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Research article

The conversion of grassland to acacia forest as an effective option for net reduction in greenhouse gas emissions

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ABSTRACT

This study aimed to evaluate the effect of forestation with leguminous *Acacia mearnsii* De Wild in native grasslands on the soil greenhouse (GHG) fluxes and their main driving factors. The experiment was conducted in the Brazilian Pampa over the period of one year in a six-year-old Acacia plantation, evaluating four treatments: Acacia (AM), Acacia with litter periodically removed (A–l), Acacia after harvest (AH) and native grassland (NG) (reference treatment). Air samples were obtained by the static chamber method, and gas concentrations were evaluated by gas chromatography. Soil and climate factors were monitored. The accumulated fluxes of methane (CH_4) and nitrous oxide (N_2O) were statistically similar between the soils in the AM and NG treatments, which tended to oxidize CH_4 (-1445 and -1752 g C–CH_4 ha^{-1} yr^{-1}, respectively) and had low emission of N_2O (242 and 316 g N–N_2O ha^{-1} yr^{-1}), most likely influenced by the low water-filled pore space and the low content of mineral N in the soil. However, the soil in the AH treatment presented higher emissions of both gases, totaling 1889 g C–CH_4 ha^{-1} yr^{-1} and 1250 g N–N_2O ha^{-1} yr^{-1}. Afforestation neither significantly affected the total organic C stocks nor their lability, keeping the C management index for the forested area similar to that in the NG treatment. The conversion from grassland to Acacia forest represents an effective option for mitigating the net reduction in greenhouse gas emissions, which is basically determined by C accumulation in biomass and wood products.

1. Introduction

The world area of grasslands, including rangeland and sown pasture, comprises approximately 70% of the world agricultural area, being one of the largest ecosystems in the world (Suttie et al., 2005). During the last decades, many of the well-watered grassland areas are being transformed into areas of farming and planted forestry, mainly in the East European Steppe, North American Prairie and South American Pampas (Suttie et al., 2005). The South American Pampas, or Campos, includes parts of Brazil, Paraguay, Argentina and Uruguay. Its dominant vegetation consists of grasslands with sparse shrub and tree formations, which have been used as a pasture source for extensive cattle grazing during the last three centuries. In the current millennium, significant grassland areas are being transformed into areas of planted forestry. In the Brazilian Pampa region, the number of acres with forestry practices in the state has increased by approximately 35 percent in the past seven years (ABRAF, 2013), and exotic species such as *Acacia* sp. and *Eucalyptus* sp. have been introduced.

Acacia mearnsii De Wild (Fabaceae, Mimosoideae, known as Black Wattle or Acacia) is originated from Australia and has been grown in many tropical and subtropical countries in southern Asia, Africa, Oceania and South America. In Brazil, Acacia has been grown in Brazil for tannin extraction, energy and manufacturing of pulp and paper (Barichello et al., 2005). This species possesses great potential for the improvement of the soil quality, contributing to the formation of the vegetative cover, the maintenance of the yield capacity, the replacement of nitrogen (N) and the increase of organic matter (SOM) stocks in the soil (Schumacher et al., 2003). The species fixes approximately 200 kg ha^{-1} yr^{-1} of atmospheric N

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(Auer and Silva, 1992). However, the effect of Acacia on the soil greenhouse gases (GHGs) flux is a gap.

Land use changes cause immediate changes in the chemical, physical and biological properties of the soil, modifying the flux of GHGs, mainly carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), between the soil and atmosphere (Dalal et al., 2008; Mosier, 1998; Kim and Kirschbaum, 2015). Studies indicate that planted forests usually improve the physical, chemical and biological conditions of the soil, thus obtaining greater aggregation, aeration and higher organic C and N stocks; this action ultimately improves biological aerobic activity, which is favorable to the influx of CH_4 (Allen et al., 2009; Lima et al., 2008; Tate et al., 2007; Werner et al., 2006). In addition to the larger aeration, forest plantation tends to decrease soil humidity and temperature, diminishing denitrification process in soil microsites and, subsequently, diminishing N_2O emission from soils under forestation (Konda et al., 2010). Well-drained soil conditions, low temperatures and low levels of mineral N encourage the influx of the gas in the soil (Allen et al., 2009; Werner et al., 2006; Kim and Kirschbaum, 2015). However, the use of leguminous tree such as Acacia favors the biological N fixation and can increase the input of N-rich litter on the soil. However, the effect of such deposition on soil mineral N contents, such as ammonium and nitrate, is not well known in Acacia plantations, as its vast root system can uptake quickly the mineralized N in the soil. Increases in nitrate and ammonium contents in the soil can accentuate the nitrification and denitrification processes, which are responsible for the emission of N_2O into the atmosphere (Inagaki and Ishizuka, 2011; Konda et al., 2010). Although forestation with leguminous trees is an ancient activity worldwide, few studies points out the effect of this change on the fluxes of CH_4 and N_2O from this practice. The understanding of GHG flux in soils with afforestation may contribute to the development of projects for the mitigation of global warming, thus minimizing the impacts arising from inadequate soil management. The opposite conversion, from secondary forest to grassland after a cycle of Acacia plantation, is also a gap. Although the conversion of forest to grassland usually increases N_2O and CH_4 emission from soil (Kim and Kirschbaum, 2015), such effect can be exacerbated in the case of leguminous forest species to grassland.

