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ENHANCED EFFICIENCY FERTILISERS FOR AGRICULTURAL SUSTAINABILITY AND ENVIRONMENTAL QUALITY IN AUSTRALIA

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Introduction

Increasing demand for food and fibre has led to an increase in fertilizer N use worldwide. In Australia in 2002, 972 Gg of fertilizer N was used with the majority used on cereals. However, nitrogen fertilizer efficiency is low, for example wheat plants assimilate only around 41% of applied nitrogen (Chen *et al*, 2008a). Losses of nitrogen can have both an economic and environmental impact. Australian agriculture is the greatest contributor to the national emissions total of the greenhouse gas (GHG) N₂O, and there is increasing interest in the role of nitrogen fertilisers in these emissions (AGO 2007, IPCC 1997). Improvements in the efficiency of fertilizer nitrogen can be achieved through changes in land management practices, but even the best management practices cannot reduce all nitrogen loss pathways in all situations. Under conditions where losses will still occur it may be possible to use enhanced efficiency nitrogen fertilizers, such as controlled release products, and urease and nitrification inhibitors to improve the efficiency of applied nitrogen. Studies have shown that these products have the potential to reduce nitrogen losses and/or improve plant yields when used in Australian irrigated agriculture, however studies on Australian dryland agricultural systems are limited as are studies under a range of temperature conditions likely to be experienced in Australian agroecological zones.

Enhanced Efficiency Fertilisers (EEFs)

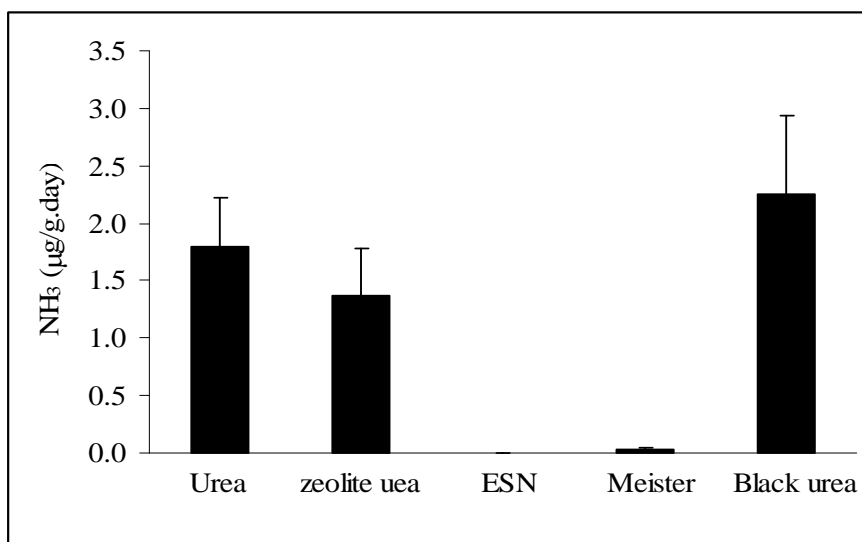
1. Controlled Release Fertilisers (CRF)

Controlled release fertilisers have been used for many years and range from simple sulphur coated urea to more sophisticated forms such as polyolefin coated products that have specific release patterns and timelines that correspond to the required crop nutrient uptake (Shaviv 2005). Controlled release fertilisers have been shown to increase plant yields in some but not all studies (Chen *et al*. 2008, Shoji *et al*. 2001) and in some studies reduced N₂O emissions have been observed (Shoji and Kanno 1994). Controlled release fertilisers are used only to a small extent in Australian agriculture due mainly to their high cost. No yield effect was found in irrigated cotton in Australia by using polyolefin-coated urea, although there were significant impacts on N uptake and mineral N (urea, ammonium, and nitrate) dynamics (Chen *et al*, 2008b).

Incubation studies were conducted recently to investigate the effectiveness of four controlled release urea fertilisers, Zeolite coated urea, ESN (polymer coated urea), Meister (polyolefin coated urea) and Black urea (humic acid coated urea), on urea hydrolysis, potential NH₃ losses, nitrification and nitrous oxide (N₂O) emissions in a wheat cropping vertosol from the Wimmera in Victoria under different soil moisture and temperature (Chen *et al*, 2007, Incitec Report).

