THE ASSESSMENT OF ENHANCED EFFICIENCY FERTILISERS (EEFs) IN A GLASSHOUSE EXPERIMENT TO INVESTIGATE NITROGEN LOSS PATHWAYS IN SUGARCANE

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Abstract

NITROGEN (N) LOSS RESULTING in negative offsite environmental impacts is an important issue for the sugarcane industry in tropical Australia. Enhanced Efficiency Fertilisers (EEFs) have the potential to reduce nutrient losses leading to improvements in nutrient uptake efficiency, productivity gains and environmental impacts. A glasshouse experiment compared fertiliser N lost in drainage and as nitrous oxide for conventional urea, polymer coated urea (PCU – AgroMaster®) and urea treated with DMPP (Entec®) applied at a rate equivalent to 100 kg N/ha. Loss of N in leachate at day 50 for PCU was approximately half that of urea and DMPP, which were similar (~28 mg/pot). Most of the N was leached as NO_x–N (>77%) at both day 50 and day 150, when losses were low and similar for all treatments (<2.4 mg/pot). Both EEFs were effective in reducing loss of N as N_2O at 50 days after fertiliser application. Nitrogen loss for DMPP was only 18% of the loss of N from urea, while PCU loss was 62% of that of urea. However, the maximum daily loss of N as N_2O of 0.04 mg/pot/day at day 50 was very low in comparison to that lost in leachate (~28 mg/pot) at the same time. These results provide options for the selection of EEF based on anticipated loss pathway for a combination of soil type, position in landscape, and seasonal weather outlook. PCU, or a blend with urea, is the preferred N fertiliser for well-drained sites in higher rainfall areas where rate of leaching is expected to be high. DMPP, or a blend with urea, would be the preferred N fertiliser for poorly drained sites in wet areas or for prolonged wet growing conditions, where rate of N_2O emission is expected to be high.

Introduction

The Australian sugar industry is regulated to limit the potential off-site impacts of fertiliser use. Legislation limits the amounts of N and phosphorus (P) that growers can apply. The inefficient use of agricultural fertilisers has contributed to the eutrophication of Australia's fresh and marine waters (Shafron, 2008). Therefore, the industry is currently under considerable and increasing pressure to minimise nutrient runoff from cane farms draining into the Great Barrier Reef and freshwater ecosystems (Brodie *et al.,* 2013).

The management of nutrient inputs is essential to maintain soil fertility and to optimise and sustain long-term crop yields. Nitrogen is quantitatively the most significant nutrient for cane growth, although its yield potential is not achieved if other nutrients are limiting. In the Herbert and Mackay areas, applications of up to 160 kg N/ha are confined to a short period between harvest and the onset of the wet season (Di Bella *et al*., 2013).

In the Burdekin area, total applications of up to 200 kg N/ha are usually applied either once or twice in a period between the harvest and when the crop can no longer be passed over by tractor-drawn application equipment. Split applications of nitrogenous fertilisers are generally not practised in Australia due to the increased application costs, the time required to undertake multiple passes due to lack of available labour, and the risk of not being able to access fields after the onset of wet weather. Research in the Australian sugarcane industry found little or no yield advantage from split urea-based fertiliser applications (Kingston *et al.*, 2008).

In tropical cane growing regions where urea is the dominant and cheapest N fertiliser, N may be lost by volatilisation, leaching, runoff and denitrification (Chapman and Haysom, 1991; Denmead e*t al*., 2008; Prasertsak *et al*., 2002; Rasiah *et al*., 2003a; Weier *et al*., 1998). Losses can be high during periods of high rainfall, waterlogged conditions and high temperatures. Loss of N in deep drainage is a major pathway on well-drained soils of Queensland's wet tropical coast (Armour *et al*., 2013). Bohl *et al.* (2001) calculated N leaching losses were in the range of 0–30 kg N/ha/y in the Herbert catchment, with the lowest leaching losses occurring on the heavy (clay) soil of the alluvial flood plain and the highest leaching losses on the colluvial fans and river bank soils.

Greenhouse gas (GHG) emission is a serious threat to the global climate (Denman *et al*., 2007). The contribution of global agriculture to total anthropogenic emissions was estimated to be approximately 70% of nitrous oxide (N_2O), 50% of methane and 20% of carbon dioxide. Production of N_2O from sugarcane paddocks by microbial processes associated with denitrification may be high, particularly from stubble retention and when cane trash from green cane harvesting is left on the soil surface (Wang *et al*., 2012). They reported N_2O emissions of 3–25 kg N/ha/y from Australian sugarcane soils. Nitrogen fertiliser management is important in controlling nitrous oxide emissions from agricultural soils (Baldock *et al.,* 2012). For fertiliser N-driven systems such as sugarcane, options to reduce nitrous oxide emissions include better matching application to plant demand for N and the use of EEF, whose cost has reduced in recent years. As well as reducing GHG, these two options may increase farm profitability. However, there is limited information on their effect on crop production as well as nitrous oxide emission.

