The role of nitrification inhibitors and polymer coated urea in N management in the sub-tropics

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Abstract

While there is a growing body of literature suggesting that the nitrification inhibitor 3,4-dimethylpyrazole phosphate (DMPP) can reduce N_2O emissions from soils in temperate environments, there is little evidence of its efficacy in subtropical and tropical environments where temperatures and rainfall intensities are typically higher. We investigated N_2O emissions in aerobic rice crops in a subtropical environment in late summer/autumn in 2014 and in an adjacent field in late summer/autumn in 2015. Crops received 80 kg/ha N as either urea, DMPP-urea, or a blend of 50 % urea and 50 % urea-DMPP in 2014, and urea, urea-DMPP or polymer-coated urea (PCU) in 2015. DMPP-urea significantly ($P < 0.05$) lowered soil N_2O emissions in the 2013-14 season during the peak flux period after N fertiliser was applied, but had no effect in the 2014-15 season. The mean cumulative N_2O emissions over the entire growing period were 190 g N_2O-N/ha in 2013-14 and 413 g N2O-N/ha in 2014-15, with no significant effect of DMPP or PCU. Our results demonstrate that DMPP can lower N_2O emissions in subtropical, aerobic rice crops during peak flux events following N fertiliser application in some seasons, but inherent variability in soil N_2O emissions limit the chances of detecting significant differences in cumulative N_2O flux over longer time periods. A greater understanding of how seasonal and/or soil factors impact the efficacy of DMPP in lowering N_2O emissions following N fertiliser application in the subtropics is needed to formulate appropriate guidelines for its use commercially.

Key Words

Aerobic rice, nitrous oxide, static chamber methodology

Introduction

The application of nitrification inhibitors (NIs) to nitrogen (N) fertilisers is a management option that may reduce agricultural nitrous oxide (N_2O) emissions. A number of NI products exist, including 3,4-dimethylpyrazole phosphate (DMPP), which has been demonstrated to be effective at lowering soil N_2O emissions following N fertiliser application, particularly in temperate environments (Gilsanz et al. 2016). The efficacy of DMPP declines as temperatures increase (Chen et al. 2010), and DMPP may therefore be less effective in subtropical and tropical environments.

We are aware of only two published studies that have investigated the impact of the addition of DMPP to granular N fertilisers on N_2O emissions in tropical/subtropical environments (Scheer et al. 2014; Soares et al. 2015), and the results are inconsistent. We thus investigated the potential for a commercially available nitrification inhibitor incorporating 1.6 kg DMPP/t urea to lower N_2O emissions from rice (*Oryza sativa* L.) crops over two seasons in the subtropics.

Methods

Trial establishment

A field trial was conducted in the Australian subtropics (Woodburn, NSW: -29.071 S, 153.345 E) in the 2013-14 growing season and a second trial conducted in an adjacent field in the 2014-15 growing season. The soils had a clay profile to a depth of 1 m, and key properties of the 0-100 mm horizon and mineral N to a depth of 1m for each site are presented in Table 1.

In both seasons the field was sown to rice cv. Tachiminori using commercial sowing equipment, and crops were managed as per typical fields in the district. The crop was sown on 7th January 2014 for the 2013-14 season, and on 7th December 2014 for the 2014-15 season, with 20 kg/ha phosphorus as superphosphate, and 480 g/L Clomazone @ 600 mL/ha applied in both seasons. Plots (3 m x 8 m) were established immediately after sowing in both seasons and were allocated to three N treatments in a randomised block design with four replicate plots per N treatment. Nitrogen fertiliser was applied on the 8th January 2014 for the 2013-14 season and the 22nd January 2015 for the 2014-15 season. In the 2013-14 season treatments were 80 kg/ha N as urea, 80 kg/ha N urea + DMPP (at 1.6 kg DMPP/t urea, herein referred to as 'urea-DMPP'), and 80 kg/ha N as 50% urea + 50% urea-DMPP (herein referred to as 'blend'). In the 2014-15 season the treatments were 80 kg/ha N as urea, 80 kg/ha N as urea-DMPP and 80 kg/ha N as polymer coated urea (PCU). All N fertilisers were accurately weighed on a per plot basis, and applied to plots by broadcasting granules by hand.