The objectives of this study were as follows: (i) to evaluate the afforestation with *A. mearnsii* De Wild in areas of native grassland in Pampa and its effects on the soil fluxes of CH_4 and N_2O; (ii) to investigate the soil variables that drive the soil fluxes of CH_4 and N_2O in this change of land use; (iii) to quantify the effect of afforestation on the soil total organic carbon (TOC) and total nitrogen (TN) stocks and on the TOC lability using the carbon management index (CMI) as the indicator of land use quality; and (iv) to estimate the net reduction in greenhouse gas emissions in forestation systems with *A. mearnsii* in Pampa compared to soils in native grassland systems.

2. Materials and methods

2.1. Study site

The study was conducted in the county of Vila Nova do Sul, Rio Grande do Sul state, Brazil (30° 22′ 37″ S, 53° 48′ 16″ W, 167 m), for 12 months beginning in September 2011. The region lies within the Pampa Gaúcho and has a subtropical climate, classified as Cfa according to the Köeppen classification system. The maximum temperature reaches 40 °C in summer and a minimum of −3 °C in winter. Rainfall is evenly distributed throughout the year, with a mean annual precipitation of 1500 mm. The soil is classified as a sandy loam Udept (Soil Taxonomy) or Cambissolo Háplico (Brazilian System of Soil Classification).

2.2. Experiment

The study was performed in four adjacent sites under different land uses, located in similar landscape positions with three replicates. The first treatment was an *A. mearnsii* forest (AM) that was six years old at the beginning of the study. At this location, we also analyzed an adjacent area where surface litter was manually removed 30 min before each sampling event (A–l) to verify the influence of the litter on the GHG fluxes. The third treatment was located at approximately 200 m from the AM and A–l sites, in which *A. mearnsii* had been harvested (AH) 30 days before the beginning of the experiment. An area of native grassland (NG) adjacent to the AH site was also studied and used as a reference for the other treatments. The mean content of clay, silt and sand for the 0–0.20 m in the evaluated sites were 100, 287 and 613 g kg^{-1} soil, respectively, and the mean soil bulk density was 1.40 g cm^{-3}. Please see the supplementary material for details regarding these attributes.

The forested and harvested areas received the same management practices during their planting and growing. The soil was plowed with a heavy disc harrow and a leveling harrow, followed by a subsoiling at an approximately 0.40 m depth only in the plant rows. Fertilization consisted of the application of 200 kg ha^{-1} natural phosphate (9% P_2O_5 soluble in water) in the plant rows. Seedlings were planted with a spacing of 3.0 by 1.5 m.

After Acacia harvesting in the A–I site, the soil of this area was left without any planting and therefore remained without vegetation cover for more than two months, until the natural restoration of vegetation and soil cover was effective; this occurred only from November 2011 to the end of the study. The NG area was isolated from the grazing area, and the grass was cut and removed manually when plant height was greater than 25 cm.

Local rainfall data of the evaluated period were obtained from the National Water Agency (ANA), for the Vila Nova Station (03053024), approximately 8 km from the study sites.

2.3. Air sampling and analysis

Air sampling for the quantification of CH_4 and N_2O occurred biweekly during one year using the static chamber system. Three rings for setting the chambers were inserted in the soil of each site, constituting the replicates. The rings, made of galvanized steel, remained in the soil throughout the period of the experiment and consisted of an inner ring inserted 0.05 m deep in the soil and an internal channel filled with water to seal the exchange of gases between the interior and exterior of the chamber. The PVC chambers measured 0.25 m diameter by 0.25 m height and were set only at the sampling events. Air mixing during the sampling was performed by a small fan inside the chambers (Gomes et al., 2009).

Air sampling always started at approximately 9 a.m., when the chambers were closed, and samples were taken at 0, 20 and 40 min after the closing using 20 mL syringes and three-way valves. During the sampling events, the temperature of the air inside the chambers and the soil temperature (0.05 m depth) were monitored. Air samples were stored in Exetainer® 12 mL bottles (Labco Ltd, High Wycombe, United Kingdom) until the analysis of CH_4 and N_2O contents, which was performed by a gas chromatograph Shimadzu Model GC2014 “Greenhouse”. The equipment uses N_2 as the carrier gas in a flux of 26 mL min^{-1} and an injector with a loop, set at 250 °C, for the direct sampling of 1 mL. Gas separation was performed by three packed columns at 70 °C, and detection was conducted by a flame ionization detector at 250 °C for CH_4 and an electron capture detector at 325 °C for N_2O. The CH_4 and N_2O concentrations were estimated based on the following equation: