The effect of inhibitor use and urea fertiliser application on pasture production and nitrous oxide emissions.

Kevin Kelly[1], Graeme Ward[2]

[1] Agriculture Victoria, Department of Economic Development, Jobs, Transport and Resources, Tatura, Vic. 3616, Australia. kevin.kelly@ecodev.vic.gov.au,
[2] Agriculture Victoria, Department of Economic Development, Jobs, Transport and Resources, Warrnambool, Vic. 3280, Australia.

Abstract
The application of nitrogen (N) fertilisers to pasture is known to increase nitrous oxide (N_2O) emissions. There is currently little information available on emissions from N fertilised dairy pastures in Australia. The objective of this work was to quantify the effect of inhibitor coatings on urea fertiliser on pasture DM production and N_2O emissions.

Field experiments (five treatments by five replicates) were conducted at two sites in south-west Victoria with contrasting drainage characteristics. Treatments were nil, urea, urea coated with dicyandiamide (DCD), urea coated with 3,4-dimethyl pyrazole phosphate (DMPP) and urea coated with N-(n-butyl) thiophosphoric triamide (nBPT). The urea+DCD treatment was replaced with urea ammonium nitrate (UAN) in Years 2 and 3. The N treatments were applied at the start of the growing season and again after every second harvest. Pasture production was measured for three years and N_2O emissions were measured for two years.

Pasture responded to the application of N fertiliser at both sites every year. There were no differences in pasture production between the urea, urea plus inhibitor coatings or the UAN treatments. Cumulative N_2O emissions where no N was applied varied with year and site, ranging from 0.23 to 0.53 kg N_2O-N/ha/year, while emission factors for urea use ranged from 0.09 to 0.31%. The use of a nitrification inhibitor reduced emissions by 30 to 75%, with the magnitude of the reduction influenced by soil water content around the time of N application. The urease inhibitor had no effect on N_2O emissions.

Key Words
emission factor, water filled pore space

Introduction
Nitrous oxide (N_2O) is an environmentally important trace gas that contributes to global warming by its action as a “greenhouse gas” and is also involved in stratospheric ozone depletion. Nitrous oxide emitted from the soil is produced primarily through the microbial process of a) nitrification, the oxidation of ammonium (NH_4^+) to nitrate (NO_3^-), and b) denitrification, the anaerobic reduction of NO_3^- to gaseous forms of nitrogen (N). There is evidence that increasing soil mineral N availability by increased use of N fertiliser on pastures can lead to substantial increases in N_2O emissions (Jones *et al*. 2007).

Over the last 30 years there has been a considerable increase in the use of N fertiliser in the dairy industry in Victoria. Annual rates range from 0- 410 kg N/ha (Dairy Farm Monitor Project 2014), with urea being the dominant N type applied to pastures. Recent studies on Australian dairy farms (Gourley *et al*. 2012) suggest that N use efficiencies are low with gross N balance assessments being less than 30% of N inputs. A number of different N fertiliser management options are available which have the potential to improve N use efficiency and reduce losses. These include improved application scheduling, different forms of N fertiliser, optimising application rate with plant requirements, slow release N fertilisers and the use of N inhibitors.

There is limited information on N_2O emissions from N fertilizer use on pasture under Australian conditions - conditions which differ significantly in climate, soils and agricultural practices to those of the northern hemisphere nations (Galbally *et al*. 2005). International research has shown reductions in N_2O emissions associated with the use of nitrification inhibitors on N fertilisers (Dobbie and Smith 2003; Zaman *et al.* 2009, and Bell *et al*. 2016), with reductions in the order of 40% reported. Similarly, the application of the urease inhibitor, Agrotain with urea, in one New Zealand study was found to increase N uptake, DM production and reduce N_2O emissions by 5% (Zaman *et al*. 2009). As with total N_2O emissions from pastures, it is likely that responses to both urease and nitrification inhibitors will vary under Australian pasture conditions.

This study evaluated the agronomic efficiency and N_2O emissions from soils growing pasture after the application of urea alone, urea plus nitrification inhibitors, urea plus a urease inhibitor and, in addition in Year 2 and 3, urea ammonium nitrate (UAN), on two contrasting soil types in south west Victoria. Our hypothesis was that all the nitrification inhibitors would be effective in reducing N_2O emissions from N fertilised pastures, however, herbage DM production would not be improved by inhibitor use.

Methods

Two experimental sites with contrasting soil types, 13 kilometres apart, were established on commercial dairy farms, in south-west Victoria, Australia. One site was on a well-structured, free draining Black Dermosol soil (Isbell 1996) derived from quaternary volcanic tuff and scoriaceous deposits at Glenormiston (38^o 10' S; 142^o 58' E) and the second site was established on a poorly drained Brown Chromosol soil (Isbell 1996), with a duplex profile derived from quaternary basalt at Terang (38^o 14' S; 142^o 55' E). The texture of the surface soils (A1 horizons) at both sites were classified as clay loams. Both sites were on long-term perennial dairy pastures composed predominantly of perennial ryegrass (*Lolium perenne* L.). Soils at both sites were moderately acid with pH ($CaCl_2$) (0 – 0.1 m) of 5.3 and 5.0, organic carbon levels of (5.1 and 4.6%) and total soil N of 0.62 and 0.41% for the Glenormiston and Terang sites respectively.