Soil N_2O flux measurements

Three 150-mm-diameter manual static chambers were placed randomly in each plot, following the application of N fertiliser treatments. Intensive sampling (minimum twice per week) occurred after the application of N fertiliser or rain events > 20 mm with weekly or fortnightly sampling in drier periods. To minimise potential diurnal variation, gas sampling was undertaken between 08:00 and 11:00 on each occasion. Preliminary testing revealed N_2O emissions were linear for in excess of the 1 h incubation period under the conditions of each trial (data not shown), and on this basis chambers were closed then sampled immediately (T0) and at 60 min (T60). Gas samples were taken using a 25 mL gas-tight syringe (SGE, 25MDR-LL-GT) and stored in pre-evacuated 12-mL Exetainer® vials (Labco, UK). The concentration of N_2O in each sample was determined using an Agilent 7890A gas chromatograph (Agilent Technologies, Santa Clara, USA) in an ISO 9001:8000 certified laboratory at NSW Department of Primary Industries, Wollongbar, NSW, Australia. Conversion of flux data to emission units was carried out as per Van Zwieten et al. (2010).

Harvest measurements

At maturity (10th May 2014 for the 2013-14 season and 21st April 2015 for the 2014-15 season), 2 m of row was cut from two separate areas of each plot by severing plants about 10 mm from the soil surface. Grain was manually threshed from straw and grain/straw tissue was dried at 40 °C for 7 d before being weighed. Grain yields were converted to a 14% moisture basis.

Statistical analyses

The series of N_2O observations were described by a model that included fixed linear trends over time and allowed to vary according to treatment plus random effects, reflecting the nested design structure due to field replicate, plots within replicates and chambers within plots. Smooth deviations about the linear trends were enabled by cubic spline functions. The model was used to interpolate N_2O emissions on a daily basis and these estimates are presented graphically. Approximate total N_2O emissions from each chamber were calculated by integration under the observed rate curve for each chamber using the trapezoidal rule. Null hypothesis significance tests for equality of average emissions under all treatments were conducted by F-ratio after construction of the nested analysis of variance table. Variance heterogeneity in cumulated N_2O in both years was controlled by transformation to the natural log scale after offset to counter chambers with negative total emissions. The statistical analysis was conducted in the R environment (R core team 2015).

Results and Discussion

During the peak flux event that occurred in late January following a 30 mm rainfall event in the 2013-14 season (fluxes > 20 µg N_2O-N/m^2/h in the urea treatment), N_2O emissions were significantly lower in the urea-DMPP and blend treatments than in the urea treatment ($P < 0.05$; Fig. 1A). From early February (around 3 weeks after N application) until after harvest in early May, N_2O fluxes in all treatments were negligible, despite heavy rainfall events > 50 mm in late March and late April. In the 2014-15 season, N_2O emissions reached 60 µg N_2O-N/m^2/h following N fertiliser application but there were no significant differences among N fertiliser treatments ($P > 0.05$; Fig. 1B).

