.m. sampling period provided a valid estimation of average daily fCH_4. This assumption is supported by the results reported by Jantalia et al. (2008), who observed that, for the same region, the middle of the morning was the most feasible time for air sampling aiming to estimate mean daily N_2O fluxes. Cumulative fluxes for 1 year and for the post-management period (90 days after winter cover-crop management) were calculated by integration of the daily CH_4 emissions.

2.3. Soil variables

The first 11 sampling events for CH_4 analyzes were joined by evaluations of soil gravimetric moisture, dissolved organic carbon (DOC), and ammonium (NH_4^+) contents in composite soil samples (4 sub-samples) at 0–0.3 m depth, and soil temperature at 0.05 m depth, within the 2 m × 2 m area. Geo-thermometers were used to evaluate soil temperature. The gravimetric moisture was obtained by drying up the soil at 105 °C for 48 h. Samples for DOC analysis were air dried, ground, and sieved through a 2 mm sieve. The DOC was extracted by horizontally shaking a solution with 5 g soil and 50 mL distilled water (1:10) for 10 h. The suspension was centrifuged and the supernatant filtrated through regenerated cellulose membrane filters of 0.45 μm pore diameter (Chantigny, 2003). The DOC contents were determined by dry combustion using a TOC VCSH Analyzer Shimadzu®. Ammonium was extracted with 1 M KCl and determined by Kjeldhal distillation method (Bremner, 1960). Based on results of gravimetric water content and soil bulk density for each crop system, reported by Vieira et al. (2008) for the experiment I and by Zanatta et al. (2007) for the experiment II, the percentage of water-filled pore space (WFPS) was calculated for each sampling date, assuming a mineral particle density of 2.65 g cm^{-3}. Local data of air temperature and rainfall for the evaluated period (Fig. 2) were obtained from an Automatic Meteorological Station at the Department of Forage and Meteorology (UFRGS), which is located about 1 km from the experimental area.

2.4. Statistical analysis

Considering that measurements of CH_4 were accomplished with two chambers in the same plot and, thus, the evaluations

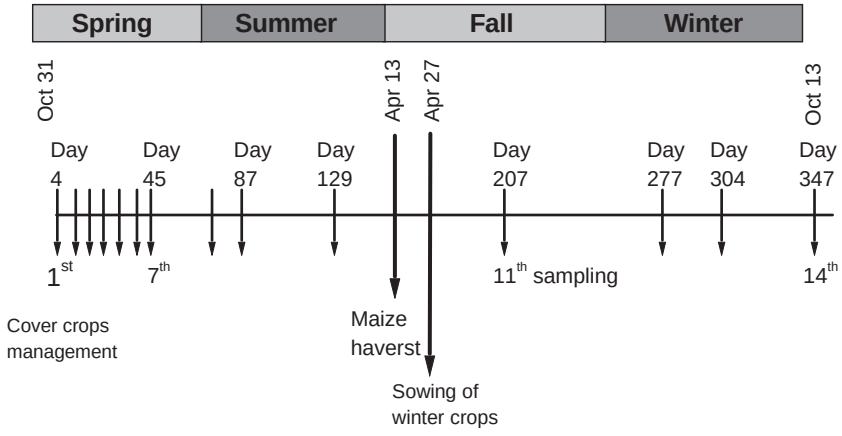

Fig. 1. Schedule of air sampling and agricultural practices.

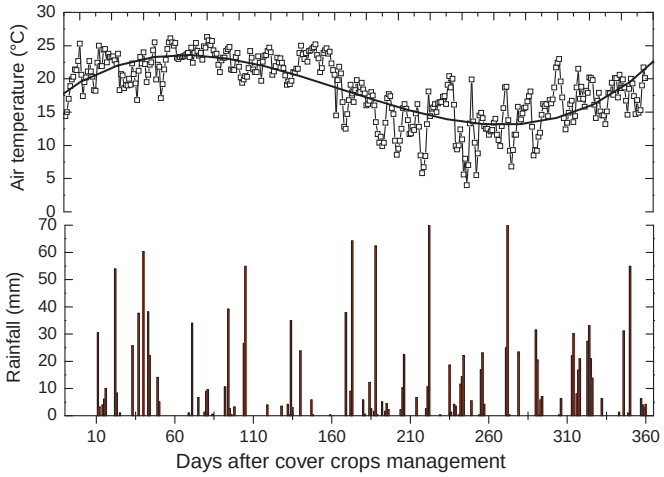

Fig. 2. Air temperature and rainfall along of the air sampling period.