Di Bella *et al.* (2013 and 2015) and Wang *et al.* (2016) reported that controlled release (CR) fertilisers might offer an opportunity to minimise N losses and increase productivity in cane production systems. This paper compares the losses in drainage and as N_2O for Entec® and AgroMaster® compared with conventional urea and non-fertilised treatments. AgroMaster (Everris™ Australia Pty Ltd) is urea coated with a polymer coating (referred to as PCU), which slows the dissolution and release of urea-N into the soil (Di Bella et *al*., 2013). Entec® (Incitec Pivot Fertilisers) is conventional urea treated with the nitrification inhibitor 3,4-dimethylpyrazolphosphate (DMPP). Both products are now commercially available to growers in the Australian sugarcane industry.

This paper will report on an experiment that measured the loss of N from the major pathways, as nitrous oxide and in deep drainage, from conventional N fertiliser (urea) and DMPP and PCU. The trial was undertaken under the controlled conditions of a glasshouse.

Material and methods

The pot experiment was undertaken at the Herbert Cane Productivity Services Limited glasshouse at its research facility at Macknade (lat. –18.5833°, long. 146.2508°).

The experiment compared the industry standard N source, urea, EEF sources (DMPP and PCU), and a nil nitrogen treatment, with five replicates and pots randomised within the glasshouse. All other nutrients were the same in all treatments, with the nitrogen source being the only variable between treatments. Seven kilograms of thoroughly mixed soil, Terrace silty loam (Wood *et.al* 2003) from Macknade Experiment Station, was added to each pot on top of 400 g/pot of rock at the base of the pot. The soil was covered with 120 g of perlite to restrict weed growth and reduce evaporative losses, with 25 g of trash under the perlite. Soil chemical properties included ammonium-N 12 mg/L, nitrate-N 167 mg/kg, total carbon 0.87% and total nitrogen 0.07%.

The total N in each pot before fertiliser was added was 6.2 g, including the N content in the cane trash. The N application equivalent to 100 kg N/ha was 0.46 g N/pot.

Three germinated one-eyed setts were planted in each pot on 20 August 2015. The fertiliser was placed in a 200 mm long band within the soil to simulate industry practice. Fertiliser was kept away from the edges of the pot to avoid higher temperatures. Mean soil temperature measured in the pots was 29.2 °C at day 50 (8 September 2015) and 31.2 °C at day 150 (17 December 2015).

The three watering regimes used were field capacity, leaching and water logging. Pots were regularly watered to field capacity, except when leaching and denitrification events were imposed on the treatments. The field capacity treatment included returning leachate to the soil surface. Waterlogged pots were maintained at field capacity for first 45 days, then water equivalent to 20 mm of rain was added to non-draining pots. Soils were allowed to dry back to field capacity and then maintained at this water content by weight using equivalent field capacity pots as the benchmark weight. Water equivalent to 20 mm of rain was added again after 145 days (biomass sampling at 150 days) and then treated as before. The leached pots were also maintained at field capacity for first 45 days, then water equivalent to 20 mm of rain was added. Leachate was collected, volume measured, then frozen before laboratory analysis. Soils were allowed to dry to field capacity and then maintained at this water content. Water equivalent to 20 mm of rain was added again after 145 days. As before, soils were allowed to dry back to field capacity and then maintained at this water content.

Harvests were made at days 50, 100 and 150. Shoots were cut at ground level, fresh weight measured, then dried, weighed and sampled for laboratory analysis.

Soil, plant and water analyses

A representative sample of the soil used was analysed for mineral N analysis (ammonium- and nitrate-N, method code 7C2, Rayment and Lyons (2011)), total N (7A5) and total C (6B2).

Soil samples were collected for mineral N analysis at days 50 and 150 coinciding with the time of gas collection. Samples were chilled to 5°C after collection and submitted to the laboratory for analysis. Mineral N concentrations were adjusted to an oven dry basis using a moisture factor calculated from the soil water content at time of sampling. Plant samples were analysed for total N and N uptake was calculated from the dry weight of shoots and N content. Leachate samples were analysed for ammonium- and oxides of nitrogen (NOx-N, assumed to be mostly nitrate-N, methods 4500-NH_3 and 4500-NO_3 (Water Environment Federation and American Public Health Association, (2005), adapted for automated flow analysis)). Loss of N in leachate was calculated from the concentration of dissolved inorganic N (comprising ammonium- and NOx-N) and the volume of water leached through the pots. All analyses were undertaken at a laboratory accredited with the National Association of Testing Authorities (NATA).

