Comparison of the ability of the nitrification inhibitors DCD and DMPP to reduce nitrification and N_2O emissions from nitrogen fertilisers

Helen Suter[A], Deli Chen[A], Huilin Li[A,B], Robert Edis[A] and Charlie Walker[C]

[A] Melbourne School of Land and Environment, The University of Melbourne, Victoria 3010, Australia. helencs@unimelb.edu.au
[B] Institute of Soil Science (ISSAS), Chinese Academy of Sciences (CAS), Nanjing 210008.
[C] Incitec Pivot Limited, Geelong, Victoria 3215, Australia

Abstract
Nitrification of applied nitrogen fertilisers leads to losses of nitrogen (N) as nitrate (NO_3^-) or as the greenhouse gas nitrous oxide (N_2O). Nitrification inhibitors can be used to suppress the ammonia oxidizing bacteria involved in nitrification and hence reduce these losses. The ability of nitrification inhibitors to reduce nitrification is dependent upon both climatic and soil conditions, and different inhibitors respond differently. The ability of two nitrification inhibitors, 3,4-dimethylpyrazole phosphate (DMPP) (1.84 kg/t urea) and dicyandiamide (DCD) (10 kg/t urea) to reduce nitrification from applied fertiliser (100 kg N/ha) in a pasture soil, in small scale (150 g) incubation studies under a range of temperatures (5, 15 and 25^oC) was studied. Both products were applied as commercially prepared granular urea products. The comparable ability of the 2 inhibitors to reduce nitrification, as measured by NO_3^- formation, were similar across all treatments, with neither effective in the topsoil and both causing reduced NO_3^- formation in the subsoil. N_2O emissions were reduced by both inhibitors. DMPP was applied at a lower concentration than DCD and performed almost, and equally as well in many cases.

Key Words
3,4-dimethylpyrazole phosphate; Dicyandiamide, nitrification rates; incubation studies.

Introduction
Nitrification of applied nitrogen fertilisers leads to losses of nitrogen (N) as nitrate (NO_3^-) or as the greenhouse gas nitrous oxide (N_2O). These losses mean that plant use efficiency of nitrogen fertilisers is low. Reducing nitrification losses can be achieved with the use of nitrification inhibitors that suppress the activity of the autotrophic ammonia oxidizing bacteria (AOB). Nitrogen is then retained in the ammonium (NH_4^+) form for longer making is available to plants and reducing the risk of leaching losses. Many nitrification inhibitors with differing modes of action have been tested in cropping systems and have shown variable reductions in nitrification, N_2O emissions and influence on crop yields (Chen *et al.* 2008; Hatch *et al.* 2005; Li *et al.* 2008; McCarty 1999; Yu *et al.* 2007). The variability in the response of nitrification to the inhibitor is related partly to climatic conditions, such as moisture and temperature, and partly to the conditions within the soil including the nitrification potential of the soil and fertilizer history (Barth 2006; Kelliher *et al.* 2008). 3,4-dimethylpyrazole phosphate (DMPP) is one inhibitor that has been reported to work as effectively as DCD at lower concentrations (Zerulla *et al.* 2001). DMPP is a newer inhibitor and has not been tested in Australian dryland agriculture and knowledge of its viability for high temperature situations is unknown, with studies covering temperatures to a maximum of 30^oC (Irigoyena *et al.* 2003). DCD has been extensively used overseas but is considered to be less effective than DMPP (Chaves *et al.* 2006; Weiske *et al.* 2001). This paper reports on laboratory studies investigating the effect of temperature on the inhibition of nitrification by DMPP and DCD from urea applications to pasture soils, in small-scale incubation experiments.

Methods
Soils
Soils were collected from a dairy farm in northern Victoria (S36^{o}25’27”, E145^{o}42’26”) from the top (0-5cm) and subsoil (5-15 cm), air dried and sieved to <2 mm. Table 1 provides details of the soils used.

Incubation trials
Soil (150 g) in small vials (15cm x 35 cm^2) was pre-wetted 2 days prior to commencement of the experiment. Granular urea was applied at a rate of 100 kg N/ha (175 ug N/g soil). DMPP was applied as the commercial product Urea with ENTEC™ (1.84 kg DMPP active ingredient/t urea (0.71 μg DMPP/g soil) and DCD was applied as a granular urea product containing 10 kg DCD active ingredient/t urea (3.8 μg DCD/g soil). A

control treatment (no fertiliser) was included to measure background N transformations. Samples were incubated at 5, 15 and 25^{o}C and at 60 % water filled pore space (WFPS). Experiments ran for 70 days with sample aeration and water replenishment at regular intervals. Nitrous oxide (N_2O) samples were collected in triplicate and analysed using a Hewlett Packard 6890 GC with 2 Porapak Q columns and a carbosorb column with an ECD detector.