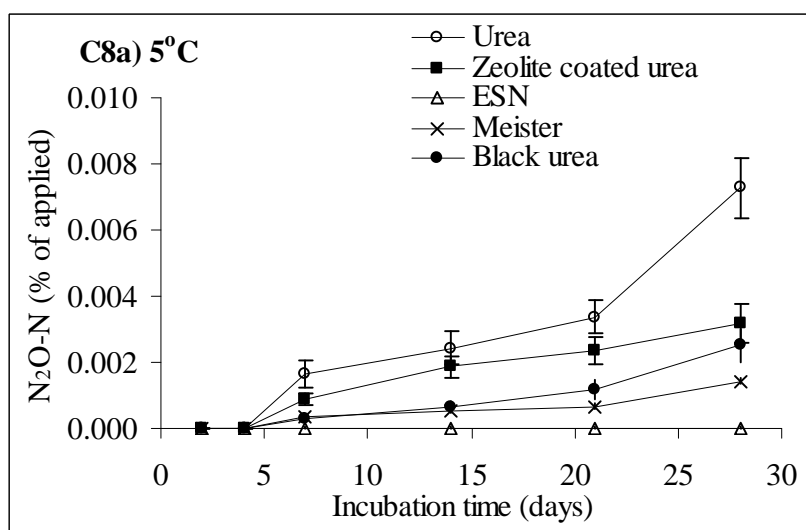
The effect of the controlled release urea fertilisers on mineral N (ammonium and nitrate) concentrations were not consistent but appeared to be more effective at lower soil moisture levels. ESN and Meister were the most effective in reducing the potential NH₃ losses under moist and warm conditions (Fig 1).

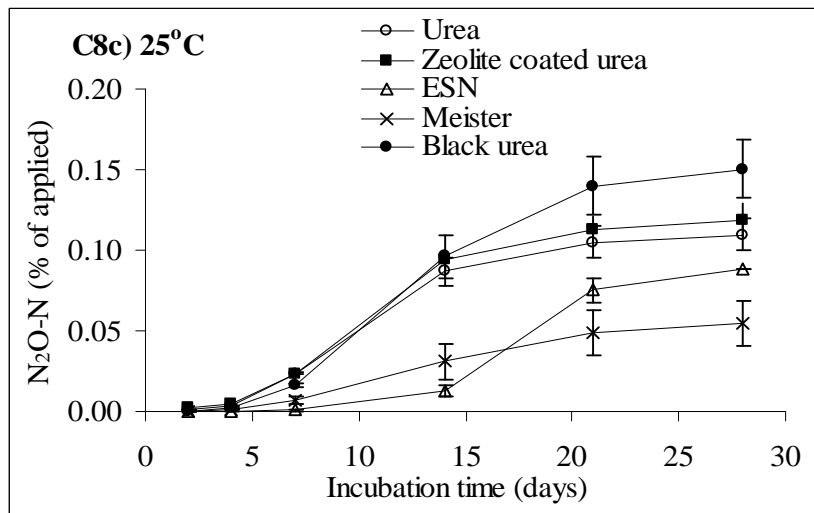
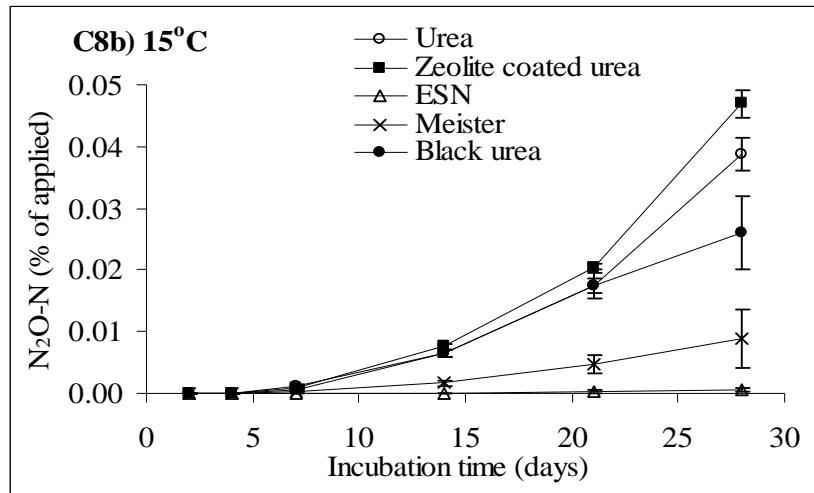
Figure 1. Ammonia (NH₃) volatilization losses measured on Day 2 of the experiment for each of the controlled release fertilizers on the wheat cropping vertisol at 50% WFPS and 25°C.