Gaseous losses

Denitrification gaseous losses were assessed at days 50 and 150. A soil core of 50 mm × 150 mm diameter was removed from the harvested denitrification pots and placed in a PVC chamber. Carbide and water were placed in the chamber with the soil sample and were mixed in the capped chamber to generate acetylene. The chamber was then placed in the soil of the pot and covered with trash to maintain the soil with the chamber at a constant soil temperature. After 24 hours, a gas sample was syringed into evacuated glass sample collection tubes provided by DSITI and analysed for N_2O and acetylene (Mahmood *et al*., 2005).

Results

Dry matter yield

Shoot dry matter increased approximately linearly for all fertiliser treatments from day 45 to day 150 (Figure 1). Yields were similar for all treatments at day 45 and for all applied fertiliser treatments at day 100 ($P<0.05$). At day 150, yield with DMPP (57.6 g/pot) was lower than with urea, while PCU and urea yields were similar (59.3 and 60.7 g/pot, respectively, ($P<0.05$).

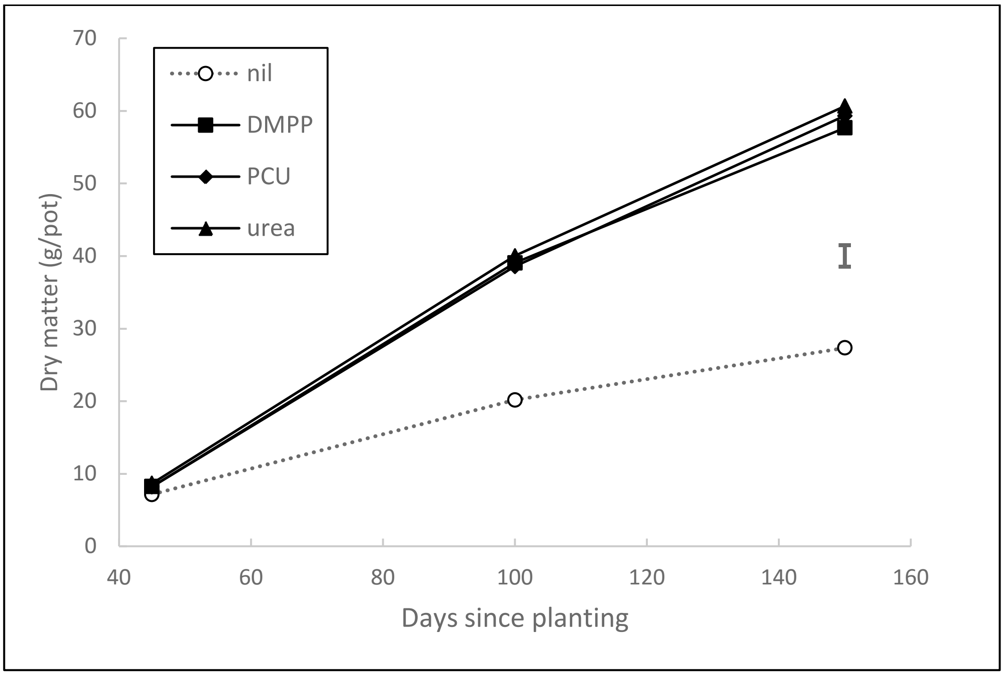

Fig. 1—Plant dry matter over time for fertiliser treatments.
*(*The vertical bar represents the lsd (P=0.05)*.)*

The field capacity water treatment had lower dry matter yield at days 100 (29.3 g/pot) and 150 (46.3 g/pot) than waterlogged (37.6 and 53.5 g/pot at days 100 and 150, respectively) and leached (36.4 and 54.0 g/pot at days 100 and 150, respectively) ($P<0.05$).

Nitrogen concentration of shoots

N concentrations in shoots decreased with time for all fertiliser treatments (Figure 2). N% was lowest for nil N at all sampling times (1.4–~0.5%, $P<0.05$). N% for PCU (2.06%) was lower than DMPP and urea (2.26%) at days 45, while all three applied fertilisers had similar N concentrations at days 100 and 150 ($P<0.05$). Field capacity, leached and water logged treatments had similar N% ($P<0.05$).

