Soil release dynamics and crop recovery of banded urea and Enhanced Efficiency Nitrogen Fertilisers (EENFs)

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Abstract
Improved synchronization of fertiliser nitrogen (N) and crop N demand is critical to increase nitrogen use efficiency (NUE) and thus improve productivity, farmer profitability, and environmental outcomes. New fertiliser technologies such as Enhanced Efficiency Nitrogen Fertilisers (EENFs) aim to slow the release of N into the soil and therefore improve NUE. This study compared the release dynamics, vertical and lateral soil distribution, and crop N recovery for banded granular urea and a range of EENF products. Granular urea was released into ammonium and nitrate forms at a linear rate over the first 80 days. Most EENFs were also released over the same period but at a slower rate initially, but no clear yield or crop N uptake advantages were observed. Two EENF products did not release fertilizer N quickly enough to meet crop demand, resulting in significantly poorer crop performance than urea. The results suggest EENF products did not improve NUE in this irrigated maize crop, and given the higher cost compared to urea, are unlikely to be adopted in commercial maize production systems.

Keywords
NUE, controlled release fertilisers, nitrification inhibitors, soil mineral N dynamics.

Introduction
Nitrogen use efficiency (NUE) remains low in agricultural systems, partly due to various chemical transformations and loss pathways inherent to soil (Cassman et al. 2002). Such processes can often result in large proportions of applied N being lost from the system before it can be utilized by the crop, leading to adverse economic and environmental outcomes. Enhanced efficiency nitrogen fertilisers (EENFs) have been highlighted as one potential solution for this challenge (Timilsena et al. 2015). These products work on the premise that delaying the release of N into the soil to better match crop uptake will aid in minimizing N losses and therefore increase NUE. However, the performance of EENFs under field conditions is often unpredictable. An improved understanding of the mechanisms by which N is released into the soil is critical to demonstrate their effectiveness under field conditions and encourage industry adoption.

Methods
Two field experiments were established at the University of Queensland, Gatton campus to investigate (i) the release and distribution dynamics of N from banded EENFs (*Experiment 1*); and (ii) N uptake and agronomic responses of an irrigated maize crop to banded EENFs (*Experiment 2*). Products included urea coated with the nitrification inhibitor DMPP (ENTEC©), and four controlled release fertilisers (CRFs), namely polymer coated urea (PCU90) and polymer coated potassium nitrate (PCKN90) with 90-day release profiles, and plant oil coated urea with 80 and 150-day release profiles (POCU80 and POCU150, respectively). Conventional granular urea was included as an industry reference and an unfertilised nil treatment accounted for background soil N dynamics. Fertilisers were band applied (10 cm soil depth) to a Black Vertosol at a rate of 150 kg N ha^{-1} (predicted to provide a sub-optimal rate of N supply relative to crop demand) spaced at 75 cm (approximately 15cm from maize rows) on 8 January 2020. The site mineral N status had been depleted previously by growing sequential summer and winter grain crops without fertiliser N application, thus crop demand on fertiliser N was maximised. All treatments were replicated four times in a randomized block design.

In *Experiment 1*, soil samples were collected at 7, 19, 46, 78 and 145 days after the onset of N release activity. Samples were collected to a depth of 22.5 cm in sampling locations aligned with fertiliser bands, partitioned into 5cm depth increments (vertically and laterally from the band). All samples were analysed for urea-N and mineral N (NO_3^- and NH_4^+) as well as pH and electrical conductivity (EC) to monitor changes in soil chemistry in and around the fertiliser band. Intact fertiliser granules recovered in soil samples were analysed for total N content to estimate the rate of N release to the soil solution.

In *Experiment 2*, urea-N was applied at rates of 0, 75, 150 and 300 kg N ha^{-1} to develop a reference N response curve and the EENF's were all applied at a rate of 150 kg ha^{-1}. Maize hybrid PAC 606IT was planted at a rate of 70,000 plants ha^{-1} and a depth of 6 cm on 17 January 2020. Experimental plots (10 m length) consisted of six maize rows with a spacing of 75 cm, each with an adjacent fertiliser band. Destructive biomass samples were collected close to anthesis and analysed for total N concentration. The crop was mechanically harvested on 7 July 2020, with central rows 3 and 4 targeted to remove grains from a 20 m linear length of the plot. Grain yield and N concentration were determined.

