Field Crops Research 225 (2018) 47–54

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

No evidence for higher agronomic N use efficiency or lower nitrous oxide emissions from enhanced efficiency fertilisers in aerobic subtropical rice

Terry J. Rose[a,b,*], Peter Quin[c], Stephen G. Morris[d], Lee J. Kearney[a], Stephen Kimber[d], Michael T. Rose[d], Lukas Van Zwieten[a,d]

[a] Southern Cross Plant Science, Southern Cross University, PO Box 157, Lismore, NSW, 2480, Australia
[b] Centre for Organics Research, Southern Cross University, PO Box 157, Lismore, NSW, 2480, Australia
[c] Tasmanian Institute of Agriculture, School of Land and Food, University of Tasmania, Private Bag 98 Hobart, Tasmania, 7001 Australia
[d] NSW Department of Primary Industries, 1243 Bruxner Highway, Wollongbar, NSW, 2477, Australia

ARTICLE INFO

Keywords:
Aerobic rice
DMPP
Entec®
NBPT
Polymer coated urea
Urea

ABSTRACT

Enhanced efficiency nitrogen (N) fertilisers (EENFs) contain chemical urease or nitrification inhibitors, or physical barriers (e.g. polymer coating) to minimise the rapid build-up of nitrate (NO_3^-) in soils. They have the potential to improve N use efficiency and lower N_2O emissions from soils. However, evidence of the efficacy of EENFs in warm, wet subtropical conditions is lacking. We therefore developed N response curves (0, 30, 60, 90, 120 and 150 kg N ha^{-1}) for urea, polymer coated urea (PCU), 3,4-dimethylpyrazole phosphate (DMPP)-urea (Entec®), N-(n-butyl) thiophosphoric triamide (NBPT)-urea (Green urea®) and a carbon-coated urea (Black urea®) in subtropical, aerobic rice (*Oryza sativa* L) crops in two fields with contrasting soils (Gleysol and Histosol), and quantified N_2O emissions from nil-N and 90 kg N ha^{-1} treatments for all EENFs and urea. In the Gleysol, cumulative in-crop N_2O emissions were relatively high (approximately 2 kg N_2O-N ha^{-1} $season^{-1}$ with 90 kg N ha^{-1} applied) with no significant mitigation from any EENFs compared to urea. Grain yield data fitted with an exponential model indicated that 95% of the estimated maximum grain yield (6.8 t ha^{-1} at 14% moisture) was achieved with 81 kg N ha^{-1} for the urea treatment. The yield response curves for all tested EENF products did not differ significantly from the urea-N yield response curve. In the Histosol, cumulative in-crop N_2O emissions were negligible (around 0.05 kg N_2O-N ha^{-1} $season^{-1}$), with no significant difference ($p < 0.05$) between N fertiliser or nil-N treatments, and 95% of the estimated maximum grain yield (5.63 t ha^{-1} at 14% moisture) was achieved with only 11 kg N ha^{-1} for urea. There was no evidence that EENFs could achieve the maximum yield at a lower applied N rate. We hypothesised that the low soil pH of 4.9 (1:5 $CaCl_2$ extract) may have inhibited nitrification in the Histosol, leading to low N_2O emissions and a limited response to N fertiliser. Ultimately, the results of this study found no evidence that EENF products could improve agronomic N use efficiency or lower N_2O emissions in the two aerobic rice crops studied.

1. Introduction

Nitrogen (N) is a critical element for plant growth and is a key driver of crop yields across the globe. The need for N inputs to sustain yields results in the application of around 137 tera g (Tg) of N per year into agricultural systems, with mineral N fertilisers contributing around half of this amount (Liu et al., 2010). The recovery of the applied N fertiliser by crops is typically low, ranging from 35 to 65 % crop recovery of applied N in the year of application (Herrera et al., 2016). While some unrecovered N may remain in the soil, N lost through NH_3 volatilisation, NO_3^- leaching and denitrification (e.g. N_2 and N_2O emissions) contributes to a range of environmental issues including eutrophication of waterways (Carpenter et al., 1998) and global warming through greenhouse gas emissions.

