

Effective use of enhanced efficiency nitrogen fertilizers when applied in sub-surface bands

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Abstract

Enhanced efficiency fertilisers (EEFs) are a tool for improving nitrogen (N) use efficiency (NUE) in agricultural systems. Whilst broadcast/dispersed EEF applications have been extensively investigated, EEF efficacy is poorly understood when applied as concentrated sub-surface bands. Laboratory incubations and a field experiment investigated N release, transformation and distribution dynamics from banded EEFs in several soils, with results benchmarked against granular urea. Banded urease inhibitor-coated urea demonstrated few characteristics that would enhance NUE. Nitrification inhibitors preserved N as ammonium in soils which restrict solute movement (i.e., high cation exchange capacity, clay and organic matter content) but showed few benefits in coarser-textured soils. Controlled-release fertilizers slowed urea hydrolysis and associated chemical impacts, allowing rapid nitrification of released N. Banding significantly affected EEF efficacy, with findings indicating that soil physicochemical properties and moisture dynamics were key determinants of effective utilization.

Keywords

Nitrification, inhibitors, controlled-release, urea hydrolysis, fertilizer management, soil fertility

Introduction

Enhanced efficiency fertilizers (EEFs) utilize controlled-release or nitrogen (N) stabilizing mechanisms that improve the opportunity for crop recovery of N-fertilizer, reducing potential environmental losses. Controlled-release fertilizers (CRFs) aim to improve the synchrony of N release to crop demand by regulating N release through characteristics of a coating material and the thickness of the coating layer (Azeem et al. 2014). Nitrogen stabilizing mechanisms typically utilize urease or nitrification inhibitors coated onto urea granules with the aim of reducing the enzymatic conversion of more 'stable' N forms to loss-susceptible nitrite (NO_2^-) and nitrate (NO_3^-). Similarly, banding of fertilizers in and / or near the root zone can enhance the opportunity for nutrient uptake by plants and minimize loss risks (Sandral et al. 2017). Whilst sub-surface banding of N-fertilizers is a commonly used strategy in a range of row crops, the performance of EEFs in banded application is unknown and preliminary studies (Janke et al. 2019) indicate considerable modification of soil chemical conditions within the band may limit the efficacy of these products. This paper details findings from laboratory and field experiments which investigated the distribution and transformation of N and inhibitors from fertilizer bands of a urease inhibitor (UI)-coated urea, a nitrification inhibitor (NI)-coated urea and a controlled-release polymer-coated urea (PCU), benchmarked against 'standard' granular urea.

Methods

Laboratory studies

The diffusive movement and transformation of N within and outside of EEF bands was initially tested under controlled conditions in soils of contrasting physico-chemical properties (Table 1). The laboratory studies also enabled detection of inhibitor distribution over time. Briefly, soil at field capacity and fertilizer treatments were incubated in round dishes (225 mm diameter) for 16 days at 25 ± 2 °C with fertilizers placed as a central band at an application rate equivalent to 150 kg N ha^{-1} (in-band concentration of 27 g N m^{-1}). Three wicks (6 mm diameter, 45 mm length of natural cotton cord) were placed vertically in an offset pattern at distances of 0-1 cm from the band (one wick only), 10-30 mm, 30-50 mm, 50-70 mm, 70-90 mm and 90-110 mm. Destructive samples were taken at 2, 6, 9 and 16 days after fertilization (DAF), with the wicks removed and scraped clean prior to soil sampling. Soil samples were taken concentrically, beginning within the fertosphere (0-10 mm zone) and moving outwards at the aforementioned distance zones. Soil samples were tested for pH, EC in 1:5 soil-water (w/v) suspensions and extracted for mineral N using a 1:5 (w/v) soil-solution extraction with 2M KCl. Aqueous ammonia (NH_3) concentrations in soil solution were calculated by applying the pK_a value of the $\text{NH}_4^+ \leftrightarrow \text{NH}_3$ reaction at 25°C to the formula detailed in Erickson (1985). Wicks were extracted in ultra-pure water at an extraction ratio of 1:6 (w/w) and analysed for urea-N and inhibitor concentrations using high performance liquid chromatography (HPLC; Janke et al. 2021).

Field experiment

The same banded fertilizer treatments were applied in the field at the Gatton Campus (University of Queensland, 27° 34' 06'' S, 152° 19' 55'' E) made up of a Grey Vertosol (Table 1). This enabled refinement of findings from the laboratory studies to field scenarios where mass flow through fertilizer bands may influence N dynamics (Janke et al. 2020). Briefly, all fertilizer treatments were applied at a rate of 150 kg N ha⁻¹ (in-band concentration of 27 g N m⁻¹) at a 12 cm depth. Urea and NI-urea fertilizer treatments were also applied at rates of 50 and 100 kg N ha⁻¹ (9 and 18 g N m⁻¹) to determine if in-band concentration of N and NI impacted inhibitory effects and efficacy of NI-urea. Samples were taken at 7, 21, 34 and 49 DAF by excavating a small trench perpendicular to the fertilizer band. Once the band was located, an open-face profile sampler was inserted to a depth of 0.25 m, sheet metal was inserted vertically down the open front, the two pieces clamped together and removed from the soil. In-tact soil blocks were wrapped in plastic and cool stored (3-5°C). In the laboratory, soil blocks were sectioned into 50 mm grids encompassing 9 individual zones of varying vertical and lateral distance from the band. The analysed zones included (distances as mm from centre of band zone): (1) 75–125 mm directly above; (2) 25–75 mm at 45° above; (3) 25–75 mm directly above; (4) 75–125 mm lateral distance; (5) 25–75 mm lateral distance; (6) band zone (fertosphere): 0–25 mm horizontal and vertical; (7) 25–75 mm at 45° below; (8) 25–75 mm directly below; and (9) 75–125 mm directly below. All 9 zones were analysed for pH, EC, and mineral N species as described for the laboratory studies and aqueous NH₃ was similarly calculated. Urea-N concentrations were determined from a sub-sample of soil, extracted in a 1:5 (w/v) soil-water suspension and analysed using HPLC.

Table 1 Soil chemical properties and physical characteristics. Where, EC is the electrical conductivity; pHBC is the pH buffering capacity; CEC is the cation exchange capacity; and TOC is total organic carbon.

	Soil Order ¹	pH	(dS m ⁻¹)	(cmol OH·kg ⁻¹ pH unit ⁻¹)	Particle size analysis (%)				(cmol(+) kg ⁻¹)	(mg kg ⁻¹)
			EC	pHBC	Coarse sand	Fine sand	Silt	Clay	CEC	Mineral N
Laboratory studies	Yellow Dermosol	6.30	0.07	1.32	38	46	9	9	4.5	10
	Black Vertosol	7.15	0.35	3.51	5	26	21	52	28.5	13.3
Field experiment	Grey Vertosol	7.80	0.07	-	3	16	21	62	49.3	2

¹Isbell (2016)

Key Results

The 'standard' urea band creates a chemical environment which inhibits nitrification

Rapid hydrolysis of a urea band resulted in significant localized increases in pH (>9.0), electrical conductivity (1.5 – 2.5 dS m⁻¹) and aqueous NH₃ (10 - 30 mg L⁻¹), with the magnitude and extent of chemical changes dependent on soil type. In the lighter-textured Dermosol, these changes occurred as far as the 70-90 mm zone whereas the higher pH buffering capacity (pHBC), cation exchange capacity (CEC) and clay content of the Vertosol limited major changes in soil chemistry to the 10-30 mm zone. These zones of chemical modification corresponded with zones of inhibited nitrification as microbes hosting the enzymes responsible for the nitrification pathway were inhibited in response to elevated pH and aqueous NH₃ concentrations.