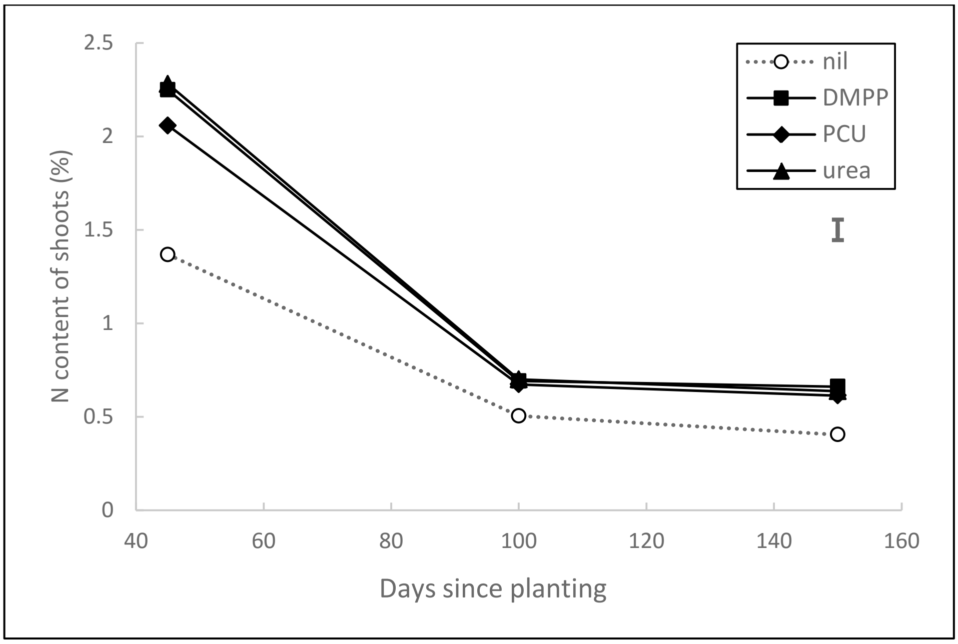

Fig. 2—N content of shoots over time.
(The vertical bar represents the lsd (P=0.05).)

Nitrogen uptake

N uptake increased approximately linearly with time for the applied fertiliser treatments but was unchanged for nil N (0.01 g/pot) (Figure 3) ($P<0.001$). At each sampling time, N uptake was similar ($P<0.001$) for the applied N treatments, although uptake for PCU tended to be lower than for urea and DMPP.

Mean N uptake for the field capacity treatment for the three harvest times (0.22 g/pot) was lower ($P<0.01$) than for leached and water-logged treatments (0.24 g/pot).

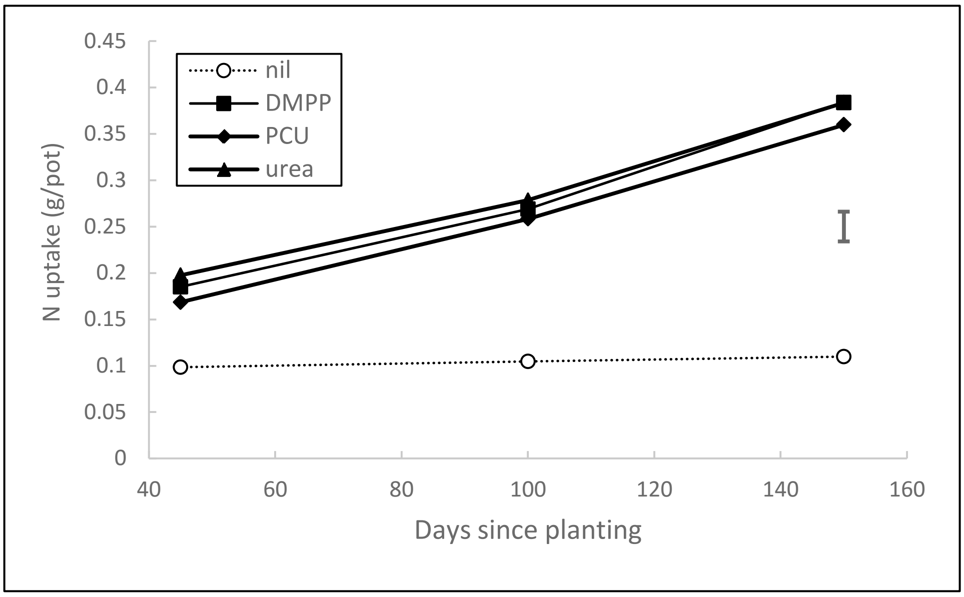

Fig. 3—N uptake in shoots over time.
(The vertical bar represents the lsd (P=0.05).)

