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# Soil $N_2O$ emissions from long-term agroecosystems: Interactive effects of rainfall seasonality and crop rotation in the Brazilian Cerrado

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ABSTRACT

In its natural state, the Cerrado biome is a mitigator of soil emissions of nitrous oxide ($N_2O$). However, the integration of this biome in agricultural activities induced changes in nitrogen (N) dynamics, consequently increasing $N_2O$ emissions to the atmosphere. For one year, $N_2O$ emissions were evaluated under interactive effects of rainfall seasonality and crop rotation in 19-year-old agricultural ecosystems in the Cerrado. The agricultural systems included: (I) no-tillage soybean in the main and sorghum in the late growing season (NTR1); (II) no-tillage maize in the main and pigeon pea in the late growing season (NTR2); (III) soybean in the main and fallow in the late growing season under conventional tillage (CT); (IV) and native Cerrado (NC), as a reference environment. Measurements in a closed static chamber were carried out from October 2013 to September 2014 to determine the fluxes by gas chromatography. The $N_2O$ fluxes were related to the following soil and climate variables: nitrate ($NO_3^-$), ammonium ($NH_4^+$), soil temperature (Soil temp.), and water-filled pore space (WFPS). The annual $N_2O$ average fluxes of the agroecosystems ranged from zero to 266 $\mu g\,m^{-2}\,h^{-1}$. Fluxes were lowest in the native Cerrado, and in certain periods of the year, especially in the dry season, inflows were observed. The total annual cumulative fluxes from CT, NTR1 and NTR2 were: 1.36; 1.00 and 0.70 kg $N_2O$ $ha^{-1}$, respectively. In NC, the annual cumulative total was 0.27 kg $N_2O$ $ha^{-1}$. Under CT, $N_2O$ peaks were highest in the dry period, especially after soybean harvest, from fallow soil. Of the total cumulative emissions in CT, 50% were accumulated during the dry season and 75% during the fallow period, indicating that for the Cerrado with rainfall seasonality, monoculture soybean followed by fallow soil is not an appropriate crop rotation sequence. Among the different tillage systems, NTR2 had the lowest cumulative $N_2O$ emissions. This crop rotation is therefore indicated as the most efficient to mitigate $N_2O$, with emission peaks not exceeding 100 $\mu g\,m^{-2}\,h^{-1}$, while in NTR1, emissions in the rainy season reached almost 270 $\mu g\,m^{-2}\,h^{-1}$.



## 1. Introduction

The Cerrado (Brazilian savanna) covers more than 2 million $km^2$, equivalent to 24% of the national territory. Due to the outstanding species richness, this biome is considered as one of 34 global "hotspots of biodiversity" (Bustamante et al., 2012). Over the past four decades, nearly one million $km^2$, or 50% of the total Cerrado area, were converted into agricultural areas, mainly between 1990 and 2011 (Lapola et al., 2014; Bustamante et al., 2014). Approximately 60% of soybean and 48% of maize in Brazil are produced in agricultural areas in the Cerrado (Conab, 2015).

The rapid agricultural expansion in the Cerrado region has led to substantial changes in the biogeochemical cycles (Cruvinel et al., 2011). Among the changes already observed, resulting from chemical, physical and biological disturbances of the soil, changes in the nitrogen (N) dynamics are particularly relevant (Bustamante et al., 2012). One of the consequences of anthropogenic interference with the N dynamics, is the noticeable alteration in nitrous oxide ($N_2O$) emissions, one of the gases related to global climate change. The complex interactions between some practices of

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management systems and soil-climatic factors affect the rates of organic matter mineralization and can increase $N_2O$ emissions from agricultural soils to the atmosphere (Jerecki and Lal, 2006; Ussiri et al., 2009; Huang et al., 2015).

Recent research reports indicate that Cerrado under native vegetation is a biome that naturally mitigates $N_2O$ emissions (Martins et al., 2015). Explanations for this behavior of the Cerrado are the good drainability and aeration of the soil (Martins et al., 2015), the composition and abundance of denitrifying microbial communities (Lammel et al., 2015), the high soil acidity, and the occurrence of dry spells during the growing season, aside from a well-defined dry season (Davidson et al., 2001). The Latosols of the Cerrado generally have lower N levels and nitrification rates, which also contributes to the low $N_2O$ fluxes of these soils (Nardoto and Bustamante 2003; Carvalho et al., 2006; Chapuis-Lardy et al., 2007; Cruvinel et al., 2011; Martins et al., 2015). However, as already mentioned, soil managements can change the soil properties and gas exchange of ecosystems drastically (Castaldi et al., 2006).

Among the agricultural practices that affect $N_2O$ emissions, soil tillage is already well-known, altering the structure and aeration as well as oxygen concentration (Butterbach-Bahl et al., 2013), the deposition and incorporation of organic residues (Ball et al., 2014), which accelerate the decomposition and N mineralization processes, according to the chemical composition of plant residues (Carvalho et al., 2012). In addition, variables such as the phenological stage of the crop (Hayashi et al., 2015), acidity and fertility levels, air and soil temperature (Butterbach-Bahl et al., 2013), the application of mineral nitrogen fertilizers, and soil moisture also affect $N_2O$ emissions (Martins et al., 2015; Soares et al., 2015; Pimentel et al., 2015). This influence is a result of the changes in nitrification and denitrification reactions, responsible for $N_2O$ formation in soils (Tatti et al., 2014). In Latin America, Brazil is the largest emitter of this gas (Bustamante et al., 2014) and the main source of Brazilian $N_2O$ emissions are agricultural soils, which account for 64% of the direct total emissions (MCTI, 2014).

