Nitrogen use efficiency for pasture production – impact of enhanced efficiency fertilisers and N rate

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Abstract
Nitrogen (N) use efficiency from granular urea application to pastures is often low (<50%) and could be improved by using enhanced efficiency fertilisers (EEFs). EEFs include nitrification inhibitors, urease inhibitors and controlled release fertilisers. A field trial established at Wye in South Australia (May-2014 to February 2015) compared biomass production in a rainfed perennial ryegrass pasture with urea and EEFs applied 5 times (May 6th, May 27th, July 3rd, August 21st and October 3rd 2014) at three N rates (17, 34 and 50 kg N ha-1). The EEFs applied were urea + urease inhibitor (n-(N-butyl) phosphoric triamide (NBPT) applied as Green UreaNV® (GU)), urea + nitrification inhibitor (3,4-dimethylpyrazole phosphate (DMPP) applied as Urea with ENTEC® (EU)) and polymer coated urea (2 month release) (PCU), and these were compared to urea (U). Cumulative biomass across all treatments ranged from 2.8 to 4.5 t dry matter (DM) ha-1. Biomass production increased with N input, but was reduced by the use of PCU. Cumulative apparent nitrogen use efficiency (NUE) (kg net-N uptake per unit N applied) ranged from 16 to 53%, and was generally greater with lower N input rates. NUE varied for each harvest, reflecting seasonal differences in biomass production, and between treatments. GU had the highest NUE at the lowest rate of N (17 kg N ha-1 per fertilisation event) suggesting substantial reductions in N loss. At higher N rates, N in excess of plant requirements may have prevented a response. The lower NUE of the PCU reflects the initial limited availability of N due to the slow release nature of the polymer coated fertiliser. The results show that efficient management of N in pasture systems requires matching N inputs to pasture requirements and this requires an understanding of the seasonal biomass responses and N losses that can occur.

Key words
Fertiliser nitrogen, surface broadcast, nitrogen loss

Introduction
Enhanced efficiency fertilisers (EEFs) are designed to reduce specific nitrogen (N) loss pathways. For example, the urease inhibitors slow urea hydrolysis and target ammonia (NH_3) volatilisation; the nitrification inhibitors slow nitrification and so target losses from nitrate (NO_3^-) leaching and gaseous emissions of nitrous oxide (N_2O) and dinitrogen (N_2) from nitrification and subsequent denitrification; the coated N fertilisers slow the release of N and so theoretically supply N at a rate that matches plant demand, reducing the risks of loss from all pathways. The EEFs have been reported to be effective in targeting different loss pathways from N applied to pastures (Suter et al. 2013; Singh et al. 2004), however the impact of the 'saved' N on biomass productivity is variable (Zaman et al. 2009; Dawar et al. 2011). The reasons for this remain unclear. Sometimes benefits may not be seen because experiments are established using standard grower application rates with and without addition of EEFs, so that sufficient N is being supplied even when losses occur. At other times the benefits may not be seen because climatic conditions are such that little N is lost through the targeted pathway. Therefore in order to assess the productivity benefit from the 'saved' N, experimental field trials need to apply N; 1) over a range of rates to incorporate those where N is applied below that required for optimal growth, and 2) across seasons to include the times when losses through the different pathways will be high. A small plot field experiment was established at Wye, SA (38^{o}01'16" S, 140^{o}53'12" E) on a rainfed ryegrass dominated pasture to assess the impact of different EEFs on biomass production, with N applied at three different rates (grower practice and 2 sub-optimal rates) over a nine month period (May 2014 to February 2015).

Materials and Methods
Background soil properties were measured across the plots prior to commencement of the experiment (12th April 2014). The soil at the site was a Tenosol; the surface horizon (0-10 cm) was a loamy sand with 3.7%

clay, 16.9% silt and 80.4% sand, and had an initial pH_{CaCl2} of 4.9. Soil total N and carbon (C) were 0.5% and 5.4% respectively. The bulk density of the soil was 1.0 g cm^{-3} (0-5 cm) and 1.1 g cm^{-3} (5-10 cm). The cation exchange capacity was 9.7 cmol (+) kg $soil^{-1}$. At commencement of the experiment the 0-10 cm soil layer contained 6.9 mg N kg^{-1} as ammonium (NH_4^+), 20 mg N kg^{-1} as nitrate (NO_3^-), 30 mg kg^{-1} Colwell P, 122 mg kg^{-1} available K, 0.5 mg kg^{-1} Zn (DTPA) and 12 mg kg^{-1} sulfate S (MCP). The pasture was dominated by perennial ryegrass with lesser amounts of cocksfoot, barley grass, subclover, and some annual grass species.