Soil physico-chemical properties dictate nitrification inhibitor efficacy

Laboratory incubations determined that soil physico-chemical properties that dictate solute movement were the dominant factors influencing NI efficacy (Janke et al. 2021). In soils where cation diffusion may be restricted (i.e., high clay, high organic matter, high CEC), the movement of NH₄-N from the fertosphere was limited. As ureolytic-induced chemical changes dissipated, the zone of nitrification was more closely aligned to inhibitor distribution (*ca.* 10 mm from fertosphere in both soils) *cf.* soils that support diffusive movement. Very little difference was seen in N transformation and distribution between the urea and DMPP-urea treatments in the Dermosol. However, a significant reduction in the production of NO₂-N and NO₃-N was observed in the later stages of the incubation in the Vertosol. In the field (Vertosol), inhibitory effects on nitrification in NI-treated soils were observed for *ca.* 50 days longer than with standard urea (Figs. 1, 2). This is considerably longer than inhibitory effects reported from broadcast/incorporated application (*ca.* 14 – 30 days; Guardia et al. 2018). Varying the rate of NI-urea application altered the extent and duration of

nitrification inhibition (Janke et al. 2020). In addition to mitigation of N losses, this effect of rates on inhibitory duration has implications for N availability to plants, particularly for crops reliant on $\text{NO}_3\text{-N}$ and where fertilizer application is close to critical/peak crop N demand (i.e., short season crops).

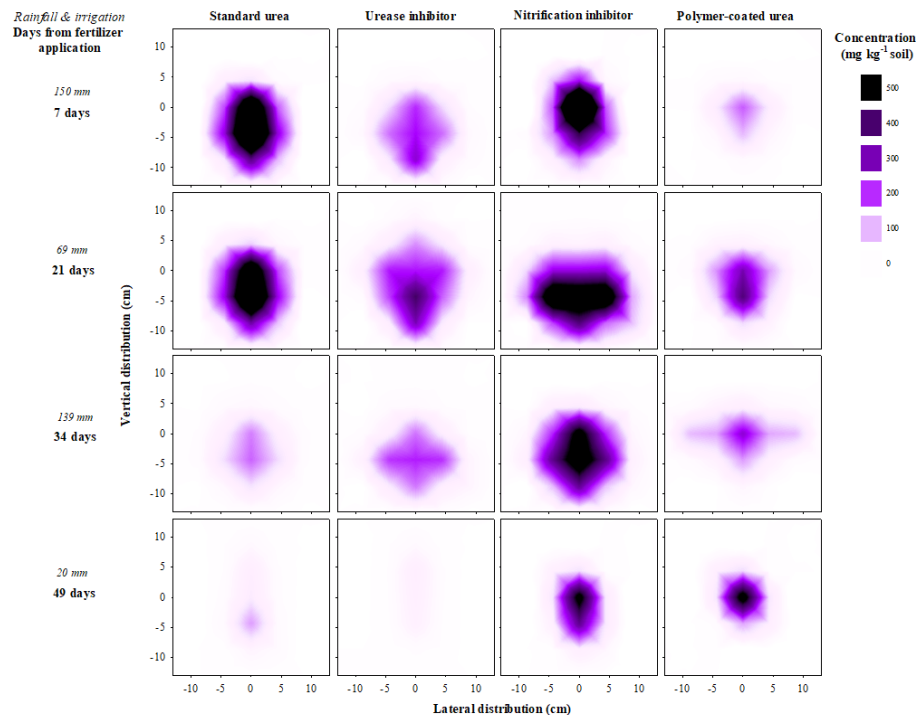


Figure 1. Distribution of $\text{NH}_4\text{-N}$ (mg kg^{-1} soil) over time in a grey Vertosol profile (field experiment) treated with 150 kg N ha^{-1} of banded N-fertilizer.

Banded urease inhibitors do not offer potential NUE benefits

Banded NBPT-urea slowed urea hydrolysis for *ca.* 7 – 21 days, as demonstrated by reduced $\text{NH}_4\text{-N}$ concentrations (Fig. 1). This is consistent with studies of broadcast/incorporated application (Cantarella et al. 2018) and indicates UI efficacy is not influenced by banding. However, preservation of N as urea permitted leaching of these uncharged molecules and resulted in deeper N distribution into the soil profile (Fig. 1). In this zone, changes in soil chemistry were minimal (Janke et al. 2020), enabling rapid nitrification (Fig. 2) despite lower $\text{NH}_4\text{-N}$ concentrations (*cf.* standard urea). Applied in sub-surface bands, UIs are unlikely to deliver improved NUE outcomes when compared to standard urea.

