



Effects of urea formulations, application rates and crop residue retention on N₂O emissions from sugarcane fields in Australia



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ABSTRACT

High fertiliser nitrogen (N) application rates, crop residue (trash) retention and the wet and warm climatic conditions in sugarcane (*Saccharum officinarum*) cropping may favour nitrous oxide (N₂O) production in soil. We measured N₂O emissions from a silty clay loam with high organic carbon content (98 g kg⁻¹) in northern New South Wales (NSW) and a sandy loam with moderate organic carbon content (16 g kg⁻¹) in central Queensland (QLD), Australia, to quantify whole season emissions under different N management regimes. High N₂O emissions occurred mostly in the first 4–6 months following N fertiliser application (October–March) around the summer season. At farmers' fertiliser application rates (160 or 150 kg N ha⁻¹ as urea), annual N₂O emissions reached 28.2 and 3.6 kg N₂O–N ha⁻¹, and the emission factors of fertiliser N were 10.0% and 1.32% in NSW and QLD, respectively. Under 80 kg urea–N ha⁻¹, the annual emissions decreased to 23.2 and 2.6 kg N₂O–N ha⁻¹ at the NSW and QLD sites, respectively. Emissions of N₂O following polymer-coated urea application decreased by ~31% at the NSW site but increased by 50% at the well-drained QLD site compared to conventional urea. Application of urea coated with the nitrification inhibitor 3,4-dimethylpyrozole phosphate (DMPP) decreased N₂O emissions from the fertilised area by ~36% but this reduction did not translate into statistically significant effects on the plot-scale emissions at the NSW site. DMPP did not significantly reduce annual N₂O emissions at the QLD site. Removal of cane trash from the soil surface decreased N₂O emissions by 24–30%, demonstrating the promoting effects of trash retention on N₂O emissions. We conclude that minimising fertiliser N application rates provides a consistently effective option for reducing N₂O emissions from sugarcane farms but the efficacy of polymer- or DMPP-coated urea varies with soil and climatic conditions.

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1. Introduction

Nitrous oxide (N₂O) is a greenhouse gas with a global warming potential of 298 times that of carbon dioxide over a 100-year time horizon. It is also the dominant ozone depleter in the stratosphere (Ravishankara et al., 2009). The agricultural sector contributes about 74% and 80% of all anthropogenic N₂O emissions in Australia (Department of Environment, 2014) and in the world (IPCC, 2014; FAO, 2015), respectively. Sources of N₂O in agriculture include soil (through amendment of nitrogenous fertilisers, manures and crop residues), manure management and biomass burning, with soil accounting for about 88% of the sector-wide emissions (FAO, 2015). The increase in nitrogen (N) fertiliser application rates in recent

decades is the major factor contributing to the accelerated N₂O emissions from agricultural soils (Dalal et al., 2003) and is recognised as the largest contributor to increases in atmospheric N₂O (Park et al., 2012).

About 27 million ha of sugarcane (*Saccharum officinarum* L.) crops are harvested in the world each year (FAO, 2015). Sugarcane farms generally receive large amounts of N fertiliser, up to 300 kg N ha⁻¹ yr⁻¹ with the recommended application rates approximately between 100 and 200 kg N ha⁻¹ yr⁻¹ for ratoon crops (Muchovej and Newman, 2004). In Australia, the average N application rate for sugarcane is about 161 kg N ha⁻¹ yr⁻¹ (Department of Environment, 2015). Combined with the wet and warm climate and the increasing adoption of cane trash (crop residues after harvest) retention, sugarcane cropping soils provide conditions that usually favour N₂O production. On a sugarcane farm adjacent to one of the present study sites in northern New South Wales (NSW) of Australia, Denmead et al. (2010) recorded an annual emission as high as 45.9 kg N₂O–N ha⁻¹ using

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micrometeorology methods. In a Brazilian sugarcane cropping system, Signor et al. (2013) observed that cumulative N₂O emissions over 50 days after fertilisation at 60–180 kg N ha⁻¹ ranged from 2.6 to 8.9 kg N₂O–N ha⁻¹ following urea application and from 1.4 to 24.2 kg N₂O–N ha⁻¹ for the ammonium nitrate treatments. However, contribution of sugarcane farming to the global greenhouse gas inventory remains uncertain due to a lack of whole cropping season measurements with adequate sampling frequencies.

Emissions of N₂O from soil can be reduced by adopting improved management practices, such as optimisation of fertiliser application techniques (with right rates, timing and placement), use of a nitrification inhibitor (NI) or controlled-release fertiliser, and crop residue management (Dalal et al., 2003; Snyder et al., 2009). A meta-analysis by Akiyama et al. (2010) indicated that N₂O emissions could be reduced, on average, by 38% using NI-treated fertilisers and by 35% using polymer-coated fertilisers compared to conventional fertilisers. However, the effectiveness of these “enhanced efficiency fertilisers” may vary substantially with climatic conditions, soil properties and land use types. Studies in a Brazilian sugarcane cropping system demonstrated that addition of NIs to urea reduced N₂O emissions by 80–100% in two consecutive cropping seasons, whereas polymer and sulphur-coated urea tended to increase N₂O emissions (Soares et al., 2015). As the ecological conditions and management practices in sugarcane cropping systems often differ significantly from those in other cropping systems and between different regions, further assessment of the above mentioned mitigation options would help develop effective low-emission strategies suitable for the region.