The small plot (5 m x 5 m) experiment was a completely randomised design with treatments replicated 4 times. The treatments were;

i) Control (no fertiliser, C),

ii-iv) Granular urea (U) at 3 rates (17, 34 and 50 kg N ha-1),

v-vii) Granular urea plus the nitrification inhibitor 3,4-dimethyl pyrazole phosphate (EU, applied as Urea with ENTEC®) at 3 rates (17, 34 and 50 kg N ha-1),

viii-x) Granular urea plus the urease inhibitor n-(N-butyl) phosphoric triamide (GU, applied as Green UreaNV®) at 3 rates (17, 34 and 50 kg N ha-1), and

xi-xiii) Polymer coated granular urea with a 2 month release pattern (PCU, applied as a 2 month release product at 3 rates (17, 34 and 50 kg N ha-1).

Each treatment was surface applied on May 6th, May 27th, July 3rd, August 21st and October 3rd 2014. No fertiliser was applied after October 3rd, as per standard local practice, as little pasture growth was expected due to high temperatures and low rainfall. The repeated N applications were made to the same plots to simulate standard pasture management practice of fertilisation following grazing. Total N application over the experiment was 85, 170 and 250 kg N ha^{-1} for the 17, 34 and 50 kg N ha^{-1} rates respectively. Basal nutrients were applied once on May 6th at a rate of 30 kg P ha^{-1}, 50 kg K ha^{-1} and 3.5 kg Zn ha^{-1}.

Biomass cuts (2.3 m^2) were taken from within each plot on May 26th (20 days after fertiliser (DAF)), July 3rd (37 DAF), August 21st (49 DAF), October 1st (41 DAF), October 23rd (20 DAF) in 2014, and February 9th 2015 (129 DAF). Collected biomass was dried at 60°C to constant weight for dry matter (DM) production (kg DM ha^{-1}). Subsamples were ground to a powder (~ 100 mm, Tissue lyser) and analysed for total C and N using a combustion technique (Hydra 20-20, SerCon).

Total rainfall (Figure 1) for the experimental period was 538 mm. For each pasture growth period the rainfall was 30 (May 6-26th), 197 (May 27th-July 3rd), 140 (July 3rd-August 21st), 44 (August 21st-October 3rd), 22 (October 3rd-October 23rd) and 106 (October 23rd-February 9th) mm.

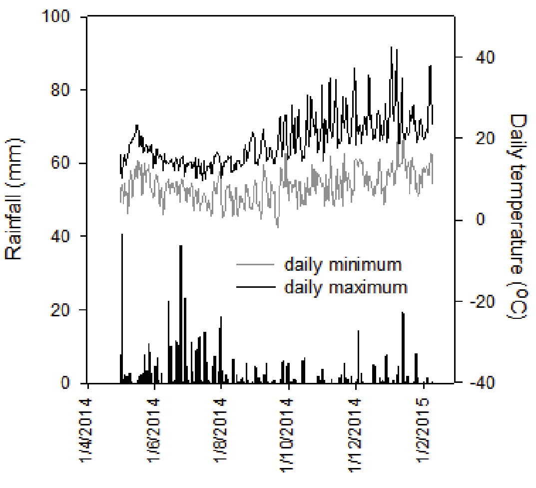

Figure 1: Rainfall and air temperature (minimum and maximum)

Results

Application of N increased cumulative biomass production by 40 to 220% compared to the control (2.0 ± 0.4 t DM ha^{-1}) (Table 1). The biomass response followed the growing seasons with significantly ($P<0.05$) more biomass (>1 t dry DM ha^{-1}) in the 21st August and 1st October harvests than in the other months (190-550 kg DM ha^{-1}). In addition there was significantly ($P<0.05$) more biomass in the July harvest (550 kg DM ha^{-1})

than in the 26th May, 23rd October, 9th February harvests (190-350 kg DM ha^{-1}). This is illustrated for the 34 kg N ha^{-1} application per fertilisation date in Figure 2. However there was no significant difference in the mean biomass production for the fertiliser treatments either cumulative (Table 1) or for each sample date (Figure 2).