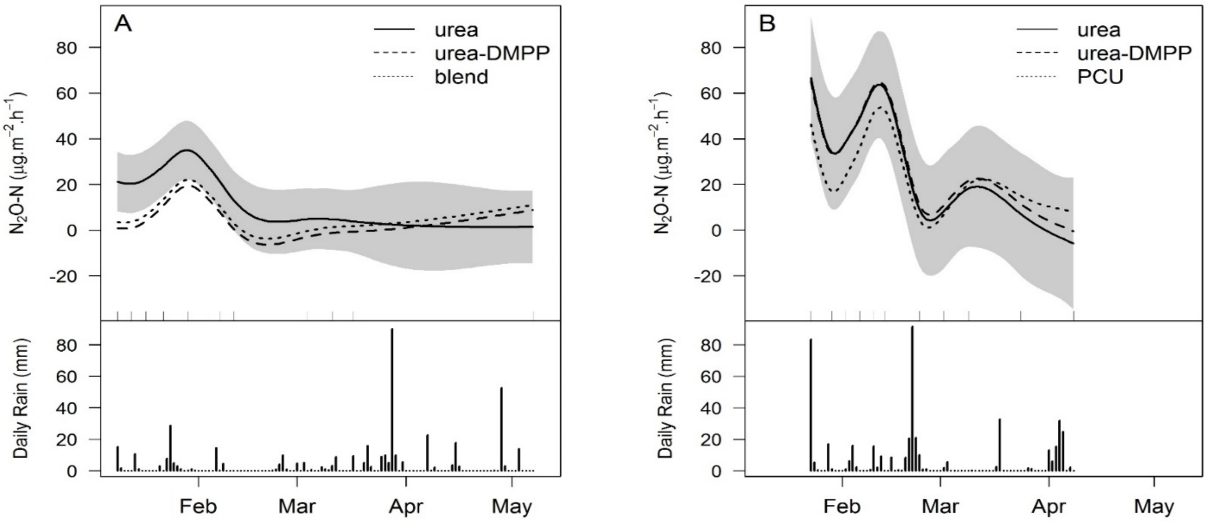

Figure 1. Estimated change in N_2O-N over time and daily rainfall in the 2014 (A) and 2015 (B) trials. Shaded areas span the urea curves +/- 2 standard errors. Tick marks on the N_2O-N charts show dates of observation.

There was no significant effect of N fertiliser treatment on cumulative seasonal N_2O emissions in either season (mean emissions of 190 g N_2O-N/ha in 2013-14 and 413 g N_2O-N/ha in 2014-15). The 2013-14 season results are consistent with the findings of Scheer et al. (2014) in the winter period in a subtropical environment, where DMPP significantly lowered N_2O emissions during the peak flux period following N fertiliser application, but had no effect on cumulative seasonal emissions. Ultimately, short duration periods of lower emissions were not sufficient to significantly reduce N_2O emissions when cumulated over the entire sampling period. In contrast to our results, however, Soares et al. (2015) reported significant reductions in cumulative N_2O-N emissions in Brazilian sugarcane crops (from 1484 g/ha with urea to 643 g/ha with urea-DMPP), but notably the concentration of DMPP used in the study of Soares et al. (2015) was 10 kg DMPP/t urea-N compared to 3.48 kg DMPP/t urea-N in our study. This discrepancy, and the fact that N_2O fluxes following N fertiliser application were significantly lower in the DMPP treatment in the 2013-14 season but not the 2014-15, highlight our poor understanding of the impact of soil and environmental conditions of the efficacy of DMPP, and the concentrations of DMPP required to enhance its effectiveness in subtropical environments.

Ultimately, there was no significant effect of N fertiliser treatment on grain yields in either season (mean yields at 14 % moisture were 6.2 t/ha in the 2013-14 season and 5.7 t/ha in the 2014-14 season), consistent with the findings of a recent meta-analysis on the impact of EEFs on crop productivity and N uptake, where overall the use of DMPP enhanced crop productivity by less than 3% (Abalos et al. 2014). However, where only one N rate is used in trials, and particularly if that N rate is near or at the recommended rate for maximum yields for a given crop in a given district, it is unlikely that EEF products will increase yields. The rate of 80 kg/ha used in our study is typically adequate to achieve 6-7 t/ha rice crops in the region without crop lodging, while rates above 80 kg/ha often increase grain yields but lead to lodging (Rose, unpublished data). It is not possible to discern whether the lack of yield response to DMPP or PCU was due to crops already reaching their yield potential with the conventional urea application, or whether the EEF products failed to provide more available N to crops. Notably, the meta-analysis by Abalos et al. (2014) did not attempt to identify whether lack of yield response in many data sets was due to the use of N application rates that already achieve maximum crop yields. The question of whether EEF products can be used at lower rates than conventional N products to achieve similar yields needs to be addressed by conducting trials with multiple N rates and subsequently deriving N response curves which can be used to obtain critical N rates for maximum yields.

Conclusion

While we observed short periods following N fertiliser application where DMPP lowered emissions of N_2O from soil, when we calculated net seasonal emissions, these differences were not detected as statistically different at p=0.05. In all likelihood, the prevailing conditions experienced under the subtropical environment, which included rainfall events to maintain soil moisture, may have resulted in the biodegradation of DMPP, thus lowering its efficacy past the first few weeks of its addition to soil. A better understanding of the impact of specific and variable soil and weather conditions on the efficacy of these products is needed, as well as more detailed N dose responses with DMPP, to optimise the technology.

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