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To burn or not to burn: The question of straw burning and nitrogen fertilization effect on nitrous oxide emissions in sugarcane

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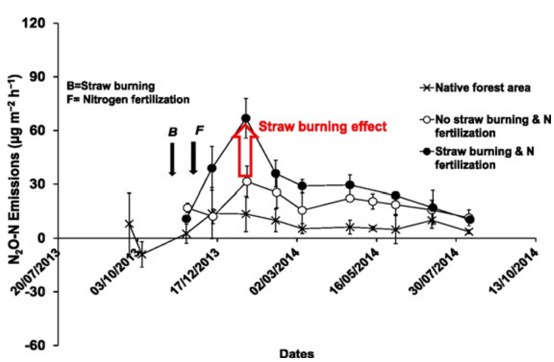
HIGHLIGHTS

- N_2O emissions due to straw burning and N fertilization in sugarcane
- A native forest area adjacent to the sugarcane as reference evidenced the rainfall and temperature influence on N_2O emission.
- The effect of N fertilization on N_2O emission was much higher when straw was burned.
- N_2O emission factor of the N applied was lower than the IPCC factor (0.73 vs 1.25%).
- Avoiding straw burning while adjusting N fertilizer would mitigate N_2O emissions.

GRAPHICAL ABSTRACT



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ABSTRACT

Nitrous oxide (N_2O) is the main greenhouse gas emitted from farming systems and is associated with nitrogen (N) fertilizer application as well as decomposition of organic matter present in the environment. The objective of this study was to determine the effect of post-harvest straw burning and synthetic N fertilization on the dynamics of N_2O emissions in the sugarcane-soil system in Tucuman, Argentina, compared with a native forest. Close-vented chambers were used to capture N_2O during three consecutive growing seasons. The highest N_2O emissions from the sugarcane-soil system coincided with the period of high soil and air temperatures, rainfall and soil N content. The effect of synthetic N fertilization on annual cumulative N_2O emission was 7.4–61.5% higher in straw burned than in unburned treatments, especially during a wet growing season. There was a significant effect of treatments on N_2O emission factors among growing seasons: 0.58–1.67% and 0.94–3.34% in the unburnt and burnt treatments, respectively. The emission factors for sugarcane are highly dependent on rainfall, temperature and crop management practices; regarding the latter, avoiding straw burning and reducing N soil availability, assessing alternative N fertilizers or new application modes such as split rates, seem to be the key for mitigating N_2O emissions from the sugarcane-soil system in Tucumán, Argentina.

1. Introduction

Greenhouse gas (GHG) emissions have increased since the Industrial Revolution due to anthropogenic action (IPCC, 1996), with agriculture

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being one of the most important sources, contributing 12–14% of the total human-generated GHGs (IPCC, 2006). Gas exchange between soil and the atmosphere contributes to GHG increment, leading to global climate change (Bouwman, 1990). Nitrous oxide (N_2O) is the main GHG emitted by farming systems (IPCC, 2007). N_2O emissions in agriculture are associated with nitrogen (N) fertilizer application (Bouwman, 1996; De Klein et al., 2006; Eichner, 1990) and decomposition of organic matter present in the environment (Aulakh et al., 1984; Vinther et al., 2004). N_2O emissions are often limited by soil N availability, which in turn is affected by physical, chemical, biochemical and microbiological soil parameters (Butterbach-Bahl et al., 2013; Carter and Rennie, 1982); hence, environmental conditions have a direct effect on N_2O exchange between soil and the atmosphere.

In Argentina, 27.8% of anthropogenic GHG emissions are from the agricultural and feedstock sector, which is responsible for 16.3% of anthropogenic N_2O emissions (Secretaría de Ambiente y Desarrollo Sustentable de la Nación, 2015), and N_2O emissions from agricultural soils have increased since 1992 in Argentina, as a consequence of a consistently increasing use of N fertilizers and decomposition of crop residues, since only sugarcane and cotton residues are burnt (Secretaría de Ambiente y Desarrollo Sustentable de la Nación, 2015). However, these estimations were based on default emission factors proposed by the Intergovernmental Panel on Climate Change (IPCC), and may not reflect the specific conditions of the agricultural sector in northern Argentina. Therefore, quantifying N_2O emissions from croplands through field studies that obtain specific emission factors will be useful for identifying regional hotspots and developing strategies to mitigate GHG emissions from agricultural systems.