The N₂O emissions were also significantly lower in all the controlled released fertilisers at cool temperatures, ESN and Meister were effective at all temperature (Fig. 2).

Figure 2. Cumulative nitrous oxide (N₂O) emissions for each of the controlled release fertilizers on the wheat cropping vertisol at 50% WFPS.





2. Urease Inhibitors

Urease inhibitors reduce the hydrolysis of urea to ammonium (NH_4^+) and ammonia (NH_3) and play a major part in preventing NH_3 loss. They do this by inhibiting ureases, which are widespread in soil and the environment, which catalyse urea hydrolysis. Their greatest benefit will be in situations where surface applied urea hydrolyses but is not washed into the soil. Numerous urease inhibitors exist including natural products such as neem, and other compounds such as metal ions, structural analogues of urea, including the phosphorylamides, with the later including such compounds as NBPT (N-(*n*-butyl) phosphoric triamide) and CHPT (cyclohexylphosphoric triamide) which are amongst the most effective compounds. NBPT has been extensively tested in many parts of the world and has been found to be effective, with efficacy depending upon such things as temperature and soil type (Carmona *et al.* 1990, Watson and Miller 1996).

Laboratory incubation studies (40 g soil) have shown that NBPT (0.1% w/w urea) reduced urea hydrolysis on a wheat cropping Vertosol from western Victoria and sugarcane trash and that the reduction in urea hydrolysis was temperature dependent (Fig 3). The urea hydrolysis on sugarcane trash was much more rapid than on the wheat cropping soil, which is most likely as a result of the high sugarcane urease activity. Studies have found plant urease activity to be around 10 times that of soil (Watson and Miller 1996). NBPT (0.1% w/w urea) was able to reduce the rate of urea hydrolysis at temperatures as high as 45°C for at least 10 days (Fig 3). By day 10 the amount of urea hydrolysed was the same at 25 and 45°C with NBPT.