Table 1. Selected source and soil properties.

	Dookie –topsoil	Dookie-subsoil
Source site	Northern Victoria	Northern Victoria
Agricultural activity	pasture	pasture
colour	Very dark grey	Brown
Texture		
%clay	21	33
%silt	28	30
%sand	50	37
pH	5.4	5.5
Org C (%)	10.0	2.4
Total N (%)	1.0	0.2
NH_4^+ (mg/kg)	35	11
NO_3^- (mg/kg)	53	33
Nitrifying potential (mg/kg/day)	18	4

Results

Nitrification rates in the control treatments were similar to those observed in the fertilizer treatments under all temperatures in the topsoil, and less in the subsoil (Figure 1). This was due to the high nitrification potential of this soil (Table 1). Addition on the nitrification inhibitors DCD and DMPP had no impact on the formation of NO_3^- in the topsoil but did reduce the level of NO_3^- formed in the subsoil, where the nitrification potential of the soil was lower. DCD appeared to perform slightly better than DMPP where inhibition was achieved (subsoil) especially under cooler temperatures.

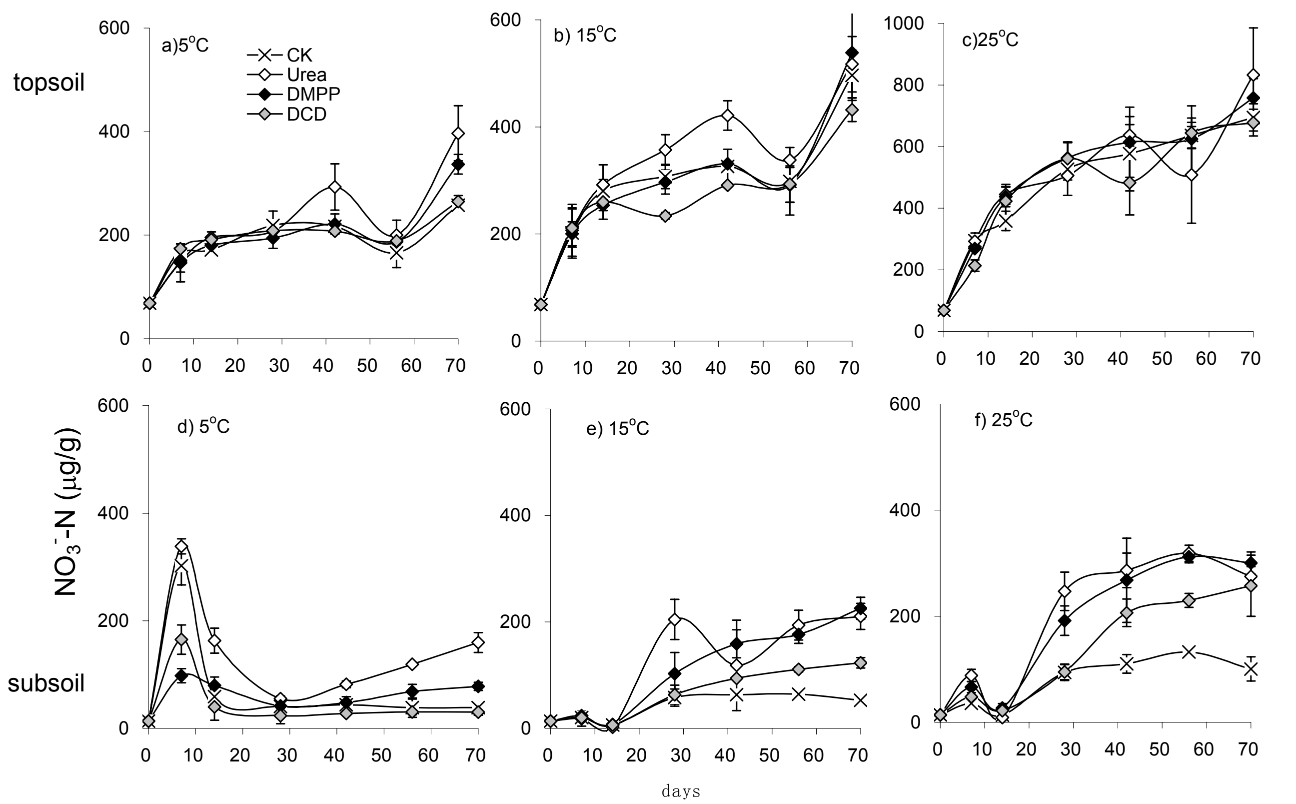

Figure 1. Nitrate (NO_3^-) formation for the control, urea, urea +DMPP and urea+DCD treatments over 70 days, at temperatures of 5, 15 and 25^{o}C.