Sugarcane (*Saccharum* spp.) is a high-biomass crop and requires a substantial amount of N to achieve maximum yields (Wiedenfeld, 1995), ranking second in the rate of fertilizers used for crop production (216 kg ha^{-1}) compared with the mean rate of 109 kg ha^{-1} for other crops worldwide (FAO, 2006). In the main sugarcane area of Argentina, Tucumán province, 17% of total CO_2eq. ha^{-1} $year^{-1}$ emitted during the agricultural stage was found to be originated from N_2O from N fertilization (Acreche and Valeiro, 2013). De Oliveira et al. (2013) also reported increased N_2O emissions from the application of vinasse with respect to an unfertilized control. In a review, Lisboa et al. (2011) reported that 40 and 17% of the total GHG emissions from the ethanol-sugarcane production system derive from N fertilization and trash burning, respectively. In fact, the advantages gained by replacing fossil fuels with bioethanol in terms of GHG emissions N_2O emissions can be offset by the effects of N fertilization in sugarcane production (Otto et al., 2016). If sugarcane-based biofuel production is a viable option to reduce energy-related GHG emissions, further knowledge regarding GHG sources related to agricultural management during sugarcane production is still needed (Lisboa et al., 2011).

The sugarcane cycle in Argentina consists of five to six cuts, corresponding to one annual plant cycle plus four to five annual ratoon cycles. Generally, most of leaves and tops are burnt in the field before and/or after harvest, whereas stalks (cane) are machine-harvested and transported to the mills for juice extraction, usually by crushing. If harvested without previous burning (current trend in Argentina), sugarcane leaves important amounts of straw (crop residues) in the field. In Tucumán, 5–8 Mg ha^{-1} (dry matter) of crop residues are left in the field (Sopena et al., 2006). Despite the legal restriction, straw burning -as in many sugarcane producing countries- frequently occurs in Argentina, either accidentally or to facilitate harvest process or – more frequently – to avoid difficulties in the following soil labors (Digonzelli et al., 2006; Scandaliaris et al., 2002). In Argentina, sugarcane straw burning contributes over 30% of total GHG emissions during the agricultural stage is the second main factor after gas oil use influencing the final GHG balance of the sugarcane industry (Acreche et al., 2013). In Brazil, it represents 98% of the total agricultural burning activities (Lima et al., 1999). Besides increasing soil C storage due to organic matter addition (Kern and Johnson, 1993), the presence of straw on the soil surface increases N_2O emissions (Acreche et al., 2013; do Carmo et al., 2013; de Oliveira et al., 2013; Weier, 1996). Thus, there are controversial results reporting the emissions of GHG from straw burnt or left in the field.

Although an expansion of the sugarcane cultivated area over native forests is uncertain, the impact of this land use change on N_2O emissions is unknown. To the best of our knowledge, no study exploring the combined effect of straw burning and synthetic N fertilization on long-term N_2O emissions from the system has been conducted, having an uncultivated system (native forest) as reference. Moreover, the scarcity of information with direct field measurements of N_2O emissions from sugarcane in Argentina and the growing demand for biofuels highlight the need for field measurements of N_2O emissions from sugarcane in Tucuman, the main crop area of Argentina. This may enable the industry to better compete in the international biofuel market.

The objectives of this study were: i) to determine the effect of post-harvest straw burning and synthetic N fertilization on the dynamics of N_2O emissions in the sugarcane-soil system in Tucuman, Argentina; ii) to obtain emission factors for sugarcane under different crop residues and synthetic N fertilization management practices, having a native forest as reference; iii) to establish if N_2O emissions in this environment are correlated with physical, chemical and microbiological environmental variables.

For this, a field experiment was carried out during three consecutive crop cycles. Our results will provide baseline information for upgrading the Argentinean GHG inventory and will help improve the understanding of the dynamics of N_2O emissions from sugarcane soils, compared to an almost unaltered native forest area.

2. Materials and methods

2.1. Location and description of the study area

The study area was located in the province of Tucumán, northwestern Argentina. The experiment was conducted in the Famaillá Experimental Station of the National Institute of Agricultural Technology (27°°03′ S, 65°°25′ W, 363 m a.s.l.) during the 2012–2013, 2013–2014 and 2014–2015 growing seasons. The soil is classified as Aquic Argiudoll characterized as silty loam with soil organic carbon content (SOC) and soil N content (SON) in the top 20 cm of 1.5 and 0.14%, respectively, and with a pH of 5.9. The climate is humid with a mean temperature in the warmest and coldest months of 25.2 and 12.2 °C (January and July), respectively; and an average annual rainfall of 1324 mm, concentrated from November to April. Meteorological data for the study period was obtained from a meteorological station located near the experiment site.

2.2. Experimental design and treatments

The experimental area was cultivated with the variety LCP 85-384, which covers >80% of the sugarcane area of Tucumán (Digonzelli, 2015). The crop was harvested mechanically; after each harvest, the following treatments were applied:

i) straw burning and N fertilization
ii) straw burning and no N fertilization
iii) no straw burning and N fertilization
iv) no straw burning and no N fertilization

Each sugarcane plot consisted of six 100-m long rows, with 1.60 m row spacing.

The experimental design was in a strip plot with three pseudo-replicates to comply with legal restrictions (Hurlbert, 1984). Treatments were planted over an area with similar topographic and edapho-climatic conditions. Soil N_2O fluxes may vary significantly over space and time, usually exceeding 100% within a few meters (Butterbach-Bahl et al., 2011; Parkin and Venterea, 2010; Davidson et al., 2000; Verchot et al.,