Stalk height

Stalk height increased over time for all fertiliser treatments with nil N height always lower than the other fertiliser treatments (Figure 4). Stalk height in the three fertiliser source treatments followed the same trend over time and there were no consistent differences among the sources (mean for all harvests was 18.6–19.3 cm). Stalk height was increasing linearly over the last four sample times (7 to 21 December 2015).

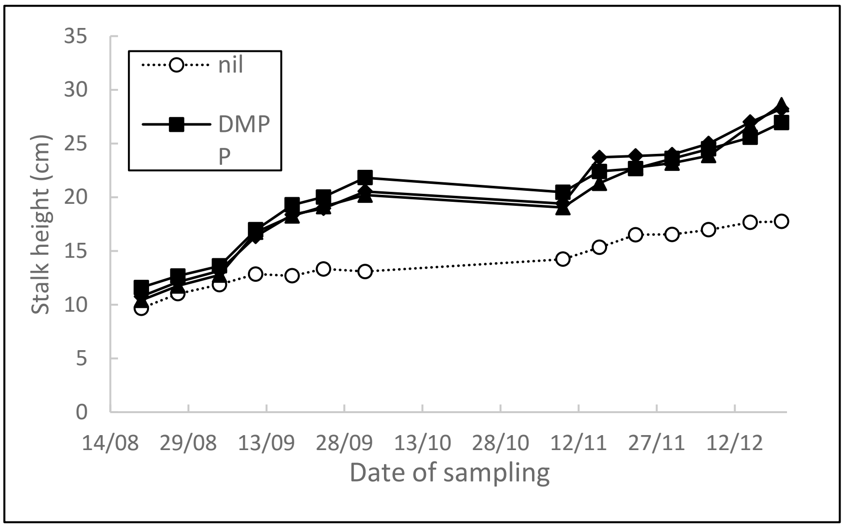

Fig. 4—Stalk height over time.
(Note standard errors of means are too small to show on graph (~0.7)).

Soil mineral N at 50 and 150 days

Ammonium-N concentrations were much lower at day 150 than at day 50 (Figure 5). Concentrations were always lowest for the nil fertiliser treatment (35 and 9 mg/kg at 50 and 150 days respectively). They were highest for PCU, particularly at 50 days (139 mg/kg) when they were approximately three times higher than the other applied N treatments. Ammonium concentrations for urea and DMPP were similar at 50 days (51–57 mg/kg) and similar for urea, DMPP and PCU at 150 days (11–15 mg/kg). There was high variability in ammonium-N values, particularly at 50 days. Nitrate-N concentrations were generally below the laboratory detection level and, thus, are ignored.

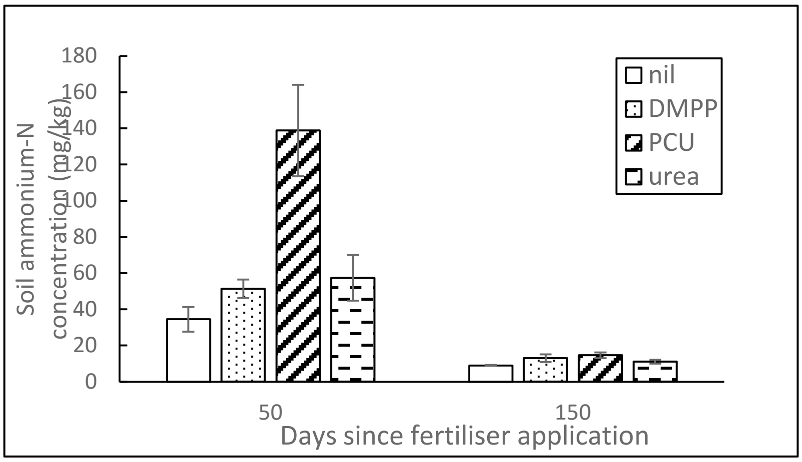

Fig. 5—Soil ammonium concentrations at days 50 and 150.
(The vertical bars represent standard errors of the mean.)

N concentration and load in drainage

Concentrations of NO_x-N (oxides of N) and ammonium-N in leachate decreased between day 50 and 150 (Figure 6). NO_x-N concentrations for urea and DMPP were similar at day 50 (38 and 31 mg/L respectively, and higher than PCU (16 mg/L) and nil (3.6 mg/L) ($P=0.001$). At day 150, concentrations for all fertiliser treatments were <2.4 mg/L and there was no difference among treatments ($P>.05$).