Despite the large number of studies in recent years on the effects of management systems on soil $N_2O$ emissions, research results about the emission/mitigation potential of no-tillage (NT) and conventional (CT) systems are still divergent (Abdalla et al., 2014). Some studies report higher emissions from NT than CT (Liu et al., 2007; Escobar et al., 2010; Siqueira Neto et al., 2011), while others highlight the mitigating potential of the former (Boddey et al., 2010; Alves et al., 2010). In NT systems, crop rotations with deposition or incorporation of organic residues (legumes/grasses), under ideal conditions of soil moisture and temperature and the formation of soluble organic compounds in different periods are considered promising for a reduction in $N_2O$ emissions from agricultural soils (Dyer et al., 2012; Abdalla et al., 2014; Huang et al., 2015). However, the understanding of the interaction between NT practices with grass- and legume-based crop rotations, as observed in southern Brazil (Bayer et al., 2014) and abroad (Liu et al., 2014), is complex and poorly understood, mainly because this interaction is controlled by environmental factors (Escobar et al., 2010; Pimentel et al., 2015).

In this way, since most studies on the combined effects of the cited practices on soil $N_2O$ emissions were carried out under other soil and climatic conditions, mainly in humid climate regions and for only one growing season (Chen et al., 2008), little is known about these interactive effects under rainfed conditions in the Brazilian Cerrado. Additionally, the monitoring of a complete crop rotation cycle is also important to determine the quantitative response of each management systems in terms of cumulative $N_2O$ emission per grain produced as well as the partial global warming potential (pGWP) (Pramanik et al., 2014; Bayer et al., 2015). According to the latest Brazilian Panel on Climate Change (MCTI, 2014), the available $N_2O$ emission data are still insufficient to allow a low-uncertainty determination of emissions from agricultural systems, due to the wide diversity of environments in Brazil.

Aside from these effects of soil management, the duration of the rainy season has a strong influence, which lasts for six months, from October to March in the Cerrado, when 90% of the precipitation falls (Klink and Machado, 2005). The Cerrado has well-defined seasons, which influence nitrification and denitrification reactions, mainly when sporadic rainfalls occur that rewet the soil after dry spells. The variability of rainfall in an agricultural year may affect $N_2O$ emissions by stimulating the mineralization of soil organic matter, promoting nitrate accumulation in dry periods and favoring $N_2O$ emissions in the rainy season (Liu et al., 2014).

This effect of rainfall seasonality of the Cerrado on $N_2O$ emissions has already been described by other authors (Alves et al., 2010; Martins et al., 2015), although in an isolated manner, without taking the interactive effects of seasons, management systems and crop rotations of long-term agroecosystems into consideration. Interactions which can lead to $N_2O$ peaks of different magnitudes in agroecosystems, are complex to understand and can vary greatly, depending on the season and period (Sommer et al., 2015). Therefore, our objective was to evaluate $N_2O$ emissions for one year under the interactive influence of seasonal rainfall and crop rotation in 19-year-old agricultural ecosystems in the Cerrado.

## 2. Material and methods

### 2.1. Local climate and soil characteristics

The study was conducted for one year, from October 2013 to September 2014, in the experimental area of Embrapa Cerrados in the municipality of Planaltina, DF, Brazil (15°33′33.99″ S, 47°44′12.32″ W, altitude 1035 m asl). The climate is seasonal, classified as tropical rainy Aw (Köppen), with two well-defined seasons: rainy summers, from October to March, corresponding to the rainy season, and dry winters, from April to September, corresponding to the dry period. The interval from October to March was considered as rainy season, since in the mean, 90% of the rainfall is concentrated in this period (Silva et al., 2014), and the other months as dry season. The mean annual rainfall (1974–2003) in Planaltina was 1346 mm, the air temperature between 16.5 °C and 27.7 °C and relative air humidity between 37.6% and 97.7% (Silva et al., 2014), according to the Climatological Standard Normals (Fig. 1a). The rainfall, mean air temperature and monthly relative air humidity of the study period are listed in Fig. 1b.

The soil of the experimental area was classified as a clayey Oxisol (Typic Haplustox) (Soil Survey Staff, 2006). The soil chemical and physical properties (0–20 cm) are shown in Table 1. According to the description of the mineralogical composition of Reatto et al. (2007), the diagnostic horizon consists of: kaolinite (320 g $kg^{-1}$), gibbsite (496 g $kg^{-1}$), hematite (142 g $kg^{-1}$), and goethite (42 g $kg^{-1}$).

### 2.2. History and description of the experiment

The long-term experiment for this study had been initiated 19 years earlier, in 1996. The plots (22 m × 18 m) were arranged in a randomized block design, with three replications. After cutting the natural Cerrado vegetation in 1995/1996, the soil of all plots was tilled with a disk plow for liming and with a moldboard plow for incorporation of organic residues into deeper layers; differences between the management systems established on this soil were only detected five years after tillage. For this study, two management systems (no-tillage, and conventional tillage) and a reference treatment in the area of dense Cerrado *sensu stricto* were selected (Table 2).