Journal of Environmental Management 169 (2016) 27–33

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Impact of biochar on nitrous oxide emissions from upland rice

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ARTICLE INFO

Article history:
Received 18 June 2015
Received in revised form
20 November 2015
Accepted 13 December 2015
Available online 22 December 2015

Keywords:
Oryza sativa
Pyrogenic carbon
Nitrification
Denitrification
Efficient use of nitrogen

ABSTRACT

The objective of this research was to assess the emission of nitrous oxide (N_2O) from soil amended with biochar in the culture of upland rice. The experiment was conducted in the field in a Cerrado Haplic Plinthosol under randomized block experimental design. The treatments consisted of fertilization with 100 kg N ha^{-1} split into two applications, 60% at sowing and 40% at 45 days after crop emergence, combined with four doses of biochar (0, 8, 16 and 32 Mg ha^{-1}), with four replications. The application of N and the emission of N_2O, moisture retention and soil temperature, respiration ($C-CO_2$), microbial biomass carbon in the soil (C-SMB), total nitrogen (TN), pH and agronomic efficiency in N use (AENu) were evaluated five years after the application of biochar. There was a significant correlation of the application of biochar with moisture retention ($r = 0.94^{**}$), N_2O emission ($r = 0.86^{**}$) and soil pH ($r = 0.65^{*}$), and N_2O emissions showed a positive correlation ($p < 0.05$) with soil moisture ($r = 0.77^{**}$) and pH ($r = 0.66^{*}$). Thus the highest N_2O emissions were observed shortly after N fertilization and in the treatments with 32 Mg ha^{-1} of biochar. Despite the higher N_2O emissions from the application of 32 Mg ha^{-1} of biochar, the emission factor was lower (0.81%) than the maximum recommended by the IPCC. The higher N_2O emissions with application of biochar are offset by more efficient use of N and consequently the possibility of reduction of applied doses.

1. Introduction

Rice (*Oryza sativa* L.) is one of the most important crops in the world, providing vital nutrition for much of the population in Asia, Latin America and Africa, including India and China (FAOSTAT, 2015). Brazil is the only non-Asian country among the top ten global producers of rice due to its well-developed traditional system of irrigated cultivation and new technology allowing production of non-irrigated upland rice. The development of new technologies is critical for sustainable future crop production, considering the current growth of global population and food consumption. According to Schneider et al. (2011), without technological development, global agriculture would need an area equivalent to one half of the current terrestrial land area by 2030 to meet food demand, assuming current growth rates are maintained.

The cultivation of rice in Brazil currently occupies an area equivalent to 2.41 million hectares, of which approximately 70% is grown under a flood irrigation system (Conab, 2014). Currently, rice production in Brazil almost equals domestic demand (~12 million tons), but the development of new technologies for upland cultivation could increase domestic production to supply local and global markets. These data serve as a warning about the need to increase domestic production, thus underlining the importance of the cultivation of upland rice in the Cerrado (Petter et al., 2012a). Upland rice grown under rain fed conditions has been touted as an alternative to expand production due to its lower environmental impact and lower costs compared to the flooded system.

The need for increased production of rice as a function of domestic or export demand generates at the same time an increase in consumption of fertilizers, especially nitrogen, since this culture has no ability to fix nitrogen (N) via atmospheric symbiosis. The average annual consumption of N for rice cultivation in Brazil is approximately 144.16 thousand tons, which is equivalent to approximately 59 kg ha^{-1} (Anda, 2013). The increased use of nitrogen fertilizers increases the availability of mineral N and consequently can lead to increased emissions of nitrous oxide (N_2O), mostly in irrigated systems (Siqueira-Neto et al., 2011). The emission of N_2O in soil is directly related to the processes of

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http://dx.doi.org/10.1016/j.jenvman.2015.12.020
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nitrification and denitrification (Stepniewski and Stepniewska, 2009), and these, in agricultural systems, are dependent on factors such as availability of water (Liu et al., 2010) and $N-NO_3^-$ (Bouwman, 1998), levels of pH (Mogge et al., 1999) and the organic material available to microorganisms in the soil.

Biochar (i.e., black carbon) is known as an important alternative for improvement of chemical-physical conditions, especially fertility, of the dystrophic and highly weathered soils typical of the Brazilian Cerrado (Petter et al., 2012b). However, the potential of biochar to alter chemical characteristics of the soil such as pH, organic material (Petter et al., 2012b), availability of N, microbial activity (Jindo et al., 2012) and soil moisture (Carvalho et al., 2014) can impact the emissions of N_2O in agricultural areas. Aside from fertility improvement, recent studies have been conducted to evaluate the potential of biochar to mitigate N_2O emissions, but with scarce and divergent results (Spokas et al., 2009; Alho et al., 2012). The divergent results among these studies are possibly due to the rate of application of biochar, since in the study of Spokas et al. (2009) doses much higher than those utilized by Alho et al. (2012) were used. Bruun et al. (2011) found that the effects of biochar on N_2O emissions depend on the dose used, in that a low dose (1% by mass) can result in an increase and high doses (3%) in an attenuating effect on N_2O emissions. Additionally, most studies that evaluated N_2O emissions from soil with biochar were conducted under controlled conditions and the assessments done in a short period of time after the application of biochar (<1 year).

Brazil is prominent in the increase of studies on this issue, aiming mainly to support the database of the Brazilian inventory of N_2O emissions from agricultural activities. However, few studies to date aimed at assessing N_2O emissions in rice, and most of these works (Zschornack et al., 2011) report on emissions in rice grown under flood irrigation. In general, most studies on N_2O emissions are concentrated in temperate regions, being still incipient in tropical regions. Allied to this, and due to the scarcity of studies on the emission of N_2O in the culture of upland rice, especially in the Cerrado region, the objective of this research was to test the impact of biochar on N_2O emissions from soil in plantations of upland rice.