Ammonium concentrations decreased to low levels (<0.1 mg/L) at day 150 for all treatments, except for nil N, which was <0.1 mg/L at both sampling times. DMPP had the highest ammonium-N concentrations (8.3 mg/L, $P<0.05$) at day 50 and PCU and urea were similar (3.5 and 4.9 mg/L respectively).

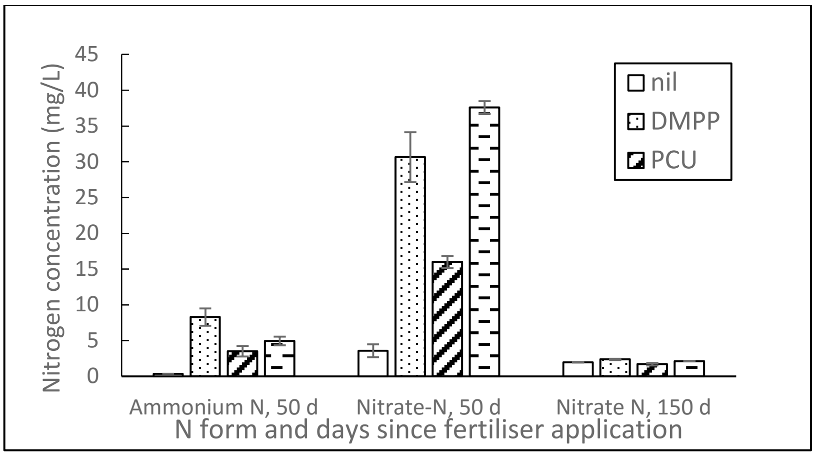

Fig. 6—Ammonium- and NO_x-N concentrations in leachate at days 50 and 150.
(The vertical bars represent standard errors of the mean. Note that concentrations of ammonium-N were too low at 150 days to plot).

Loads of DIN (dissolved inorganic N; NO_x- and ammonium-N) in leachate were much higher at day 50 than at day 150 (~2 mg/pot), except for the nil treatment, which was low at both times (~2 mg/pot) (Figure 7). At day 50, urea and DMPP had higher loads of DIN in drainage (30 and 26 mg/pot respectively) than PCU (14 mg/pot) ($P<0.01$. NO_x-N comprised most of the DIN at day 50 (PCU and urea were 82–89%, while DMPP was 77%) and ~98% at day 150.

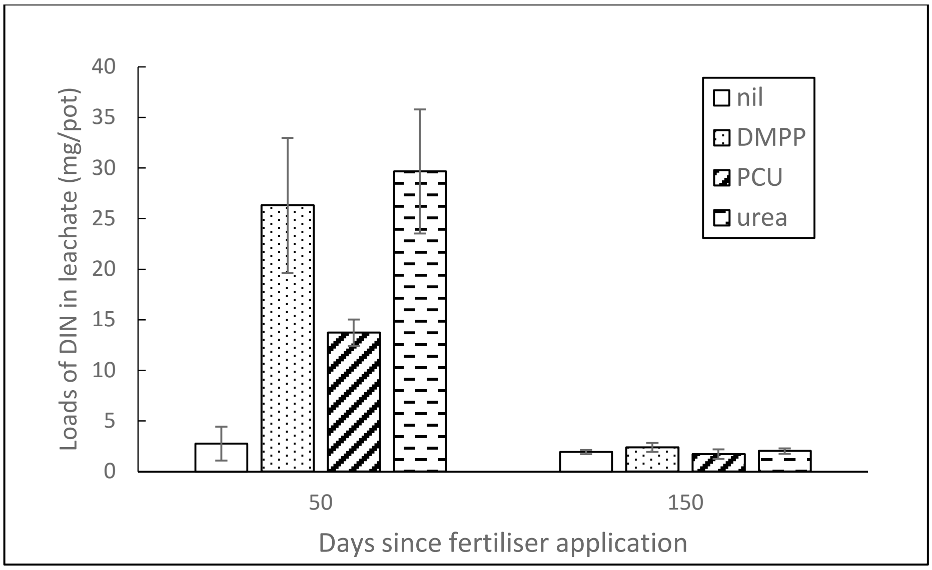

Fig. 7—Loads of DIN in leachate at days 50 and 150.
(The vertical bars represent standard errors of the mean).

The volume of drainage was similar for all fertiliser treatments at day 50 (mean 0.69, range 0.65–0.73 L) and day 150 (mean 0.96, range 0.94–0.98 L).

Gaseous loss measurements

Nitrous oxide (N_2O) and acetylene emission was measured over periods of 2, 6 and 24 hours. N_2O concentrations increased approximately linearly between two and 24 hour periods (Figure 8). N_2O concentrations at 24 hours for EEF fertilisers were lower than for urea with PCU measuring 62% of urea and DMPP 18% of urea.