The region has a winter dominant rainfall distribution. Terang's long-term (117 years) annual average rainfall is 780 mm and Glenormiston's is 725 mm. The mean annual maximum air temperature for Terang is 18.5^{o}C and a minimum of 7.7^{o}C, with February being the hottest month and July the coldest month (mean maximum temperatures of 25.3^{o}C and 12.3^{o}C respectively). Annual rainfall (July-June) during the experimental period was 595, 841 and 579 mm for 2012/13, 2013/14, 2014/15 respectively at Glenormiston and 590, 860, and 602 mm at Terang. Despite having wet winters, the 2012/13 and 2014/15 years had relatively short growing seasons at both sites with dry springs and late autumn breaks.

Treatments and experimental design

At both sites, the experimental design consisted of five replicated blocks of five treatments. Individual plots were 2.5 m by 3 m with a 1 m buffer between each plot. In 2012, five treatments were applied to both sites: nil, urea, urea + DMPP, urea + DCD, urea + nBPT. Two of these treatments were urea (46% N) coated with the nitrification inhibitors DMPP (3,4-dimethyl pyrazole phosphate) (1.84 kg a.i./t urea), and DCD (dicyandiamide) (10 kg a.i./t urea), and a third treatment was the urease inhibitor nBPT (N-(n-butyl) thiophosphoric triamide) (1 kg a.i./t urea). In 2013 and 2014, the urea + DCD treatment was replaced with urea ammonium nitrate (UAN) (32% N). All N treatments (50 kg N/ha) were applied at the beginning of the experiment (July 2012) and after the autumn break in 2013 and 2014 at both sites. These treatments were re-applied annually at 50 kg N/ha after every second defoliation of the pasture until the end of the growing season. In 2012, N treatments were applied twice, 19 July and 22 September at both sites; two times at Glenormiston (19 September and 7 November) and three times at Terang (18 July, 19 September and 7 November) in 2013. In 2014 N treatments were applied two times at Glenormiston (19 Jun and 21 Aug) and three times to the Terang (22 May, 17 July and 18 September).

N_2O flux measurements

Nitrous oxide emissions were monitored by static chambers using the sampling protocols and chamber design recommended by the Global Alliance on Agricultural Greenhouse Gases (de Klein and Harvey 2012). Emissions were monitored from the Glenormiston site in 2012, the Terang site in 2013, and both sites in 2014. One stainless steel chamber base (0.5 m by 0.5 m) was permanently installed to a depth of 0.1 m in each plot. Chambers (0.25 m height) were of aluminium and perspex construction covered with a reflective plastic insulation layer and equipped with a mixing fan. Gas sampling intensity varied with time after fertiliser application and soil water content, ranging from 2 to 28 day intervals, with samples collected between 1030 and 1330 hours. At time 0, the chambers were placed on the baseplate and an initial gas sample was collected. Subsequent samples were collected 20, 40 and 60 minutes after closure during 2012 and 2013. In 2014 sampling, times were changed to 0, 30 and 60 minutes after closure because emissions estimations from the previous two years data using both linear and non-linear methods of analysis showed no evidence to support the use of non-linear method of analyses. Gas samples were analysed for N_2O concentrations using an Agilent 7890 gas chromatograph equipped with a flame ionization detector, thermal conductivity detector and micro-electron capture detector.

Soil water and pasture measurements
Soil water content was measured at both sites using thetaprobes, calibrated for each soil type. Soil bulk densities were measured at each site and, together with soil water content, used to calculate water filled pore space (WFPS).

The herbage dry matter (DM) yield of each plot was assessed at each harvest by mowing a strip down the length of the plot with a rotary lawn mower (0.5 m width), to a height of 0.05 m. All herbage from the whole harvested strip was collected, weighed and subsampled for DM determination.

Statistical analysis
All statistical analyses were performed using GenStat v14.1 (VSN International Ltd., 2011). As examination of the estimated total emissions residuals did not justify any data transformations, all cumulative emissions were analysed as untransformed data.

Results and Discussion
Pasture DM production in each of the three years and at both sites responded ($P<0.05$) to the application of N. There was no difference between DM yield of the urea alone treatment and the urea coated with any of the inhibitor treatments, nor with the use of UAN in Years 2 and 3 (Table 1). The majority of the response to N application (80-100%) occurred in the first harvest period after application.

