Soil nitrous oxide emissions in irrigated cotton are reduced by nitrification inhibitors applied with pre-plant anhydrous ammonia

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Key findings

- N_2O emissions at the Gunnedah site were approximately 10 times higher than at the Emerald site, due to the wet soil conditions and high pre-season rainfall at Gunnedah which led to denitrification of N from pre-season anhydrous ammonia application.
- Two nitrification inhibitors, DMPS ("Big N-sure®", Incitec Pivot Fertilisers) and nitrapyrin ("N-serve®", Dow AgroSciences) directly injected into anhydrous ammonia during pre-plant N application delayed the conversion of applied ammonium in the soil to nitrate for a period of 2–3 months.
- At the Gunnedah site, cumulative N_2O emitted was reduced by 86% (DMPS) and 65% (nitrapyrin), compared to untreated ammonia.

Introduction

This experiment aimed to assess the efficacy of two nitrification inhibitors, 3,4-dimethylpyrazole (DMP) and nitrapyrin, when applied directly into the anhydrous ammonia stream during pre-plant nitrogen (N) application for commercial irrigated cotton production. Pre-plant N fertiliser application produces a large pool of mineral N in the soil that is at risk of loss through nitrate-denitrification, a process that produces nitrous oxide (N_2O) – a greenhouse gas. Nitrification inhibitors restrict the conversion of ammonium to nitrate for a period of up to several months, thus reducing the nitrous oxide emissions during the pre-sowing and early crop establishment phase of irrigated cotton production. Currently, no nitrification inhibitors are commercially applied with anhydrous ammonia in Australia. This experiment investigated the potential for two inhibitors, nitrapyrin (N-Serve® from Dow Agrosciences, used commercially in USA) and DMPS (Big N-sure® from Incitec-Pivot, not used before with anhydrous ammonia) to reduce nitrous oxide emissions from soil.

Site details

Locations	'Barwin' (Emerald) and 'Ruvigne' (Gunnedah)
Co-operators	Ross Burnett (Emerald), Rod Smith (Gunnedah), Incitec-Pivot Big-N team
Soil type and nutrition	Black Vertosols at both sites. Soil (0–30 cm) at Emerald was 42% clay, 44% sand, 14% silt. The profile had 34 kg N/ha of mineral N to 90 cm before N application. Soil (0–30 cm) at Gunnedah was 65% clay, 9% sand and 26% silt, and also had 34 kg N/ha in the profile to 90 cm when sampled at the conclusion of the previous cotton crop in late April 2016.
Rainfall and irrigation	At Emerald, there was 10 mm of rain during the 10-day pre-plant period between N application and sowing, then another 195 mm rainfall during the cropping season from sowing to harvest. The crop was irrigated 8 times including once pre-plant. A total of 7.375 ML/ha was applied. At Gunnedah, there was 280 mm of rain during the 69-day pre-plant period between N application and sowing, then another 216 mm rainfall during the cropping season from sowing to 1st February 2017. The crop was irrigated a total of 8 times. Because of the wet pre-season, no pre-plant or post-plant flush up irrigations were applied.

Trial design and treatments

Randomised complete block design with three treatments (T1 = ammonia, T2 = ammonia + DMPS [Big N-sure®], T3 = ammonia + nitrapyrin [N-serve®]) and three replications. A Raven SideKick Pro direct injection system was used to apply nitrification inhibitor at a rate

Nutrition and soils

of 2.5 L/ha (for both products) into the anhydrous ammonia stream at the supercooler unit before the distributor.

At Emerald, the pre-plant N rate was applied at 150 kg N/ha, followed by 150 kg N/ha as a urea side-dress just prior to the second irrigation. We used normal urea to side-dress T1 and T3, and DMPP-coated urea [ENTEC®] to side-dress T2. There was no equivalent nitrapyrin-coated urea product available to use in T3. The pre-plant ammonia was injected into the plant bed to a depth of 30 cm at a distance of 25 cm from the plant row on both sides of the plant bed. The side-dressed urea was applied at a depth of 5 cm on only the irrigated side of the plant bed, then immediately followed by cultivation.

At Gunnedah, the pre-plant N rate was 300 kg N/ha. No in-crop N application was planned, but the experimental area was inadvertently top-dressed with 75 kg N/ha as broadcast urea late in the vegetative growth period. The pre-plant ammonia was applied using a delta-T applicator centred on the middle of the non-irrigated furrow. Approximately 42.5% of the N is applied 9 cm either side of the mid-line as super-cooled ammonia (liquid), with the remaining approximately 15% of the N applied as vapour in the centre of the furrow.