Fertiliser N losses are particularly high in the tropics and subtropics, where higher temperatures and intense rainfall increase losses through the major loss pathways of NH_3 volatilisation and NO_3^- leaching (Weier, 1994). These rainfall and temperature conditions in the subtropics can also lead to large N_2O emission events (Rowlings et al., 2016). While the total amounts of N lost through N_2O emission are minor compared to NO_3^- leaching losses, N_2O is problematic because it is a potent greenhouse gas with a heat trapping capacity 298 times

---

[*] Corresponding author at: Southern Cross Plant Science, Southern Cross University, PO Box 157 Lismore, NSW, 2480 Australia.

E-mail addresses: terry.rose@scu.edu.au (T.J. Rose), Peter.quin@internode.on.net (P. Quin), Stephen.morris@dpi.nsw.gov.au (S.G. Morris), Lee.Kearney@scu.edu.au (L.J. Kearney), Stephen.Kimber@dpi.nsw.gov.au (S. Kimber), Mick.rose@dpi.nsw.gov.au (M.T. Rose), Lukas.van.zwieten@dpi.nsw.gov.au (L. Van Zwieten).

https://doi.org/10.1016/j.fcr.2018.06.001
Received 18 February 2018; Received in revised form 1 June 2018; Accepted 3 June 2018

higher than CO_2 on a 100 year time scale (Myhre et al., 2013). The agricultural sector is estimated to contribute 58% of anthropogenic N_2O emissions (IPCC, 2007), and options to mitigate these losses are therefore needed.

One means of lowering N_2O emissions from agricultural fields is the use of enhanced efficiency N fertiliser (EENF) products, which aim to minimise the build-up of large pools of NO_3^- in the soil. These products can be broadly classified as acting physically (slow or controlled release) or chemically (containing urease or nitrification inhibitors) (Chalk et al., 2015). A number of recent meta-analyses have indicated that nitrification inhibitors lower N_2O emissions by an average of 30–45 % across studies (Akiyama et al., 2010; Gilsanz et al., 2016; Thapa et al., 2016) while controlled release products such as polymer coated urea (PCU) lower emissions by an average 35% (Akiyama et al., 2010). Significant mitigation of yield-scaled N_2O emissions have also been reported following application of the urease inhibitor NBPT (reviewed by Feng et al., 2016). However, most of the studies used in the meta-analyses cited above were conducted in temperate environments, with few data sets available from warmer and wetter sites in the tropics and subtropics. While some recent studies from the humid subtropics have found significant abatement of N_2O emissions from the product Entec® (urea + the nitrification inhibitor 3,4-dimethylpyrazole phosphate [DMPP]) (e.g. De Antoni Migliorati et al., 2014; 2016; Scheer et al., 2016) or PCU (Scheer et al., 2016) compared to urea, these studies were conducted in lower rainfall ($<$ 800 mm per annum) areas of the subtropics. In high rainfall environments ($>$ 1500 mm annual precipitation), one study with sugarcane reported that the nitrification inhibitors DMPP and dicyanamide (DCD) significantly lowered seasonal N_2O emissions compared to urea, but a controlled release fertiliser (a PCU product) did not (Soares et al., 2015). Another study with sugarcane found no significant abatement of N_2O emissions with DMPP or PCU compared to urea (Wang et al., 2016a). Our own studies in the wet subtropics found no significant mitigation of cumulative, in-crop N_2O emissions from aerobic rice crops fertilised with urea containing DMPP vs a urea control, despite a significant lowering of N_2O emissions during the peak flux period following fertiliser application in one season (Rose et al., 2017). The potential for EENFs to mitigate N_2O emissions in the wet subtropics therefore remains unresolved.

The potential for EENFs to improve agronomic efficiency - that is, to achieve the same yields at a lower rate of applied N (Rose et al., 2018) – in tropical and subtropical environments is also unclear. A meta-analysis of earlier studies on the nitrification inhibitor nitrapyrin found that on average, nitrapyrin increased nitrogen use efficiency (Wolt, 2004), but few studies from tropics or subtropics were included in the meta-analysis. For other nitrification inhibitors including DMPP or DCD, PCUs or the urease inhibitor NBPT, while a number of meta-analyses have been conducted on yields and NUE (e.g. Abalos et al., 2014; Linquist et al., 2013), few studies used in these meta-analyses characterised full N fertiliser response curves for these products compared to urea. While a vast number of studies have examined N_2O emissions from EENFs, these have generally been conducted at only one or two N rates, and such data sets do not enable assessment of the agronomic efficacy of these products (Rose et al., 2018). We found only two studies that have generated full N response curves for DMPP vs urea, both of which were conducted in lower rainfall ($<$ 800 mm per annum) areas of the subtropics. Neither study found compelling evidence that urea-DMPP could be applied at lower rates than standard urea to achieve maximum grain yields (De Antoni Migliorati et al., 2016; Lester et al., 2016). The only multi-N rate studies we are aware of that have compared PCU to urea found no consistent yield benefits from PCU in temperate environments (Grant et al., 2012; Malhi et al., 2010). We are not aware of any studies that have conducted multi- rate N trials to compare yield responses of grain crops to N provided as urea vs controlled release N products such as PCU in tropical or subtropical environments.