Table 1. Cumulative annual pasture DM yield (t DM/ha) of urea, urea with and without nitrification (DCD, DMPP) and urease (NBPT) inhibitors; and urea ammonium nitrate (UAN) treatments during the 2012, 2013 and 2014 growing seasons at the Glenormiston and Terang trial sites

	Glenormiston			Terang		
	2012	2013	2014	2012	2013	2014
No. of Harvests	4	3	5	5	6	6
Treatments						
Nil	3.42	2.37	1.86	6.17	4.64	3.07
Urea	5.72	4.42	4.63	8.11	7.82	6.66
Urea + DCD	5.52	-	-	7.70	-	-
Urea + DMPP	5.63	4.34	4.24	7.83	7.70	6.40
Urea + NBPT	5.62	4.42	4.35	8.10	7.79	6.41
UAN	-	4.05	4.12	-	7.39	5.96
l.s.d.(P=0.05)	1.256	0.409	0.314	0.680	0.260	0.432

Nitrous oxide emissions were measured at Glenormiston in Year 1 (20 July 2012 to 5 July 2013) and in Year 3 (23 June 2014 to 12 April 2015). In both years emissions were elevated above the nil treatment for 25-30 days after each application of fertiliser. Nitrous oxide emissions in Year 1 peaked at 0.018 kg N_2O-N/ha/day, and in Year 3 at 0.005 kg N_2O/ha/day. Soil temperatures were similar for the two years. In Year 1, WFPS during the first 30 days after application of fertiliser averaged 81 and 73% after the first and second application respectively, however, in Year 3, WFPS's were lower averaging 65 and 53% in the first 30 days after first and second fertiliser applications, respectively. In Year 1, there were significant ($P<0.05$) reductions (about 55%) in cumulative N_2O emissions from the application of urea coated with the nitrification inhibitors but there was no effect on emissions when coated with the urease inhibitor nBPT (Table 2). Calculated N_2O emission factors for urea application were 0.31 and 0.16% at Glenormiston for Year 1 and 3 respectively.

Nitrous oxide emissions were measured at Terang in Year 2 (19 July 2013 to 22 May 2014) and Year 3 (23 May 2014 to 14 April 2015). Emissions were elevated above the nil treatment for 20-25 days after each application of fertiliser, peaking at 0.022 kg N_2O-N/ha/day in Year 2, and 0.015 kg N_2O/ha/day in Year 3. Water filled pore space in Year 2 for the first 30 days after each application of fertiliser averaged 76, 91 and 78% respectively, and 73, 95 and 71%, respectively in year 3. In both years there was a significant ($P<0.05$) reduction of about 55 to 75% in cumulative emissions from the application of urea when a coated with the nitrification inhibitor DMPP relative to urea alone, and no effect when coated with the urease inhibitor nBPT. Emissions from the application of UAN were higher than emissions from urea alone when WFPS was high immediately after fertiliser application. Calculated emission factors were 0.09 and 0.18% for Terang in Years 2 and 3 respectively.

Nitrous oxide emissions from the application of urea and UAN resulted in annual emissions factors in the range of 0.09 to 0.31%, with variations between years and sites. These differences are likely to be related to soil water conditions around the time of N application (Bell *et al*. 2015). Emissions attributed to these N applications, were higher when WFPS was about 75%. Higher N_2O emissions occurred at the Terang site following the application of UAN fertiliser when WFPS was >80%.

Nitrification inhibitor use was effective in reducing emissions following a single urea application particularly when WFPS was greater than 75%. The lack of any effect on emissions from the use of the urease inhibitor was expected given that within 24 hours of treatment application rainfall of 5 to 25 mm was recorded.

Table 2. Cumulative nitrous oxide emissions (kg N_2O-N/ha) and emission factors[A] (%) at the Glenormiston and Terang sites

	Glenormison[B]				Terang[B]			
	2012-13		2014-15		2013-14		2014-15	
	Cumulative emissions	Emission factor	Cumulative emissions	Emission factor	Cumulative emissions	Emission factor	Cumulative emissions	Emission factor
Nil	0.44		0.32		0.23		0.50	
Urea	0.75	0.31%	0.48	0.16%	0.38	0.09%	0.73	0.18%
Urea+DCD	0.56	0.12%					-	
Urea+DMPP	0.60	0.16%	0.42	0.10%	0.31	0.04%	0.59	0.06%
Urea+nBPT	0.80	0.36%	0.46	0.14%	0.38	0.08%	0.68	0.12%
UAN	-	-	0.42	0.10%	0.45	0.13%	0.82	0.21%
l.s.d.(P=0.05)	0.203		0.083		0.114		0.189	

[A] Emission factor = (emissions from N applied treatment – emissions from nil N treatment)/kg N applied
[B] Nitrogen applied - Glenormiston 100 kg N/ha and Terang 150 kg N/ha

Conclusion

The use of nitrification inhibitors was effective in reducing N_2O emissions, when conditions conducive to emission losses were high, such as when WFPS was above 70%. Overall, as the total loss of N as N_2O was small, a production response from nitrification inhibitor use is unlikely.

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