One of the major management changes in the sugarcane industry in recent decades is the increasing adoption of green cane trash blanketing (GCTB). With this practice, sugarcane is harvested green and the cane trash is left over the ground in a thick layer of mulch. GCTB has been adopted on approximately 75% of Australian sugarcane farms. Compared to pre- or post-harvest burning of cane trash, GCTB has a number of advantages including operational convenience, protection of soil from erosion, soil water retention, weed suppression, nutrient and soil health benefits, and reduction in herbicide use. While there have been numerous studies on N₂O emissions in response to different plant residue management practices in other cropping systems (Wang et al., 2011; Muhammad et al., 2011), the effects of GCTB on N₂O emissions during the whole cropping season remain to be investigated.

In this paper, we present the results of a study on N₂O emissions in two Australian sugarcane production regions where soil properties, climate conditions and cane trash management

practices differed substantially. The main objectives were to quantify whole cropping season N₂O emissions and to examine the efficacy of different N fertiliser formulations, application rates and trash management for mitigating N₂O emissions from sugarcane cropping systems.

2. Materials and methods

2.1. The experimental sites

Two field experiments were conducted in two consecutive years. Experiment I was located on an estuarine floodplain (28°20'S, 153°24'E) close to the township of Murwillumbah in northern NSW, Australia. Annual mean temperature of the region in the last 38 years was 20.2 °C, with the lowest monthly mean temperature in July (14.8 °C) and the highest in January (24.7 °C). Mean annual rainfall was 1585 mm, with about 50% received from December to March. Sugarcane had been grown on the farm for at least 10 years, with pre-harvest burning. The field trial was in a paddock of first ratoon cane (regrown cane from the stubble of the previous harvested crop) planted in 2004 with a row spacing of 1.5 m. Limestone was applied 5 t ha⁻¹ before planting. In addition to about 130 kg N ha⁻¹ as urea, a mixed fertiliser containing 8.5% N as urea, 9.4% P as superphosphate and 26.5% K as KCl was applied at 200 kg ha⁻¹ at planting. The preceding plant cane crop was burnt and harvested in early October 2005 with the trash (2.9 t ha⁻¹ containing 19 kg N ha⁻¹) retained on the soil surface. The soil was a Hydrosol in Australian soil classification (Isbell, 2002) or Gleysol in the World Reference Base (WRB) classification (IUSS Working Group WRB, 2014) with evident acid sulphate soil features below the top 20–30 cm layer. Water drainage trenches were constructed around the site to prevent prolonged inundation during the high rainfall seasons. The water table was usually 0.5–0.7 m below the soil surface. The top 30 cm soil was silty clay loam. Key soil physical and chemical properties are given in Table 1.

Experiment II was located on a sugarcane farm near Mackay (21°09'S, 149°07'E) in Queensland (QLD), Australia. Mean annual temperature in this area is 22.3 °C, with the lowest mean monthly temperature in July (16.8 °C) and the highest in January (26.4 °C). Mean annual rainfall is 1665 mm, about 70% of which is received from December to March. The soil is classified as Kandosol in Australian classification (Isbell, 2002) or Lixisol in the WRB classification (IUSS Working Group WRB, 2014), with a texture marginal between sandy loam and loam in the top 30 cm. Basic soil properties are given in Table 1. The cane was a fifth ratoon (cv. Q135) planted in 2001 with a row spacing of 1.5 m. Tillage to

Table 1
Soil physico-chemical properties and mineral nitrogen (NH₄⁺ and NO₃⁻) contents at commencement of the experiments.

| Depth (cm) | Sand ^a (%) | Silt ^a (%) | Clay ^a (%) | BD ^{b,c} (g cm ⁻³) | TOC ^d (g kg ⁻¹) | TN ^e (g kg ⁻¹) | pH ^f | NH ₄ ⁺ -N ^c (mg kg ⁻¹) | NO ₃ ⁻ -N ^c (mg kg ⁻¹) |
|--------------|--------------------------|--------------------------|--------------------------|--|---|--|-----------------|--|--|
| The NSW site | | | | | | | | | |
| 0–10 | 24 | 40 | 36 | 0.76/0.85 | 97.8 | 6.4 | 4.9 | 1.9/1.5 | 25.0/12.9 |
| 10–20 | 31 | 35 | 34 | 0.79/0.81 | 98.7 | 6.4 | 4.4 | 2.1/2.0 | 26.8/16.3 |
| 20–30 | 33 | 35 | 32 | 0.77/0.91 | 97.0 | 6.5 | 4.0 | 2.2/1.9 | 25.7/14.0 |
| The QLD site | | | | | | | | | |
| 0–10 | 74 | 12 | 14 | 1.13/1.47 | 16.3 | 0.7 | 4.8 | 6.7/2.0 | 7.7/4.4 |
| 10–20 | 72 | 12 | 16 | 1.35/1.54 | 13.5 | 0.6 | 4.7 | 4.5/1.6 | 5.8/3.8 |
| 20–30 | 73 | 11 | 16 | ND | 13.6 | 0.6 | 4.7 | 1.4/0.2 | 2.6/2.2 |

^a International classification: sand 20–2000 μm; silt 2–20 μm; clay < 2 μm.

^b Bulk density; ND, not determined.

^c Bed/furrow.

^d Total organic carbon.

^e Total nitrogen.

^f Soil to water ratio 1:5.

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