Release and availability of N from CRFs may be complicated by banding and soil moisture status

Laboratory experiments demonstrated that banding PCU limited the availability of N to soil solution as a result of diminished concentration gradients slowing diffusive release. This extended the predicted release period and resulted in an unpredictable N supply. In the field, the relatively ‘benign’ chemical conditions of PCU bands produced nitrification rates similar to that of standard urea (*ca.* ratios of 46% [$\text{NO}_3\text{-N} : \text{NH}_4\text{-N}$], Figs. 1, 2). This suggests that under prolonged wet conditions, if nitrified N is not rapidly assimilated into the crop, then there is increased risk of denitrification and/or leaching loss. However, water uptake and release is part of the N release mechanism in PCU granules; dry soil conditions will reduce N release and potentially lock N within the granules. Soil moisture is therefore a key factor influencing PCU efficacy. An additional effect of slow N release was the reduction in N distribution around PCU bands by *ca.* 0.05 m *cf.* standard urea (Figs. 1, 2). Effective N crop uptake from PCU bands will likely rely on placement of the fertilizer band close to the root zone.

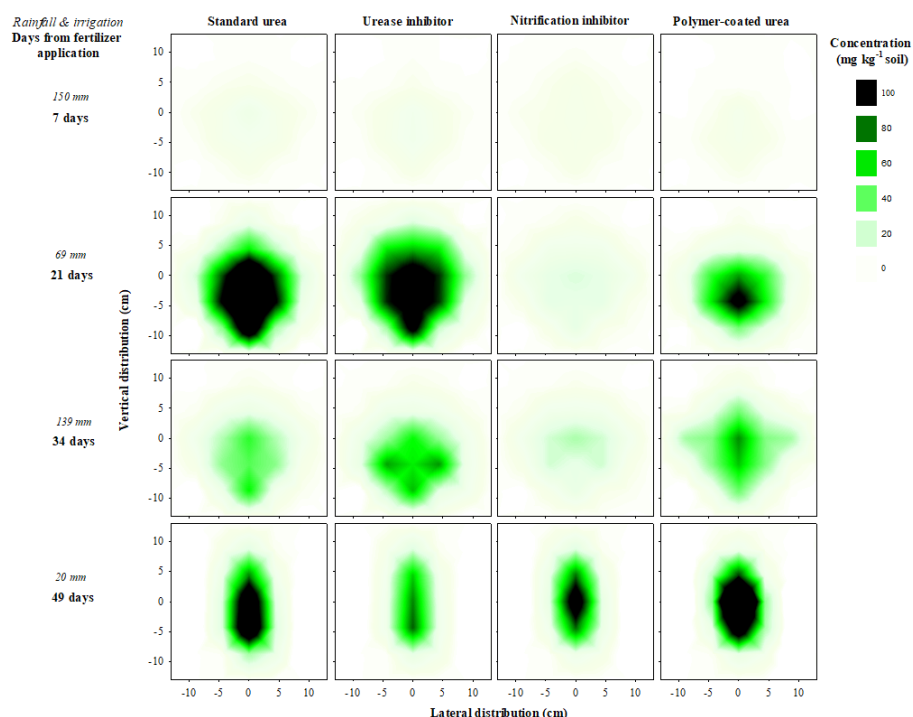


Figure 2. Distribution of $\text{NO}_3\text{-N}$ (mg kg^{-1} soil) over time in a grey Vertosol profile (field experiment) treated with 150 kg N ha^{-1} of banded N-fertilizer.

Conclusion

Understanding the impacts of banding on EEF efficacy will assist in the effective utilization of EEFs for improved NUE in agricultural systems. When applied in concentrated bands, the efficacy of NIs is largely dictated by soil properties which influence inhibitor distribution. Whilst still effective, UIs offer minimal benefits for improving NUE when applied in sub-surface bands. Nitrogen dynamics from CRF bands can be unpredictable with release likely influenced by soil moisture status. Fertilizer application method, soil type and moisture are key factors influencing EEF efficacy.

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