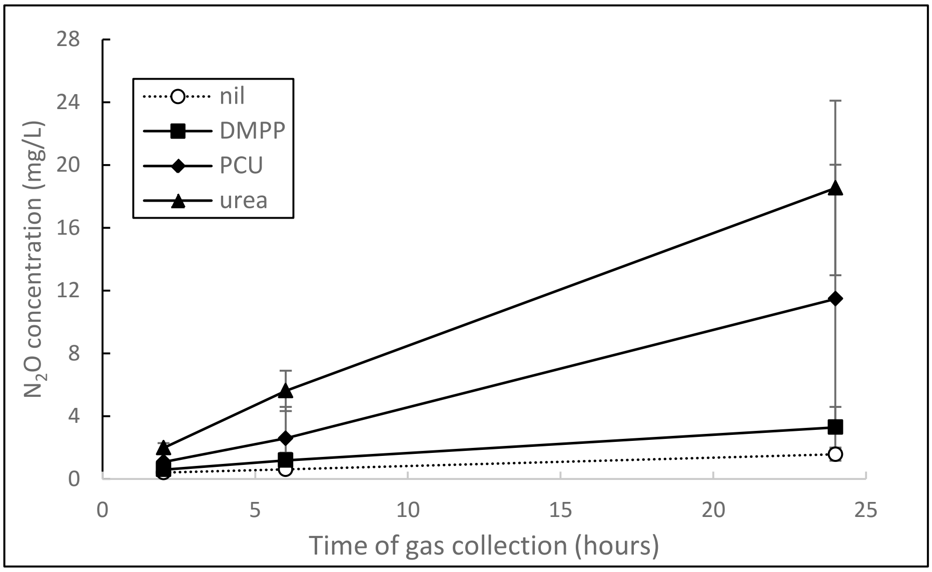

Fig. 8—N_2O emission over time at day 50.
(The vertical bars represent standard errors of the mean).

Acetylene concentrations were 8–11% and increased over time, though concentrations tended to asymptote after six hours.

At 150 days after fertiliser addition, concentrations of N_2O were much lower (0.5–1.8 mg/L) than at day 50 (Figure 9). Concentrations for urea, PCU and nil were similar (~0.6 mg/L) and lower than DMPP (1.8 mg/L).

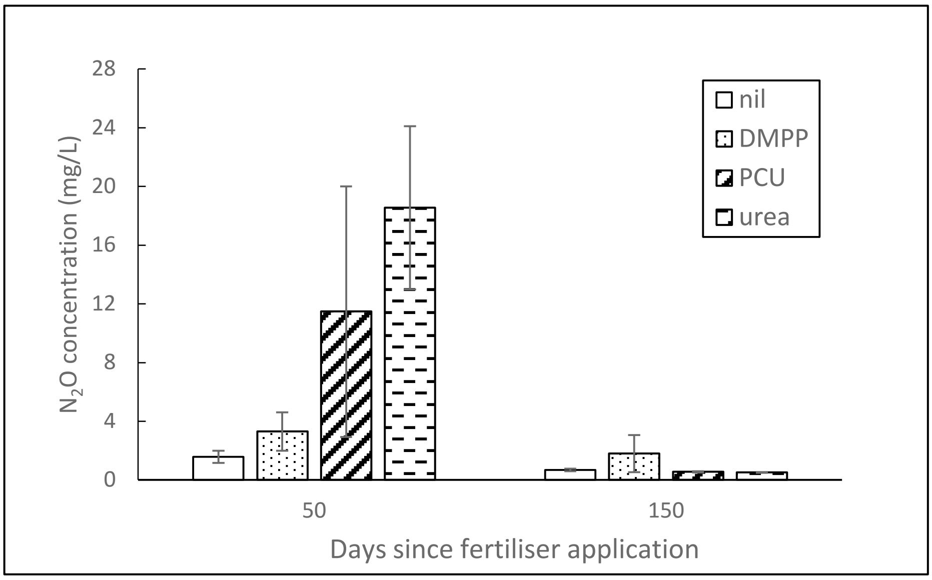

Fig. 9—N_2O emission over 24 hours at days 50 and 150.
(The vertical bars represent standard errors of the mean).

Concentrations of N_2O at days 50 and 150 were converted to a loss of N on a pot basis (Table 1). The daily losses even at day 50 were very small compared with both the fertiliser application of 460 mg/pot and the N content of the soil at planting of 6.2 g/pot.

Table 1—Loads of N lost as N_2O over 24 hours at days 50 and 150 (Standard error of the mean).