Nitrous oxide measurements

Nitrous oxide emissions were measured during 5 (Emerald) and 6 (Gunnedah) separate 7–14 day-long campaigns with samples collected 1, 2, 4, 7 and sometimes also 10 or 14 days after a significant rainfall or irrigation event. Four manual chambers within each of the 9 plots per site were sampled at 0 and 60 minutes after sealing the chamber with a gas-tight lid. Samples were analysed by a laboratory gas chromatograph.

Sowing dates and varieties

The Emerald site was sown with Sicot 746B3F on 20 August 2016. The Gunnedah site was sown with Sicot 748B3F on 6 October 2016.

Harvest date

Cotton picking at Emerald was on 13 February 2017. Picking at Gunnedah was not yet done at the time of writing.

Results

Trial 1. Emerald

In general, N_2O emission rates were low throughout much of the season, with the first irrigation causing only a few temporary and highly variable emission peaks in treatment 1 (ammonia control). There was almost no response to the 21.8 mm rainfall event at the end of September 2016. Side-dressed urea followed by irrigation increased N_2O fluxes for at least 4 days in treatments 1 and 3, which had standard urea applied. Treatment 2, side-dressed with DMPP-coated urea, showed little N_2O loss during the same period. Further irrigations also produced N_2O emission responses, with some highly variable results from the irrigated side of the hills where the side-dressed urea had been applied.

The net result of these manual chamber measurements is shown as a cumulative emission of N_2O in Figure 1. Sampling in short campaigns meant that there were gaps in the timeline, but losses during these gaps would have been minimal based on the low N_2O fluxes measured at the end of each event. From pre-plant N application until side-dressing, both inhibitors kept total losses of N_2O to a minimum compared to the untreated ammonia control (T1). Cumulative N_2O was reduced by 77% (both inhibitors), compared to untreated ammonia. After the side-dressing, T1 and T3, which received untreated urea, continued to increase in N_2O loss while the DMPP-coated urea kept emissions to a minimum until the final measurement event when a single high flux in one replicate plots of T2 increased the average cumulative nitrous oxide loss for that treatment. The DMPP-coated urea reduced N_2O emission after side-dressing by 27%, compared to untreated urea. The untreated urea following the nitrapyrin (T3) appeared to increase N_2O emitted by 99% during this period, although the high variability of results meant that differences were not statistically significant.

As a proportion of the N applied, the seasonal losses were low, at only 0.2% (T1 and T3) or 0.09% (T2) of the N applied.

There were no significant impacts of the inhibitors on cotton lint yield at the Emerald site, as assessed by hand biomass cuts (data not shown).

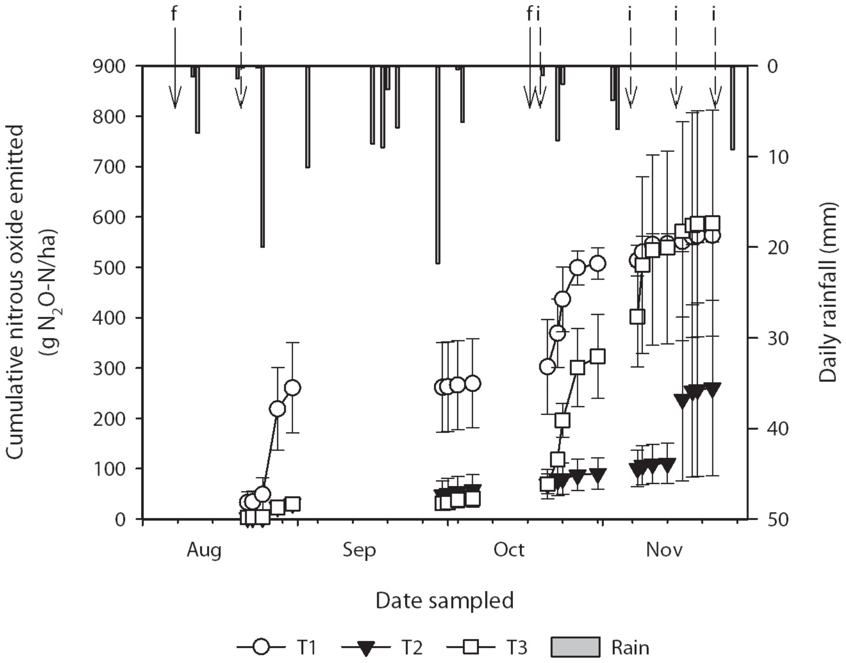

Figure 1. Cumulative nitrous oxide emissions from the Emerald experiment as influenced by treatment, rainfall and irrigation. Solid arrows at the top indicate dates of N application (f). Irrigation events within the measurement period are shown as dotted line arrows (i).

Trial 2. Gunnedah

Both inhibitors proved to be highly effective at maintaining much of the applied pre-plant N as ammonium in the soil for at least two months after application (Figure 2), compared to the control treatment (T1) where the mineral N was mostly found in the nitrate form by late September. By December, nitrate in T1 had declined to much lower levels, while in T2 and T3, nitrate concentrations were still high, especially in the fertilised furrow position.