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

Cumulative nitrous oxide (N_2O) emissions measured in the urea treatments was greater than in the inhibitor (DCD and DMPP) treatments and in the control under all conditions (Figure 2). DCD and DMPP were both able to reduce the N_2O emissions over 70 days. The reduction in N_2O emissions after 70 days with DCD was 81 (5°C), 64 (15°C) and 37% (25°C) in the topsoil, and was 88 (5°C), 86 (15°C) and 44% (25°C) in the subsoil. The reduction in N_2O emissions after 70 days with DMPP was 65 (5°C), 61 (15°C) and 14% (25°C) in the topsoil, and was 76 (5°C), 74 (15°C) and 31% (25°C) in the subsoil. DCD appeared to perform better than DMPP most noticeably at 5°C. However DCD was applied at a greater application rate (10 kg/t urea) than DMPP (1.84 kg/t urea).

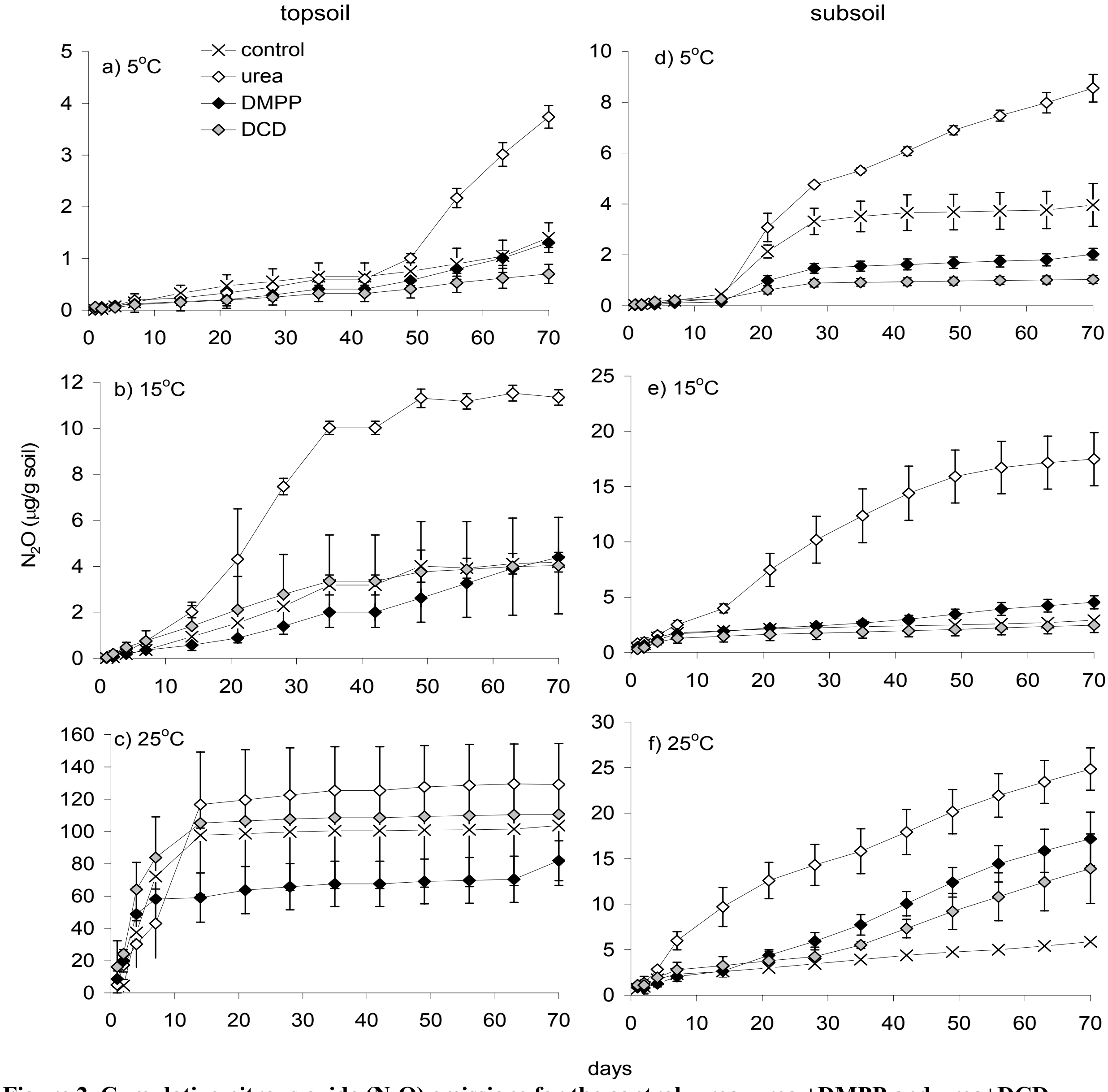

Figure 2. Cumulative nitrous oxide (N_2O) emissions for the control, urea, urea +DMPP and urea+DCD treatments over 70 days, at temperatures of 5, 15 and 25°C.

Conclusion

Nitrification rates in the topsoil of the pasture soil were very high and addition of fertiliser made no difference to the level of NO_3^- produced. Under these conditions neither DMPP nor DCD were able to reduce nitrification rates. In the subsoil both inhibitors were able to reduce the nitrification rate and rate of NO_3^- formation relative to urea. Emissions of N_2O were greatest with fertiliser addition and both DMPP and DCD were able to reduce the emissions. Temperature affected how much reduction in N_2O emissions was observed for both inhibitors.

References

Barth G (2006) Influence of soil properties on the effect of 3,4 - dimethylpyrazole - phosphate as nitrification inhibitor. Technischen Universität München.

Chaves B, Opoku A, De Neve S, Boeckx P, Van Cleemput O, Hofman G (2006) Influence of DCD and DMPP on soil N dynamics after incorporation of vegetable crop residues. *Biology and Fertility of Soils* **43**, 62-68.