were not taken in the field replicates, a non-descriptive statistical analyses was performed and the mean standard deviation values were used to discriminate the effect of cropping systems on soil CH_4 emissions. Relationship between soil variables and CH_4 emissions was evaluated by the significance of determination coefficient (r^2) of simple and multiple linear regressions.

3. Results

3.1. Brief comments on long-term no-till cropping systems effect on soil quality

Historical soil quality data are summarized in Table 1. A remarkable effect of the high aboveground biomass-C input by legume cover crops-based cropping systems (5.75–7.84 Mg ha^{-1} yr^{-1}; V/M, O + V/M + C, P + M, and L + M) on the enhancement of the biological, chemical, and physical soil quality indicators was observed in this no-tilled soil, in comparison to lower biomass-C input grass-based cropping system (4.00 Mg ha^{-1} yr^{-1}; O/M). Among the soil variables, we underline the potential of the summer and winter cover-crops to improve the soil organic matter content and lability, microbial biomass-C and its activity (CO_2–C), enzymatic activity, and soil aggregation (Table 1).

3.2. Soil methane fluxes and soil variables

Soil CH_4 fluxes in cropping systems varied from -40 ± 2 to $+62 \pm 33$ μg C m^{-2} h^{-1} (Fig. 3). The greatest oscillation in the soil CH_4 fluxes occurred in the first 3 months after the cover crops management in this no-tillage soil (post-management period, Fig. 3), concomitantly to the period in which the highest oscillation in soil variables were observed, mainly NH_4^+ (0.04–9.10 mg N kg^{-1} soil) and DOC (0.13–0.36 mg C kg^{-1} soil) contents (Fig. 4).

In the post-management period, predominance of net CH_4 emission to atmosphere was observed in soil under tropical legume cover crops-based cropping systems (P + M and L + M), reaching peaks up to $+62 \pm 33$ μg C m^{-2} h^{-1}. In contrast, soils under winter legume (V/M), mixed system (O + V/M + C), and grass cover crops-based cropping system (O/M) had predominantly net CH_4 uptake (Fig. 3), reaching net CH_4 oxidation rates up to -27 ± 10 μg C m^{-2} h^{-1} (Fig. 3). This distinct behavior of cropping systems was reflected in the cumulative soil CH_4 fluxes in the post-management period. Summer cover crops-based cropping systems had a net CH_4 emission to atmosphere ($+90 \pm 60$ g C ha^{-1} in L + M and $+334 \pm 18$ g C ha^{-1} in P + M), while the soil under the other cropping systems had a net CH_4 oxidation, ranging from -191 ± 201 to -132 ± 102 g C ha^{-1}.