2. Materials and methods

2.1. Characterization and experimental design of the study area

The field experiment was implemented in Nova Xavantina, MT, Brazil, in the Cerrado biome (14°34′50″S, 52°24′01″W, at 310 m altitude), in January of 2013, in a Dystric Plinthosol soil. The chemical and physical characteristics at a depth of 0–0.20 m showed: pH (H_2O): 5.3; P (Mehlich method): 14.2 mg dm^{-3}; exchangeable K: 0.21 $cmol_c$ dm^{-3}; Ca: 1.1 $cmol_c$ dm^{-3}; Mg: 0.8 $cmol_c$ dm^{-3}; Al: 0.2 $cmol_c$ dm^{-3}; H + Al: 3.1 $cmol_c$ dm^{-3}; Base saturation (V%): 41; Cation Exchange Capacity (CEC): 5.2 $cmol_c$ dm^{-3}; SOM: 11.3 g kg^{-1}; Fe: 37.0 mg dm^{-3}; Mn: 39.0 mg dm^{-3}; Zn: 9.0 mg dm^{-3}; Cu: 0.7 mg dm^{-3}; Clay: 170 g kg^{-1}; Silt: 67 g kg^{-1}; Sand: 763 g kg^{-1}. Analyses were determined according to Embrapa (1997). In Brazil, the levels of Na^+ in the study region (Cerrado Biome) are very low and for this reason the values are disregarded for the CEC calculation. Base saturation value was obtained using the following equation (%) = 100{(Ca + Mg + K)/[Ca + Mg + K+(H + Al)]}. The density of the soil in the experiment it was 1.37 Mg m^{-3}.

The pH was determined using the electrode method; P, K, Cu, Fe, Mn and Zn were extracted with diluted concentration of strong acids [HCl 0.5 N + H_2SO_4 0.025 N (Mehlich I)]; Ca, Mg and Al were extracted in KCl 1 N; Phosphorus was determined by colorimetric method; Ca and Mg were determined by atomic spectroscopy and K by flame emission spectrometry; Potential acidity (H + Al) was determined by extracting with 0.5 mol L^{-1} calcium acetate solution at pH 7.1–7.2, and titrating with 0.025 mol L^{-1} NaOH, using 10 g L^{-1} phenolphthalein as indicator. Cation exchange capacity was obtained through the sum of Ca, Mg and K. SOM was determined by the Walkey–Black method (Nelson and Sommers, 1996), without external heating, using sulfuric acid to generate internal heat for the reaction. This method is based on the reduction of dichromate ($Cr_2O_7^{2-}$) by organic carbon molecules in the soil and subsequent determination of $Cr_2O_7^{2-}$ not reduced by redox titration with Fe^{2+}.

Two doses of N (0 and 100 kg ha^{-1}) and four doses of eucalyptus biochar (0, 8, 16 and 32 Mg ha^{-1}) were tested in a randomized block design, with four replicates. We used as control treatment plots without nitrogen and biochar. The application of N and the measurements of N_2O were done five years after the application of the biochar. In each plot twenty rows of rice plants 10 m in length were cultivated, with a total of 40.5 m^2 as plot area, of which 25.2 m^2 was considered useful in the study. The variety of aerobic rice (*O. sativa*) used was ‘Primavera’, developed by the Brazilian agricultural research company, EMBRAPA. Sixty per cent of the N fertilizer (urea) was applied at sowing and 40% at 45 days after sowing, which corresponds to 38 days after emergence.

The rice was cultivated under rain fed conditions (non-irrigated) using a no-till system from January to April of 2013. Sowing was done mechanically with application of 80 kg ha^{-1} of seeds at a depth of 2–3 cm and spacing of 0.2 m between rows. The natural monthly precipitation (rain) during the conduct of the experiment was of 246 mm, 232 mm, 259 mm and 30 mm for the months of January, February, March and April of 2013, respectively. These volumes are considered normal for these months in the study region. Weed infestation was chemically controlled with glyphosate (3 L ha^{-1}) applied at around 15 days prior to sowing and with 2–4 D (0.5 L ha^{-1}) applied around 10 DAE. Additionally, manual weeding operations were conducted at around 30 and 60 DAE.

2.2. Biochar

Biochar was applied to the soil only once (in 2008), before planting, and it was incorporated to a 0–0.15 m soil depth using a rotary hoe. This was the only occasion when the soil was physically moved. After that, the experiment was performed in no tillage system. Before incorporation into the soil, biochar was ground to pass through a 2 mm sieve. The biochar was made from eucalyptus timber via slow pyrolysis in a cylindrical metal kiln using temperatures around 400–500 °C. The elemental and molecular composition (Table 1), determined by ^{13}C nuclear magnetic resonance

Table 1
Elemental composition (extractable values) of charcoal used in the experiment.

Total carbon[a]	g kg^{-1}	774.0
Total nitrogen[a]		3.3
Oxidizable carbon[b]		33.0
Calcium	$cmol_c$ kg^{-1}	2.8
Magnesium		2.3
Aluminum[c]		0.0
Potential acidity[c]		0.0
Available phosphorus	mg dm^{-3}	137.3
Potassium		1937.3
Copper		1.0
Iron		74.0
Manganese		88.0
Zinc		36.0
Ratio C:N	–	273.6

[a] Determined by the Dumas method using an elemental analysis.
[b] Determined by the Walkley-Black method. The other elements were determined using a methodology for analysis of soils.
[c] Below the limit of detection.
Source: Petter et al. (2012 b).