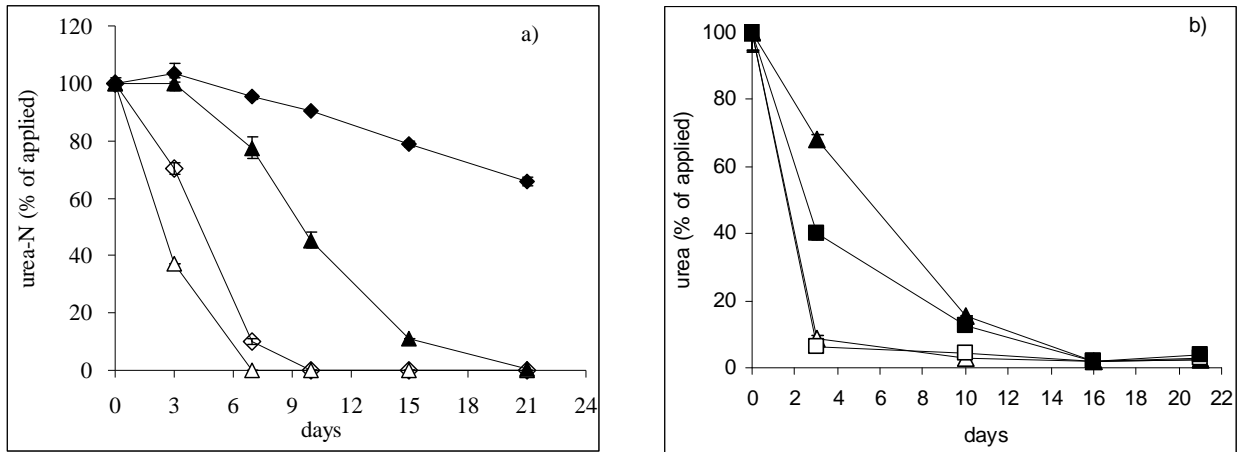


Figure 3. Urea (% remaining in a) a wheat cropping soil, and b) sugarcane trash at 15°C from urea (◇) and urea + NBPT (◆), at 25°C from urea (△) and urea + NBPT (▲), and at 45°C from urea (□) and urea + NBPT (■).

The continuous air flow chamber studies on sugarcane trash showed that NBPT was very effective at reducing NH₃ volatilisation from surface applied urea at 25°C (Fig 3) from day 1 to day 8. NH₃ emissions were reduced with NBPT by 54% for sugarcane and 74% for wheat soils, making NBPT an effective N-loss mitigation tool for the sugarcane industry in temperate climates.

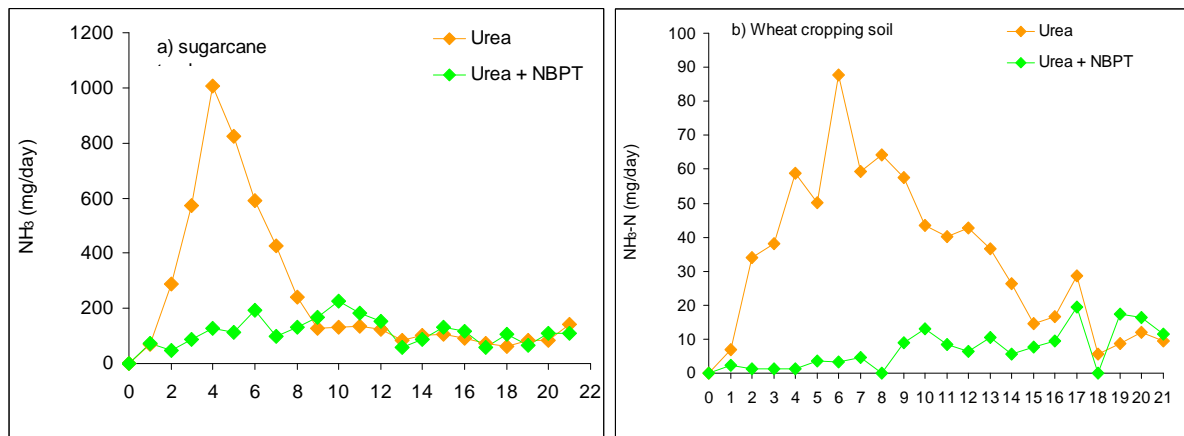
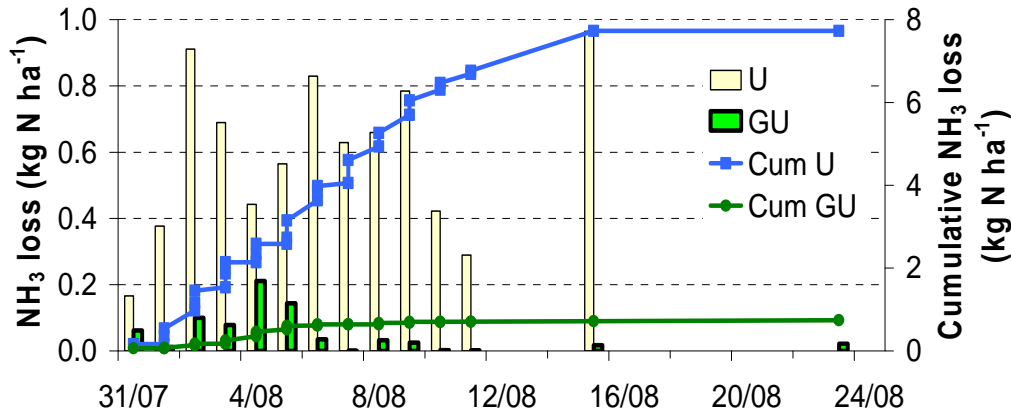


Figure 4. NH₃ emissions from urea and urea + NBPT surface applied to a) sugarcane trash at 25°C and b) a wheat cropping soil from western Victoria in a controlled flow chamber experiment.