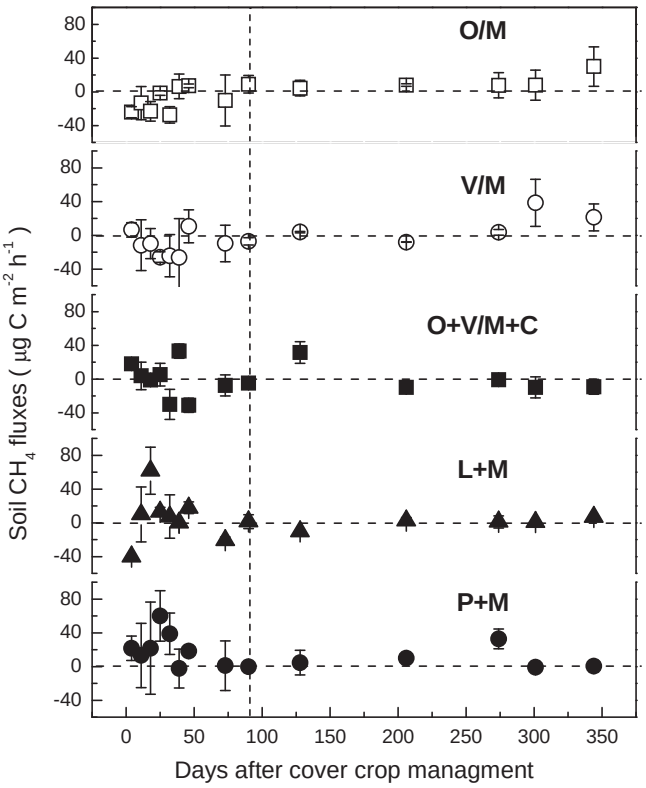

Fig. 3. Methane fluxes in subtropical Acrisol under five long-term no-till cropping systems. O/M = black oat/maize; V/M = vetch/maize; O + V/M + C = oat + vetch/maize + cowpea; L + M = lablab + maize; and P + M = pigeon pea + maize. Vertical bars represent mean standard deviation (n = 2), and the dotted vertical line denotes the end limit of the post-management period (90 days after cover crops management).

Individual fluxes of CH_4 in the post-management period had no relationship with any soil variable. However, a close relationship was observed between cumulative soil CH_4 flux rates and weighted NH_4^+–N and DOC contents in the 0–30 cm soil layer in the post-management period (CH_4–C flux = $-1731 + 179$ NH_4^+–N + 4800 DOC, $r^2 = 0.95$, $n = 5$, $p = 0.05$). After the post-management period, the soil CH_4 fluxes were smaller, reaching background values (closed to zero) in the most cropping systems (Fig. 3).

Annual soil CH_4 fluxes ranged from -50 g C ha^{-1} in O + V/M + C to +994 g C ha^{-1} in P + M cropping system (Fig. 5), and apart from the P + M system, they have a close and negative relationship with annual aboveground biomass-C input by the cropping systems (annual soil CH_4–C flux = 1212–187 biomass-C input, $r^2 = 0.99$, $p = 0.003$).

4. Discussion

The range observed in the soil CH_4 fluxes (Fig. 3) was very similar to those reported in a review of 63 studies performed in tropical soils under different soil uses, where most soils (>80%) had fluxes varying from -50 to $+50$ μg C m^{-2} h^{-1} (Priemé and Christensen, 1999). However, the annual rates (-50 ± 310 to $+994 \pm 105$ g C ha^{-1}) indicated a weaker soil CH_4 sink strength in comparison with grassland and mineral arable European soils, which CH_4 oxidation rates vary from -86 to -7800 g C ha^{-1} (Boeckx and Van Cleemput, 2001; Smith et al., 2000).

The highest oscillation of soil CH_4 fluxes in the post-management period was probably related to the biomass stimulation effect on soil microorganisms resulting from C and N input (Figs. 3 and 4), as well as to the higher temperature and moisture conditions in spring and part of the summer seasons (Fig. 2). This

