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Nitrous oxide and ammonia emissions from N fertilization of maize crop under no-till in a Cerrado soil

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ABSTRACT

The low natural fertility of Oxisols in the Cerrado region makes some crops in this region very dependent on high rates of synthetic N-fertilizers, which are of growing environmental concern as a major source of N_2O emissions in agriculture. In a field experiment, we quantified direct N_2O emissions and NH_3 volatilization (a source of indirect N_2O emissions) from surface-applied N fertilizer on a no-till maize (*Zea mays* L.) crop in Cerrado biome. We used four fertilizers at the rate of 120 kg N ha^{-1} as topdress-N (V4–V6 growth stage), which were regular urea, urea + zeolite, calcium nitrate and ammonium sulfate, and a non-topdressed control. The total N losses as volatilized NH_3 ranged from 2.2% (calcium nitrate) to 4.5% (urea + zeolite). The N loss as volatilized NH_3 from urea was very low (3.2%), with no significant difference between urea + zeolite, ammonium sulfate and calcium nitrate. Significantly, higher cumulated N_2O emissions were observed with ammonium sulfate than with the control. No significant differences among fertilizers were found for emission factor (EF), which was 0.20% on average (0.14–0.26%), indicating that use of IPCC default EF (1.00%) would substantially overestimate N_2O emission. Free drainage and acidity of Oxisols and occurrence of dry spells, known as '*veranicos*', are characteristics of Cerrado biome that may naturally mitigate N_2O emissions.

1. Introduction

The Cerrado is the second largest biome in Brazil and the largest tropical savanna in America, representing 2 million km^2 (IBGE, 2014), of which almost half exists on Oxisols (EMBRAPA, 2006). This biome is the most important for Brazilian agriculture because of the 1.1 million km^2 of soils considered legally apt for expansion of agriculture, 72% are located in Cerrado region (Coelho, 2011). However, the low natural fertility of Oxisols in Cerrado makes most crops in this region very dependent on high rates of synthetic fertilizers, including those containing N (Lopes, 1996).

The increasing use of N-fertilizers is of growing environmental concern, since they are a major source of nitrous oxide (N_2O) emissions in agriculture (Klein et al., 2007). Nitrous oxide is a greenhouse gas (GHG) that has a half-life of 131 years (Hartmann et al., 2013) and also causes depletion in the ozone layer in atmosphere (Ravishankara et al., 2009). This has direct implications for global GHG emissions in Brazil, which, as a signatory of the Copenhagen Accord, has committed to cut by 36.1–38.9% of GHG emissions considering the projected levels in 2020 (Lau et al., 2012). Since agriculture is one of the most important economic sectors in Brazil, it is essential to adopt specific measures aimed at mitigating emissions associated with agricultural activity, such as choosing N-fertilizers that emit as little as possible N_2O. Moreover, there is a need of more precise estimates for tropical regions of the fraction of fertilizer-N emitted as N_2O, *i.e.*, emission factors (EF), which are a basic parameter for developing national inventories of GHG emissions.

The lack of available data to provide appropriate country-specific emission factors (direct and indirect N_2O emissions) is one of the main uncertainties in developing of GHG inventories (Klein et al., 2007). Obtaining these data is an indispensable step for Brazil towards the use of Tier 2 IPCC equations with country-specific EFs instead of Tier 1 equations with default EFs, thus improving the precision of N_2O emissions in its national inventory. According to IPCC guidelines, the default EF for N application of mineral fertilizers is 1.00% for direct N_2O emissions with an uncertainty range of 0.30–3.00%. However, some field studies have shown that

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these IPCC default values are overestimated for Brazil, including those for the Cerrado region (Davidson et al., 2001; Metay et al., 2007; Jantalia et al., 2008).

Nitrous oxide emission from N-fertilizers occurs directly (nitrification and denitrification) and indirectly. The indirect pathways of N_2O emission involve off-site emissions after N losses by NH_3 volatilization, leaching, runoff and harvest of crops (Nevison, 2000). It is estimated that indirect N_2O emissions account for approximately one-third of the agricultural N_2O source (Mosier et al., 1998). In the Cerrado biome, there are uncertainties on the direct and indirect N_2O emissions, which come from (i) the occurrence of dry spells from one to three weeks during the peak rainy season, locally called "*veranico*" (Kornelius et al., 1979); (ii) the typical occurrence of well drained and aerated soils in Cerrado (Bustamante et al., 2009); (iii) the increase of no-till area with placement of fertilizers on the soil surface in contact with undecomposed plant residues; and (iv) the possible use of different types of N fertilizer.

The N fertilizer most widely applied in Brazil is urea (ANDA, 2011), owing to its high N content, which reduces its transportation cost, as well as its relatively simple production by fertilizer industry (Cantarella and Marcelino, 2007). However, the use of this N source can result in high N losses by NH_3 volatilization associated with urease activity, representing an economic loss and considerable environmental concern (Fenn and Hossner, 1985; Soares et al., 2012). Use of N sources other than urea, such as some ammonium or nitrate salts, or modified forms of urea, may represent alternatives favoring increased N-use efficiency and/or mitigation of direct and indirect N_2O emissions. For instance, the use of NO_3^--based fertilizers, such as calcium nitrate, can reduce ammonia volatilization, but their greater susceptibility to denitrification may lead to increased emissions of N_2O (Harrison and Webb, 2001). Another possible technology for mitigating direct and indirect N_2O emission is the use of finely ground zeolites added to urea during fabrication of the granules. Zeolites are negatively charged alumino-silicates which can sorb NH_4^+, reducing N-NH_3 loss by volatilization (Kithome et al., 1999; Werneck et al., 2012). The use of zeolite as soil amendment is considered as a strategy to reduce N_2O emissions from soil (Zaman and Nguyen, 2010).