Table 1. Average cumulative biomass and apparent nitrogen use efficiency (NUE) for the different treatments and N application rates, from May 2014 to February 2015 (± standard deviation).

N applied (kg N ha^{-1})$^{+}$	Biomass (t DM ha^{-1})			Apparent nitrogen use efficiency (NUE)* (%)		
	85	170	250	85	170	250
Treatment						
U	3.1 ± 1.1	4.1 ± 1.2	4.5 ± 0.9	47 ±32	40 ±21	33 ± 13
EU	3.0 ± 0.4	4.0 ± 0.9	4.2 ± 1.1	35 ± 16	37 ± 15	32 ± 17
GU	3.3 ± 0.6	3.8 ± 1.1	4.3 ± 1.2	53 ± 19	40 ± 173	34 ± 14
PCU	2.8 ± 0.8	3.0 ± 0.4	3.3 ± 0.4	36 ±29	21 ± 7	16 ± 15

*Apparent NUE = (N uptake in the treatment (kg N ha^{-1}) – N uptake in the control (kg N ha^{-1}))/(N applied (kg N ha^{-1})) x 100. N uptake = pasture DM (above ground biomass) (kg ha^{-1}) x N content (%) of the above ground biomass
$^{+}$ N applied is the cumulative rate for 5 applications of 17, 34 and 50 kg N ha^{-1}.

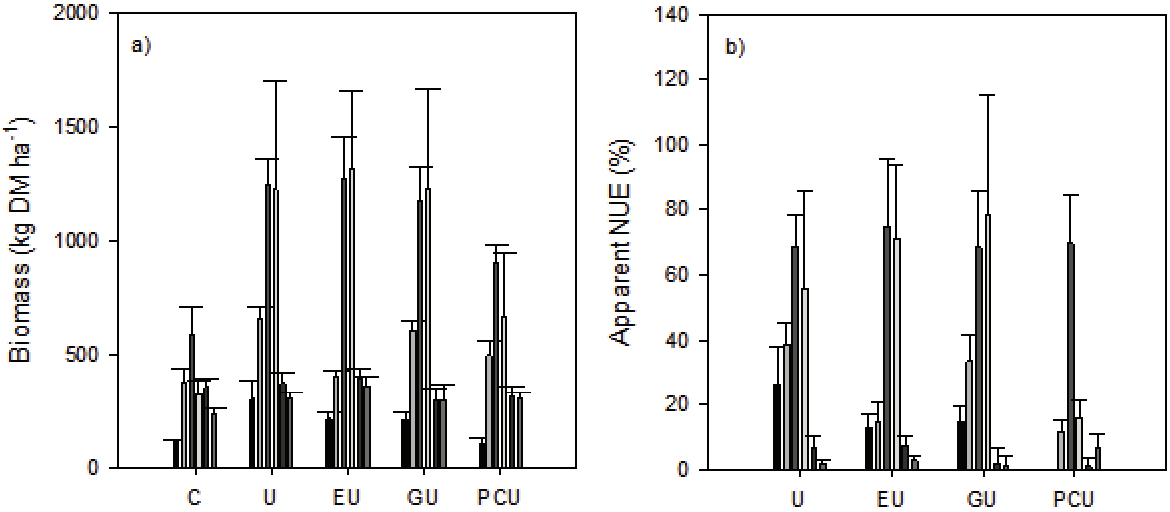

Figure 2: Biomass (a) and apparent NUE (b) for the different treatments at each sample date (May 26th (□), July 7th (□), August 21st (□), October 1st (□), and October 23rd (□) 2014, and February 9th (□) 2015) with application of 34 kg N ha^{-1} per fertilization date. Error bars are standard errors of the mean of 4 replicates.