Figure 5. Daily and cumulative NH₃ losses for the urea (U and Cum U) and green urea (GU and Cum GU) treatments in a wheat cropping soil in Victoria. (Note: losses for the 15/08 & 23/08 are accumulated losses since previous measurement).



In the field study on a wheat cropping soil from the Wimmera District in Victoria using micrometeorological measurements techniques, NH₃ losses were reduced from 7.7 kg N ha⁻¹ (9.7% of applied N) for the urea treatment to 0.8 kg N ha⁻¹ (1.0% applied N) for the green urea (Urea + NBPT) treatment (Fig. 5).

3. Nitrification Inhibitors

Nitrification inhibitors reduce the oxidation of ammonium (NH₄⁺) to nitrate (NO₃⁻) and hence reduced the risk of NO₃⁻ leaching loss and emissions of N₂O from nitrification or denitrification. The greatest benefit will be where NO₃⁻ leaching and denitrification are high (eg. coarse soils, wet conditions). Numerous nitrification inhibitors exist, some of which have been tested extensively (eg. N-serve, dicyandiamide (DCD)), and others which are newer (eg. 3,4-dimethylpyrazole phosphate (DMPP)). Their efficacy is dependent upon temperature, moisture and soil type (Di and Cameron 2004, Zerulla *et al.* 2001). Other nitrification inhibitors that have been used successfully in field trials include acetylene and substituted acetylenes, such as acetylenes 2-ethynylpyridine and phenylacetylene. These products are very effective inhibitors of nitrification in the field (Chen *et al.*, 2008a), but their current price restricts their use by farmers. A polyethylene matrix containing small particles of calcium carbide and various additives to provide controlled water penetration and acetylene release, has been developed as an alternative slow-release source of acetylene.

DCD appeared to be less stable under warm and moist conditions, such as sugarcane fields in north Australia and irrigated pasture in southern Australia in the summer. DMPP shows more promise for inhibition under warmer conditions, for example it inhibited up to 90% of nitrate and N₂O production in incubation studies at both 25 and 35°C in a sugarcane Ferrosol from far north Queensland, (Fig. 6).

Figure 6. NO_3^- -N in the Ferrosol with urea (granule or powder) +/- DMPP at a) 25°C and b) 35°C.