Results

Granule N release

Nitrogen release (%) from EENF granules (POCU80, PCU90, PCKN90, POCU150) was found to vary between products ($p < 0.001$) and with time ($p < 0.001$), with a significant interaction effect ($p < 0.01$; *l.s.d.* 13.9) (Fig 1). The PCU90 and POCU products performed similarly, except for the large initial release of N from POCU80 at 7 days, suggesting possible coating failure. The slowest N release was seen for PCKN90, which due to its lower N content (11% cf. ~ 40% for other CRFs in this study) and the consequent larger volume of product applied, may highlight a potential interaction between the density of granules in the band and nutrient release mechanisms (i.e., reduction in concentration gradient). While N release from POCU80 and PCU90 was complete (~85–90 %) at 78 days, the POCU150 continued to release N (~ 12 %) between 78 and 145 days, while the PCKN90 released just 71% of its N by the end of the experiment.

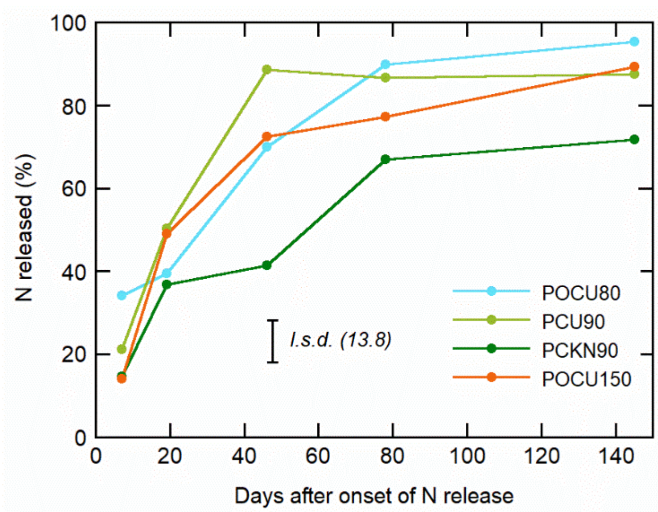

Figure 1. Total nitrogen (%) released from EENF granules (POCU80, PCU90, PCKN90 and POCU150) at 7, 19, 46, 78 and 145 days after onset of N release. Mean values at each time step shown.

Soil N dynamics

The net mass of fertiliser N (i.e., sum of urea-N, NO_3-N and NH_4-N recovered in all sample locations on and around the band) in the sampling zone through time for granular urea shows an approximately linear release pattern over the first 80 days (Figure 2a). The release of N from most EENFs was delayed relative to urea, although most release also occurred within the first 80 days (Fig 2b). Most release of N from POCU80 occurred within the first 40 days, which was much earlier than its intended 80-day release period. Release of N from DMPP-urea was more rapid than from granular urea over the first 46 days (Fig 2b), although most of this was retained in the ammonium form (data not shown). This is consistent with the inhibition of nitrification that is expected from DMPP.

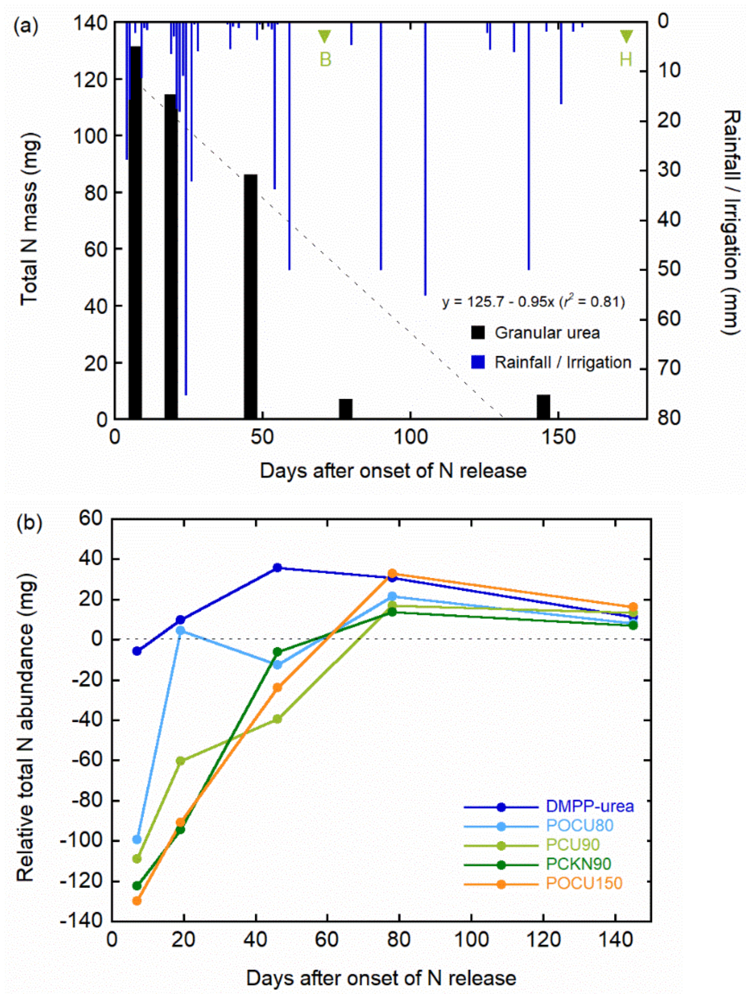

Figure 2. (a) Total mass of fertiliser N (mg) recovered in the soil sampling zone for granular urea (including rainfall and irrigation) and (b) mineral N (nitrate + ammonium + dissolved urea) for EENFs relative to granular urea at 7, 19, 46, 78 and 145 days following the onset of N release. Values shown are the mean of four replicates.