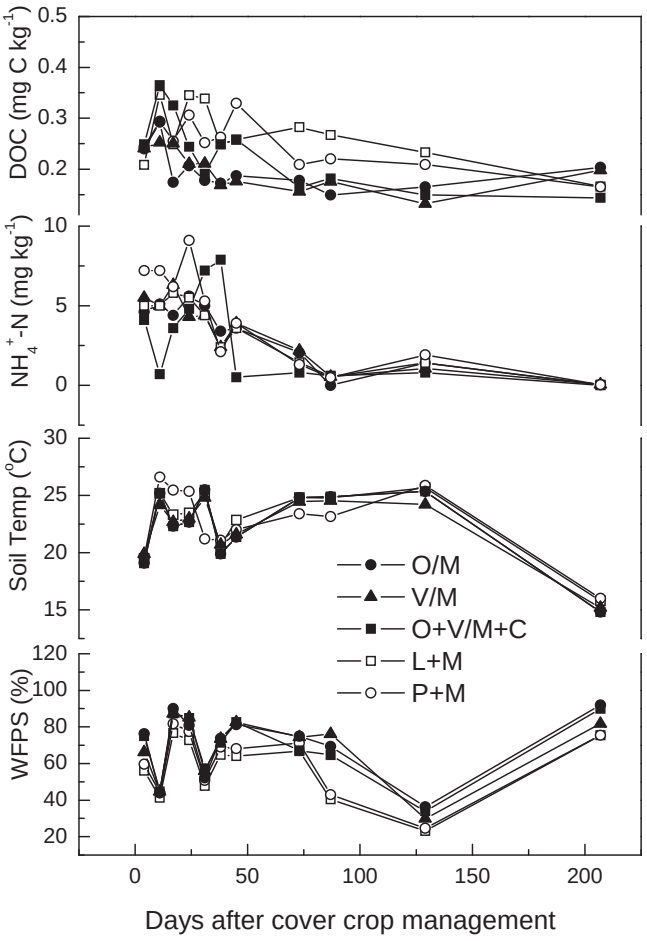

Fig. 4. Dissolved organic carbon (COD), NH_4^+–N concentration, soil temperature (Soil Temp), and water filled pore space (WFPS, %) in the 0–30 soil layer in an Acrisol under five long-term no-till cropping systems. O/M = black oat/maize; V/M = vetch/maize; O + V/M + C = oat + vetch/maize + cowpea; L + M = lablab + maize; and P + M = pigeon pea + maize.

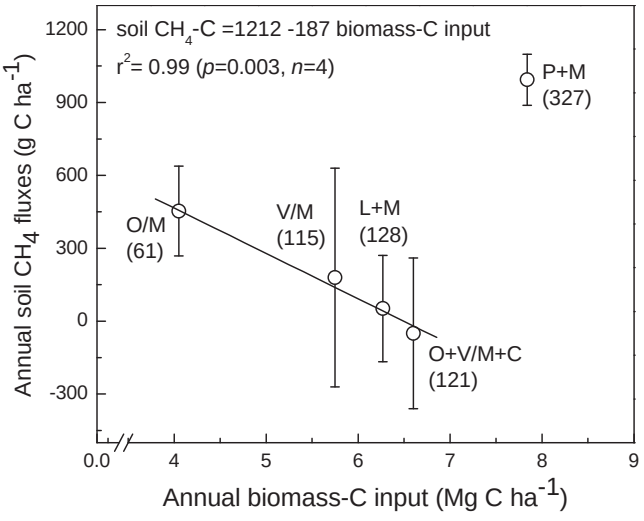

Fig. 5. Relationship between aboveground biomass-C input and annual CH_4 fluxes in an Acrisol under five long-term no-till cropping systems. O/M = black oat/maize; V/M = vetch/maize; O + V/M + C = oat + vetch/maize + cowpea; L + M = lablab + maize; and P + M = pigeon pea + maize. Vertical bars represent mean standard deviation ($n = 2$). Values between parentheses denote the annual N input by cover-crops in each cropping system. Linear equation does not include P + M cropping system.

interaction between environment and management practices resulted in the most favorable conditions to microbial activity in soil in comparison with the following period.

Soil CH_4 fluxes had a close relationship with mean weighted NH_4^+–N and DOC soil contents in the post-management period. These results suggest an additive effect of these nutrients on soil CH_4 fluxes, where great NH_4^+–N and DOC contents resulted in a decrease in methanotrophy concomitantly to an increase in methanogenesis, respectively. The injurious short-term effect of NH_4^+ on methanotrophic bacteria in agricultural soils is very well described in the literature concerning the effect of ammonium-based fertilizer (Acton and Baggs, 2011; Reay and Nedwell, 2004; Sitauta et al., 2000; Suwanwaree and Robertson, 2005); however, few studies have demonstrated this deleterious effect on CH_4 oxidation resulting from legume residues (Baggs et al., 2006; Boeckx and Van Cleemput, 1996; Tlustos et al., 1998). The immediate NH_4^+ effect on soil CH_4 oxidation is related to the competition between methanotrophs and nitrifiers for the enzyme methane monooxygenase (Bender and Conrad, 1992; Hutsch, 2001). According to Hutsch (1998a), oxidation of NH_4^+ and CH_4 exclude each other in soil and CH_4 oxidation only occurs after NH_4^+ nitrification is almost completed. Although mineral N fertilization effect in soil is usually considered as being much ephemeral (Hutsch, 1998a), extended injurious effect (up to several weeks) has been observed in some studies (Suwanwaree and Robertson, 2005).