During the first two months after pre-plant N application, intense rainfall events on an already wet soil led to waterlogging in the paddock and some very large daily fluxes of N_2O from T1, the untreated control. The effectiveness of the nitrapyrin appeared to have worn off by the time of the post-planting rainfall in October (T3), whereas the DMP inhibition (T2) continued until the first irrigation.

The cumulative N lost as N_2O (during the measurement periods only) is shown in Figure 3, with clear treatment differences. Total N_2O emissions for the overall season would have been higher, particularly in the untreated control (T1), as measured daily fluxes were still high at the end of most 7-day sampling campaigns. In total, DMPS reduced measured nitrous oxide emissions by 86% and nitrapyrin by 65%, compared to anhydrous ammonia applied without any nitrification inhibitor.

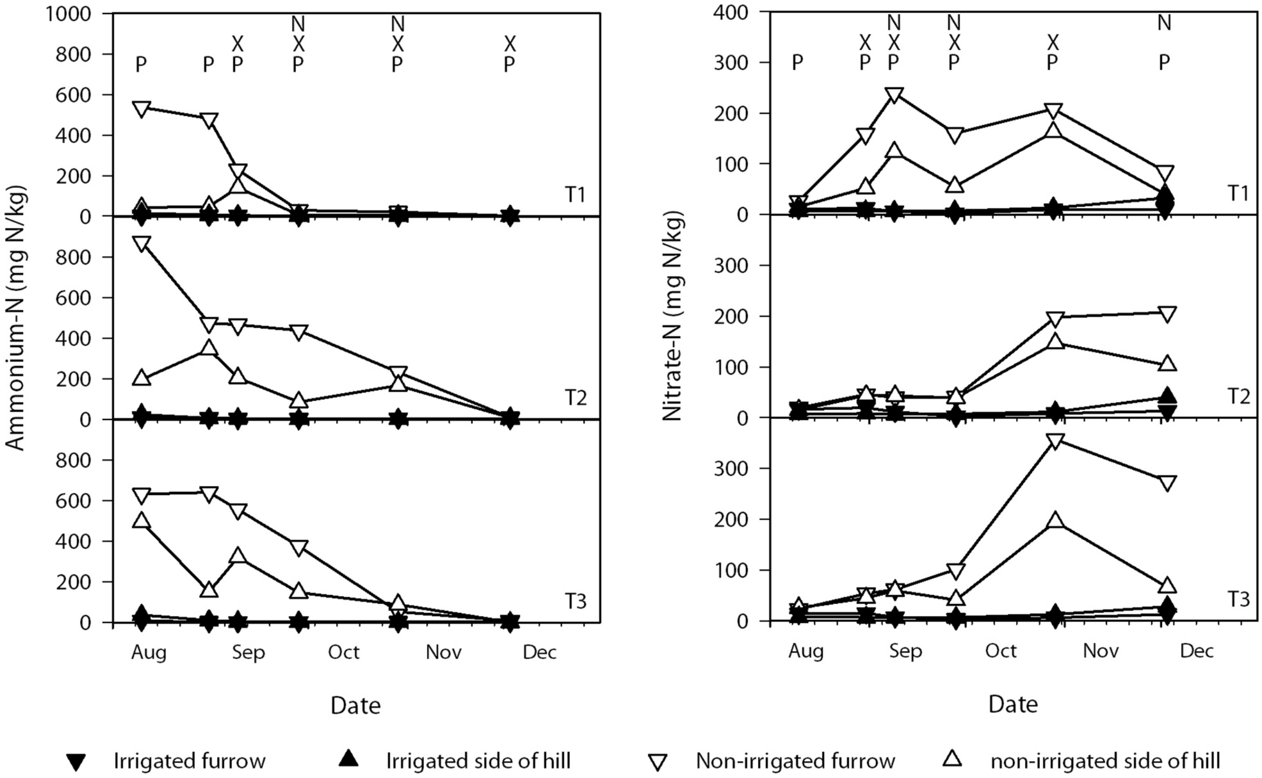

Figure 2. Surface soil (0–10 cm) ammonium-N (left) and nitrate-N (right) concentrations at four positions within each treatment at the Gunnedah trial. Letters above a sampling date indicate significant N treatment (N), chamber position (P), and N × P interactions (X), and apply to all three graphs in each column.