Our aim was to quantify, under field condition, the N losses by N_2O emissions (direct losses) and NH_3 volatilization (a source for indirect losses) after broadcasting of fertilizers in an Oxisol cultivated with maize (*Zea mays* L.) under a no-till system in Cerrado biome.

2. Material and methods

The field experiment was conducted in the 2012–2013 cropping season in Luis Eduardo Magalhães, a municipality located in the extreme west of the State of Bahia, Brazil, within the ecosystem of the Cerrado biome (12°00′S, 46°03′W and altitude of 844 m). More specifically, the predominant vegetation in the region, considering the canopy cover, is Cerrado *sensu stricto* (typical scrubland with small trees). Climatologically, the area belongs to the tropical megathermal zone, or Köppen's Aw (a tropical climate with a dry winter and an average temperature of the coldest month >18 °C). The mean annual rainfall from 2008 to 2013 in the area was 1473 mm, with an annual distribution that peaks in the period from October to March and a severe dry season in the period from April to September.

The soil in the experimental area is an Oxisol (Xanthic Hapludox) based on the U.S. Soil Taxonomy (Soil Survey Staff, 2010). This area has been used for twenty years for commercial production of maize and soybean [*Glycine max* (L.) Merr.] in rotation since substitution of the Cerrado vegetation by agriculture. No-till was adopted eleven years before the field experiment. Soybean was the crop in the year before the experiment with maize. Physical and chemical soil properties are shown in Table 1.

Three months before establishing the experiment, phosphorus was applied as single superphosphate at 35 kg P ha^{-1}. Maize was mechanically sown on December 4, 2012. Ammonium sulfate was applied as banded starter fertilizer (40 kg N ha^{-1}) placed below and to the side of the seed position. Potassium (125 kg K ha^{-1}) was broadcast 13 days after sowing as potassium chloride.

The experimental treatments consisted of four different N-fertilizers broadcast on the soil surface at the V4-V6 growth stage of the maize and one control without N fertilizer at this time. The N-fertilizers were (i) regular urea, (ii) urea granulated with powdered zeolite in mass proportion of 4:1 (urea + zeolite), (iii) calcium nitrate and (v) ammonium sulfate. The N fertilizers were broadcast 15 days after sowing (DAS) at a rate of 120 kg N ha^{-1}. A randomized complete-block design with 6 replicates was used. Each plot was 10.0 m long by 5.6 m wide, considering 1.0 m of the extremities as borders. A row spacing of 0.70 m and 5 plants m^{-1} was used.

After application of the N-fertilizers, the plots received semi-open chambers for NH_3 volatilization measurement. The detailed description and validation of these chambers using ^{15}N recovery technique was reported in studies conducted by Araújo et al. (2009) and Jantalia et al. (2012). Briefly, the chamber consists of transparent polyethylene terephthalate bottle (carbonated soft-drink bottle 2 L) with the bottom removed, which is subsequently fixed on the top of the bottle. Inside each chamber, there was a 250 mm long wire designated to support a foam strip (2.5 cm × 25 cm, 3 mm thick) presoaked in acid solution and a plastic pot (60 mL) that contained the acid solution to keep a foam strip moist during sampling periods.

The chambers were placed in two positions considering the rows of maize plants. One chamber was located in the row of plants, *i.e.*, right beside two plants in the same row, and the second chamber was positioned in the center of the space between two rows of plants, *i.e.*, 35 cm from the stems. To ensure a better homogeneity of broadcasting of the fertilizers in the location of chambers, an area of 2.0 m long × 1.4 m wide was reserved inside each plot to receive a corresponding amount of fertilizer, which was very carefully spread to guarantee the uniformity of granules in soil surface. The foam strips were replaced 1, 2, 3, 5, 7, 10, 13, 17, 21, 25, 30 and 37 days after N-fertilization. The collected foam strips were transported inside the plastic pots to the laboratory and were then carefully transferred to Erlenmeyers flasks by rinsing the plastic pots with 40 mL of deionized water. The Erlermeyer flasks were shaken for 20 min at 220 rpm on an orbital shaker. After that, the content was transferred to 100 mL volumetric flasks with careful washing of the foams and the flasks completed to 100 mL. An 10 mL aliquot of this solution was used for analysis of NH_4^+ by steam distillation (Keeney and Nelson, 1982). The amount of N recovered in this analysis was multiplied by a factor of 1.47 calculated considering the efficiency of chambers, calibrated with the ^{15}N technique (Jantalia et al., 2012).

Table 1
Physical and chemical properties of a Xanthic Hapludox under no-till system from Bahia State, Brazil.

Property	0–10 cm	10–20 cm
Sand (g kg^{-1})	737	754
Silt (g kg^{-1})	49	28
Clay (g kg^{-1})	214	218
Bulk density (g cm^{-3})	1.41	1.48
pH (H_2O)	5.2	5.1
Organic C (g kg^{-1})	6.4	4.2
Total N (g kg^{-1})	0.2	0.2