Treatment	N loss at day 50 (mg/pot)	N loss at day 150 (mg/pot)
Urea	0.041 (0.011)	0.001 (<0.001)
PCU	0.025 (0.017)	0.001 (<0.001)
DMPP	0.007 (0.002)	0.004 (0.003
Nil	0.004 (<0.001)	0.001 (<0.001)

Discussion

This assessment of the major loss pathways of fertiliser N from sugarcane production provides options for the selection of EEF based on the anticipated loss pathway for a combination of soil type, position in landscape, climate and seasonal weather outlook. PCU would be the preferred N EEF for well-drained sites in higher rainfall areas, where rate of leaching would be expected to be high. Loss of N in leachate for PCU was only 46% of the loss for urea at day 50.

Moderately and highly permeable soils, which may be defined as well-drained, comprise approximately 64,000 ha of sugarcane production in the Wet Tropics region (M. Shaw, pers. comm.). For poorly drained sites in wet areas or for prolonged wet growing conditions, DMPP would be the preferred N EEF. The rate of N_2O emission would be expected to be high under these conditions. The loss with DMPP was only 18% of the loss for urea at day 50. Poorly drained soils, or those with slow to very slow permeability, comprise approximately 115 000 ha of production in the Wet Tropics (M. Shaw, pers. comm.).

Another, more cost-effective option reported by Di Bella et al. (2015) is the inclusion of PCU at 15–40% of a blend with urea. In December 2016, a fertiliser blend treated with DMPP was approximately 13% more expensive than an equivalent urea-based product, while the PCU was approximately 20% more expensive. Over time, it is expected that the cost of EEFs will decline. However, they are not expected to ever match the price of conventional urea. In the Herbert cane growing region, growers generally offset the additional cost of the EEF by reducing the N being applied by 20–25%. This approach has been effective in decreasing total N use.

As expected, there was a large increase in the growth of sugarcane with applied N fertiliser, equivalent to a modest rate of 100 kg N/ha, at days 100 and 150. Growth for the three fertiliser sources was generally similar, although dry matter level from the DMPP treatment at the final harvest was 96% of the urea and PCU treatments figures. However, the detailed measurement of stalk height showed that growth of the DMPP treatment decreased noticeably in comparison to urea and PCU only at the final two measurements.

Although N content of the shoots decreased with time, N uptake increased approximately linearly for the N fertiliser treatments. N uptake for PCU tended to be lower at each sampling time but this effect was not significant. Mariano *et al*. (2016) also reported that N concentrations decreased with time.

The field capacity treatment, the standard treatment for all pots apart from the leaching and waterlogging treatments imposed at days 45 and 145, had lower growth than the other two water regimes. This was assumed to be due to improved water availability from additional water added to the pots, equivalent to 20 mm of rain, during hot growing conditions. N content of the shoots and N uptake were not affected by the field capacity treatment.

There was a marked effect of N fertiliser source on soil ammonium concentrations at day 50. PCU had the highest NH_4-N concentration of 139 mg/kg, which was 2.5-fold higher than urea and DMPP, and was clearly effective at retaining N in the ammonium form by restricting the normally rapid formation of nitrate. Differences among treatments had disappeared by day 150, when concentrations for all treatments were <15 mg/kg. The reduction in ammonium-N concentrations was attributed to immobilisation in the soil, plant uptake and some loss by leaching and gas emission. Soil nitrate concentrations were very low at both sampling times.

Most of the N in leachate was nitrate-N and consistent with other research (Armour *et al.*, 2013; Aulakh and Malhi, 2005). Concentrations of nitrate-N for the added fertiliser treatments were as high as 38 mg N/L at day 50, even though soil nitrate concentrations were low (<0.1 mg/L). The leaching event imposed, equivalent to 20 mm of rain, represents only a small rain event in the wet tropics of Queensland. PCU was the more effective EEF in reducing the loss of nitrate and had a DIN load that was 46% of the load for urea, while the DMPP load was 88% of that for urea. Concentrations of nitrate and hence loads of DIN in leachate at day 150 were low with no differences among fertiliser treatments. The maximum loss of N in leachate for both small leaching events was 32 mg/pot, which was equivalent to 0.6% of the total N in the pot and 7% of the applied N in fertiliser.

Both enhanced efficiency fertilisers were effective at reducing loss of N as N_2O 50 days after fertiliser application. Loss for DMPP was only 18% of the loss with urea and PCU loss was 62% of that with urea. However, the maximum daily loss of N as N_2O of 0.04 mg/pot/day at day 50 was very low in comparison to that lost in leachate (32 mg/pot) at the same time.

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