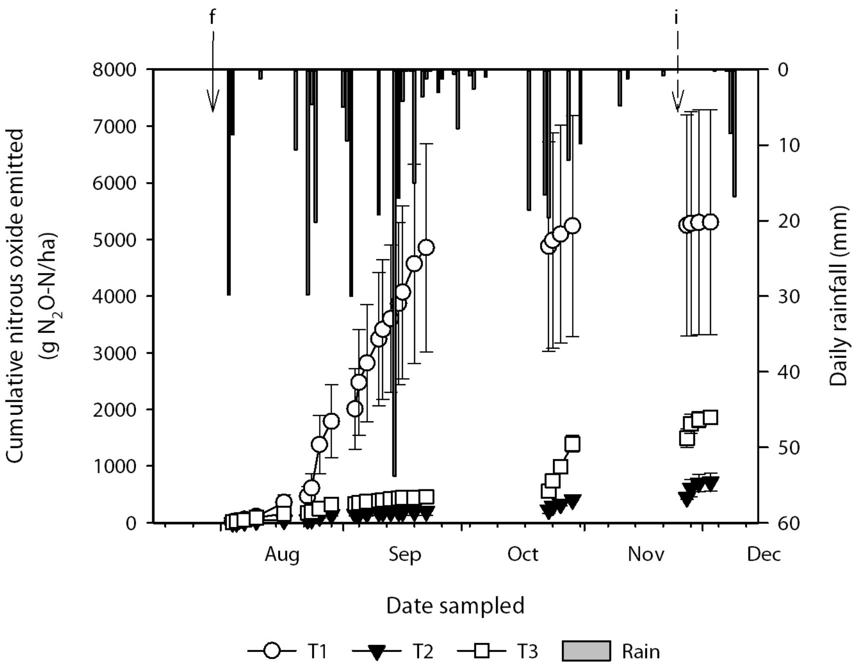

Figure 3. Cumulative nitrous oxide emissions from the Gunnedah experiment as influenced by treatment, rainfall and irrigation. Solid arrows at the top indicate dates of N application (f). Irrigation events within the measurement period are shown as dotted line arrows (i).

Does the prevention of N loss by using these products affect crop production? We attempted to answer this at Gunnedah by soil coring to 90 cm depth just prior to sowing. While the results appeared to show that the inhibitor treatments had reduced large losses of mineral N (data not shown), the treatment variability was too high to demonstrate statistically significant treatment differences. The definitive proof of any treatment effects would be observed as a plant productivity response, but inadvertent top-dressing of the trial area prevented any conclusive outcome of these inhibitors on crop performance and economic benefit. Despite this, both products demonstrated a clear environmental benefit on significantly reduced N_2O emissions.

Conclusions

In a season such as that experienced at the Emerald 2016–17 site, there were only minor environmental benefits from using a nitrification inhibitor in conjunction with anhydrous ammonia. However, these experimental conditions may not be typical as pre-plant fertiliser is usually applied earlier in the year at Emerald than it was at this site. A longer period of time between pre-plant application and plant establishment would provide greater opportunity for N_2O losses to occur, although the potential for heavy winter rainfall tends to be low in the Emerald region. While both inhibitor products clearly reduced emissions during the first two measurement periods, it was apparent that the effectiveness of these products had dissipated by the time of the second irrigation. The additional inhibitor application with the side-dressed urea boosted the N_2O reduction period for the DMPP treatment, while the application of untreated urea to the other treatments allowed further losses matching those of the untreated control after the initial pre-plant N application.

The 2016–17 Gunnedah experiment provided the perfect testing conditions for nitrification inhibitors as the soil was very wet at application, and received frequent heavy rainfall during the next 3 months. These inhibitors were designed to retain mineral N from applied N fertiliser in the soil during periods of excessive rainfall that may otherwise lead to large losses of nitrate N through denitrification and leaching. Leaching occurs through downward movement of nitrate with water in the soil, but we found no evidence of this having occurred in the soil core samples we took just prior to sowing. For heavy clay soils such as this one at Gunnedah, denitrification of soil nitrate during periods of anaerobic soil conditions is the most likely major N loss pathway. The results of the gas sampling campaigns highlighted the almost complete mitigation of N_2O emissions during this period by adding nitrification inhibitors. The Big N-sure® inhibitor appeared to remain active for longer in the soil than the N-serve®.

Acknowledgements

This experiment was part of the project *Determining optimum nitrogen strategies for abatement of emissions for different irrigated cotton systems* (AOTG14013; 2013–17), with joint investment by NSW DPI and DAWR, and administered by CRDC. Thanks to Ross Burnett and Rod Smith for providing the experimental sites and for applying the anhydrous ammonia and urea in field, and to Amanda Noone for carrying out the field work at Emerald, Pete Perfrement, Tim Grant and Wayne McPherson at Gunnedah. Technical assistance with the application of both inhibitors was provided by the Incitec-Pivot Big-N team and is gratefully acknowledged. Incitec-Pivot provided the Big N-sure® inhibitor and ENTEC®-urea, and Dow Agrosciences provided the N-serve® inhibitor. All soil and plant N analyses were carried out by Clarence Mercer in the ISO9001-accredited laboratory at Tamworth Agricultural Institute, NSW DPI.