The cumulative DM response averaged 10 kg DM per kg N applied (range 5-15) across all treatments. Across the individual harvests the DM response ranged from nil to 36 kg DM kg N^{-1}. There was a significantly ($P<0.05$) greater DM response to N in the 21st August and 1st October harvests (average 17 and 22 kg DM per kg N applied respectively). The average DM response to N in the 3rd July harvest (5 kg DM per kg N applied) was significantly ($P<0.05$) greater than that in the 26th May, 23rd October, 9th February harvests (-0.5-3 kg DM per kg N applied) (Figure 2).

There was no significant difference in the apparent NUE based on either the cumulative or individual pasture harvests across all treatments. The cumulative apparent NUE ranged from 16 to 53 % (Table 1). Apparent NUE across all treatments and all harvest dates ranged from -4 to 119% (data not shown), with greater efficiency at lower N application rates. There was significantly ($P<0.05$) higher NUE in the 21st August and 1st October harvests (average 69 and 61%, respectively). The highest NUE on both dates was for the GU17 treatment (91 and 119% on 1st October and 21st August respectively). The average NUE in the 3rd July harvest (26%) was significantly ($P<0.05$) greater than that in the 26th May, 23rd October, 9th February harvests (4-10%). The variation in apparent NUE with time of harvest is depicted in Figure 2 for the 34 kg N ha^{-1} application per fertilisation event rate.

Discussion

Temperature and rainfall fluctuated over the course of the experiment reflecting the different seasons, which led to variations in pasture biomass production (Figures 1 and 2).

The highest production period was between July and October when there was sufficient soil moisture for growth. The lowest production occurred in May, and late October to February which reflected hotter drier conditions, with only 129 mm of rain falling between October 1st 2014 and February 9th 2015. The site showed a responsiveness to N with increased N inputs leading to increased biomass production. However the increase in N inputs led to decreased NUE, suggesting a non-linearity in the N response curve across the N rates used. When conditions were optimal for growth (July to October) the NUE was highest as pasture growth was not limited by other factors. At other times the NUE was lower as other factors, such as limited water, affected the conversion of N into biomass. Overall the PCU had comparatively low NUE (particularly in May when the NUE was 0% due to the slow release and hence uptake of N), resulting from the slow release nature of the product (2 month release pattern). The release of N from the PCU product appears to be too slow for plant demand, particularly during periods of high growth.

The main reason for no observable major effect of the EEF treatments on biomass production and NUE over the course of the experiment, with the exception of the GU at lower rate, could be due to a combination of 1) other factors influencing biomass production (mainly water), particularly outside the July-October period, 2) low ammonia loss at other times, due to cooler wet conditions, so whilst N may be saved in the urease inhibitor (GU) fertiliser treatments this additional N only has a positive impact when N application is low (17 kg N ha^{-1}), 3) low loss from targeted pathways (eg. leaching and denitrification losses targeted by the nitrification inhibitors (EU)), and 4) high growth rates (optimal conditions) so that any small savings in N with the EEFs do not translate into biomass because the system is operating at a higher efficiency (NUE). Powell et al. (2010) report NUE from fertiliser in dairy pastures ranging from 17 to 77%, suggesting that the system we examined is operating at the upper end of NUE during periods of high productivity. The short term impacts of reducing N loss with the EEFs on biomass productivity may not been seen due to availability of sufficient N from the soil reserves (Total N 0.5%, 20 mg kg^{-1} NO_3^- at commencement of the trial).

Conclusion

Increasing N inputs to the rainfed ryegrass pasture led to greater biomass production, but reduced the NUE of the fertilisers. The role of EEFs was unclear, with improvements in productivity and NUE seen only for the GU on a single harvest date, and the PCU showed decreased productivity. Improving the efficiency of N management in pastures requires an understanding of the seasonally determined potential productivity and the drivers of low or high efficiency. Through this understanding, application of N to better match plant needs, whether through use of EEFs or by adjusting one or a combination of N rate, timing and choice of product, can be used to improve the efficiency of conversion of fertiliser N to pasture biomass.

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Acknowledgements

The work reported was from a project funded by the Department of Agriculture and Incitec Pivot Fertilisers.