Chen D, Suter HC, Islam A, Edis R, Freney JR (2008) Prospects of improving efficiency of fertilizer nitrogen in Australian agriculture; a review of enhanced efficiency fertilizers. *Australian Journal of Soil Research* **46**, 289-301.

Hatch D, Trindade H, Cardenas L, Carniero J, Hawkins J, Scholefield D, Chadwick D (2005) Laboratory study of the effects of two nitrification inhibitors on greenhouse gas emissions from slurry-treated arable soil: impact of diurnal temperature cycle. *Biology and Fertility of Soils* **41**, 225-232.

Irigoyena I, Muro J, Azpilikueta M, Aparicio-Tejo P, Lamsfus C (2003) Ammonium oxidation kinetics in the presence of nitrification inhibitors DCD and DMPP at various soil temperatures. *Australian Journal of Soil Research* **41**, 1177-1183.

Kelliher FM, Clough TJ, Clark H, Rys G, Sedcole JR (2008) The temperature dependence of dicyandiamide (DCD) degradation in soils: A data synthesis. *Soil Biology and Biochemistry* **40**, 1878-1882.

Li H, Liang X, Chen Y, Lian Y, Tian G, Ni W (2008) Effect of nitrification inhibitor DMPP on nitrogen leaching, nitrifying organisms, and enzyme activities in a rice-oilseed rape cropping system. *Journal of Environmental Sciences* **20**, 149-155.

McCarty GW (1999) Modes of action of nitrification inhibitors. *Biology and Fertility of Soils* **29**, 1-9.

Weiske A, Benckiser G, Ottow JCG (2001) Effect of the new nitrification inhibitor DMPP in comparison to DCD on nitrous oxide (N_2O) emissions and methane (CH_4) oxidation during 3 years of repeated applications in field experiments. *Nutrient Cycling in Agroecosystems* **60**, 57-64.

Yu Q-G, Chen Y-X, Ye X-Z, Tian G-M, Zhang Z-J (2007) Influence of the DMPP (3,4-dimethyl pyrazole phosphate) on nitrogen transformation and leaching in multi-layer soil columns. *Chemosphere* **69**, 825-831.

Zerulla W, Barth T, Dressel J, von Locquenghien KEKH, Pasda G, Rädle M, Wissemeier AH (2001) 3,4-Dimethylpyrazole phosphate (DMPP) – a new nitrification inhibitor for agriculture and horticulture. *Biology and Fertility of Soils* **34**, 79-84.