Agronomic performance

The crop showed significant responses to applied granular urea up to 75 kg Nha^{-1} for biomass at anthesis (63 days after sowing, DAS), and up to 150 kg ha^{-1} for N uptake at anthesis (Table 1). Both grain yield and grain N content showed significant responses up to 300 kg ha^{-1}. The rate of 150 kg ha^{-1} at which the EENFs were compared was therefore in a responsive part of the N response relationship only for grain yield and grain N content.

Despite the obvious differences in N release patterns, none of the EENF products resulted in a greater biomass production, grain yield or grain N relative to conventional granular urea at the same rate (Table 1). One EENF (PCKN90) was incompletely released, resulting in significantly lower grain yield and grain N. The lack of any advantage of the EENFs over granular urea, even during the wettest period of the season, suggests that either N losses during the growing season were minimal, or that any reduction in loss afforded by the slower N release pattern of EENFs was not sufficient to overcome the yield penalty due to insufficient supply early in the growing season. Early season demand for N by maize is generally low (approximately 20% within the first 40 DAS), after which it rapidly increases as the rate of biomass accumulation increases up to approximately 100 days (O'Keeffe 2009).

Table 1. Biomass production (t ha^{-1}), crop N uptake (kg N ha^{-1}), grain yield (t ha^{-1}) and grain N removal (kg N ha^{-1}) for standard granular urea at 0, 75, 150 and 300 kg N ha^{-1} and EENFs applied at 150 kg N ha^{-1}

	Anthesis		Grain	
	Biomass (t ha^{-1})	N uptake (kg N ha^{-1})	Yield (t ha^{-1})	Grain N (kg N ha^{-1})
N response curve (urea fertiliser, kgN ha^{-1})				
0	5.1^{a}	40.0^{a}	3.2^{a}	28.4^{a}
75	9.6^{b}	106.5^{b}	6.8^{b}	70.0^{b}
150	11.2^{b}	162.9^{c}	9.5^{c}	109.6^{c}
300	11.1^{b}	167.4^{c}	10.9^{d}	138.0^{d}
l.s.d.	*2.2*	*28.2*	*1.2*	*16.6*
Relative performance of EEFs (150 kg N ha^{-1})				
Urea	11.2^{ab}	162.9^{b}	9.5^{c}	109.6^{b}
DMPP-urea	12.8^{b}	202.3^{b}	8.3^{b}	113.2^{b}
POCU80	11.2^{ab}	181.1^{b}	9.8^{cd}	117.6^{b}
PCU90	12.5^{b}	188.7^{b}	8.1^{b}	108.7^{b}
PCKN90	10.0^{ab}	136.3^{ab}	5.8^{a}	78.5^{a}
POCU150	9.1^{a}	112.2^{a}	8.6^{bc}	97.7^{ab}
l.s.d.	*2.1*	*43.7*	*1.1*	*21.3*

Discussion

The application of EENFs delayed fertiliser N release relative to standard urea, although variation between products was evident. The plant oil coating POCU80 was almost fully released within 40 days, which was more rapid than its target period of 80 days, suggesting that when coating thickness is limited, plant oil coatings may provide a reduced capacity to support the gradual release of N into the soil. In contrast, PCU90 had a polymer coating of sufficient structural integrity to release N gradually over the target 90-day period. Granule N release was slowest for POCU150 and PCKN90, highlighting that increased coating thickness (POCU150) and increased granule density (PCKN90) in the band may both result in increasingly gradual N release. DMPP was found to inhibit nitrification for approximately 46 days, and consequently conserved the mass of N within the sampling zone, longer than conventional granular urea.

Despite the obvious differences in N release dynamics across EENF technologies, there were no clear advantages relative to banded urea in terms of crop productivity and grain yield. The lack of any advantage over urea, even during the wettest part of the season, suggests either N losses were minimal during the growing season or the reduction in losses afforded by the slower release of N from EENFs was not adequate to overcome the yield penalty due to insufficient supply of N early in the growing season. In this irrigated maize crop, EENF products did not demonstrate improved NUE. Given the higher cost of these EENFs compared to granular urea, EENFs are unlikely to be adopted in these agricultural systems.

References

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