Rice is a major global food crop that has traditionally been grown under flooded (anaerobic) conditions in most growing regions. However, competition for water and increasing water scarcity has led to modified rice farming techniques that use less water, including alternative wetting and drying techniques (Rejesus et al., 2011). In the Australian wet subtropics, rice is increasingly being grown in rotation with sugarcane as a rain-fed, aerobic crop yielding 5-6 t ha^{-1} in a typical season (Rose, 2016; Rose et al., 2017). The aim of this study was two-fold: i) to investigate the potential for a range of EENF products, including controlled release N products and products with either a nitrification inhibitor or urease inhibitor, to lower N_2O emissions from aerobic rice crops compared to a standard urea fertiliser treatment in a wet, subtropical environment; and ii) to investigate whether the products could be applied at a lower application rate than urea to achieve the maximum rice grain yields for the given site in a given season by deriving N response curves for all tested products.

2. Materials and methods

2.1. Trial sites and experimental design

Two field trials were conducted in the Australian wet subtropics during the 2015-16 rice growing season under rain-fed conditions. The first trial was established on a clay loam soil (Redoxic Hydrosol; Isbell, 1996) near Woodburn, NSW (29.071 °S, 153.345 °E) and the second trial was established on a peat soil (Organosol; Isbell, 1996) near Coraki, NSW (28.993 °S, 153.282 °E). These soils are classified by the FAO as a Gleysol and Histosol, respectively (IUSS Working Group WRB, 2014), and will herein be referred to using the FAO classification. Key properties of the 0–100 mm soil layer and mineral-N concentrations to a depth 0.9 m are presented in Table 1. Exchangeable base cations were quantified using 1 M NH_4OAc according to method 15E1 in Rayment and Lyons (2010). Soil pH (0.01 M $CaCl_2$ (1:5)) was determined as per method 4B2 and available (Bray 1) P by method 9E2 of Rayment and Lyons (2010), while KCl-extractable NO_3^- and NH_4^+ were measured by flow injection analysis.

Soil N_2O emissions at each site were quantified within larger trials investigating rice yield responses to N fertiliser rate and product. The

Table 1
Selected physiochemical properties of the 0–100 mm horizon of the Gleysol (Woodburn) and Histosol (Coraki) and mineral N concentrations to 900 mm depth.

Soil property	Gleysol	Histosol
Total carbon (%)	4.3	7.7
Total nitrogen (%)	0.3	0.6
KCl extractable ammonium (mg kg^{-1})	4.9	5.2
KCl extractable nitrate (mg kg^{-1})	6.3	3.1
pH ($CaCl_2$)	5.5	4.9
EC (dS m^{-1})	0.1	0.1
Bray 1 phosphorus (mg kg^{-1})	10	15
CEC (cmol + kg^{-1})	26	14
Base cations (%)		
Calcium	40	17
Magnesium	50	12
Potassium	2	1
Sodium	5	3
Aluminium	2	43
Mineral N (mg kg^{-1})		
NH_4^+ (0–100 mm)	4.9	5.2
NO_3^- (0–100 mm)	6.3	3.1
NH_4^+ (100–300 mm)	8.9	4.2
NO_3^- (100–300 mm)	4.0	2.9
NH_4^+ (300–600 mm)	5.6	2.7
NO_3^- (300–600 mm)	2.6	0.6
NH_4^+ (600–900 mm)	4.4	2.1
NO_3^- (600–900 mm)	1.4	0.5

Soil samples were analysed at NSW Department of Primary Industries, Wollongbar, Australia, using methods from Rayment and Lyons (2010).