Higher DOC soil contents at 0–30 cm layer result from a large input of labile C on the soil surface of this no-tillage soil. Considering a mean bulk soil density of 1.4 Mg m^{-3}, the variation of 0.36–0.13 mg C kg^{-1} soil (maximum DOC content in the post-management period and background DOC content in the following period, respectively) represents an amount of 966 kg ha^{-1} of DOC in 0–30 cm soil profile, which is concentrated mostly in soil surface layer. Thus, the intense biological oxidation of this labile C source probably resulted in anoxic conditions, mainly in niches of high microbial activity, creating favorable conditions to methanogenesis (Baggs et al., 2006; Topp and Pattey, 1997). In addition, methanogenesis may have been favored by the highest values of water-filled soil porosity (up to 90%; Khalil and Baggs, 2005) verified in the post-management period as a result of rainfall events (Fig. 4).

The close and negative relationship between the annual soil CH_4 fluxes and annual aboveground biomass-C input by cropping systems (Fig. 5) is possibly related to the effect of soil quality restoring under high input cropping systems, increasing CH_4 oxidation in soil. One exception was the cropping system with pigeon pea, which had the highest C and N inputs (7.84 Mg ha^{-1} and 327 kg ha^{-1}, respectively) and the highest values in most of the soil quality indicators. The soil under this summer cover crop species had the highest annual CH_4 emission (+994 ± 105 g C ha^{-1}), which was probably related to the longer and more intense injurious effect of the high input of biologically fixed N on soil CH_4 uptake capacity.

According to our study, recovery of soil CH_4 oxidation capacity is a very slow process and several decades are required to a significant effect of conservation management systems mitigating CH_4 emissions from soil. This finding is the same of that obtained by Jacinthe and Lal (2006, 2005) and Suwanwaree and Robertson (2005) in temperate soils. In addition to the intrinsic slow recovery of soil CH_4 oxidation capacity, our results suggest that the recovery of soil CH_4 uptake capacity – as consequence of the improvement in soil quality – may be hampered by an injurious effect of long-term biologically fixed N input on soil methanotrophic microbiota, and by the occurrence of methanogenesis, as a result from O_2 exhaustion in niches of high biological activity in the surface layer of the no-tilled soils. The distinct location of the zone of maximum

CH_4 oxidation (5–15 cm; Hutsch, 1998a; Jacinthe and Lal, 2006) in relation to the main layer of soil profile where soil quality is primarily improved (0–5 cm) should also be addressed in future studies aiming to evaluate its role on the low impact of conservation management systems on the recovery of soil CH_4 sink strength.

5. Conclusions

No-till soil had net methane consumption or emission depending on the period of the year and on the cropping system. Greatest oscillation in soil methane fluxes was observed in the period after cover crops management in the spring season, when methane fluxes were closely related to the ammonium and dissolved organic carbon in soil. In general, a small decrease in the annual soil methane emissions was observed in high aboveground biomass-C input cropping systems, which was attributed to their favorable impact on biological, physical and chemical soil quality. We hypothesized that recovery of soil CH_4 uptake capacity under high biomass input cropping systems has been restrained by an injurious effect of long-term biologically fixed N input on soil methanotrophic microbiota, and by the occurrence of methanogenesis in high biological activity niches in the surface soil layer of this no-tillage soil.

Acknowledgments

This project was funded by the Brazilian Council for Scientific and Technologic Development (CNPq) and Foundation of Research Support of Rio Grande do Sul State (Fapergs).

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