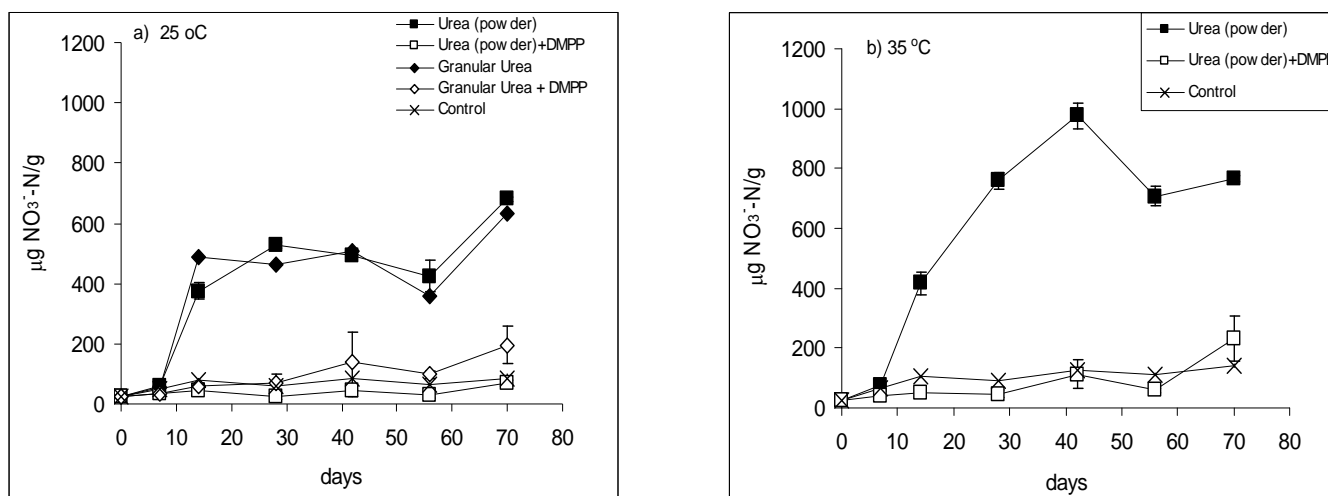
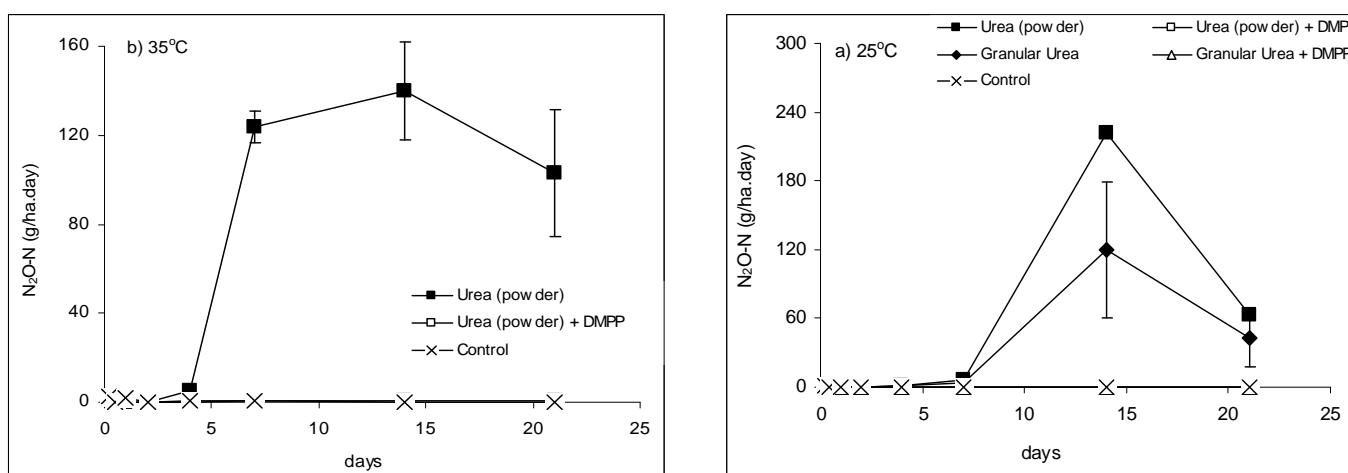


Figure 6. N_2O in the Pin Gin Ferrosol with urea (granule or powder) +/- DMPP at a) 25°C and b) 35°C.



Conclusions

Enhanced efficiency fertilisers show promise for use in Australian agricultural systems to improve N use efficiency, but the results have been inconsistent. The causes of inconsistency are not fully understood because the processes are complex. There have not been any comprehensive system-based studies of the impact of EEFs on N cycling and plant growth and interactions of EEFs with other nutrients (such as phosphorus) in soil and environmental conditions. A process based agroecosystem model, capable of incorporating all soil and environmental variables, management practices, plant growth and interactions with other N processes and other nutrients, is required for such a complex system. A number of process-based agroecosystem models have been developed for the purpose of simulating crop growth and nutrient cycling, such as DNDC, Daycent and WNMM (Chen *et al.* 2008c). However, there have been no comprehensive studies of the impact of EEFs and incorporation of EEFs into systems modeling. By simulating different management, environmental and climate scenarios, such a model could be used to develop a decision tool for fertiliser N management. This has been done for conventional fertiliser in the irrigated maize and wheat system in the north China Plain, and it significantly enhanced the dissemination of best management practices for fertiliser N (Chen *et al.* 2006).

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