Dicyandiamide (DCD) reduces nitrate losses from Irish soils

Samuel Dennis[AB], Keith Cameron[A], Hong Di[A], Jim Moir[A] and Karl Richards[B]

[A]Department of Soil and Physical Sciences, Lincoln University, New Zealand, Email samuel.dennis@lincoln.ac.nz
[B]Teagasc, Environment Research Centre, Johnstown Castle, Co. Wexford, Ireland

Abstract
Nitrate leaching is a concern for both environmental and public health reasons. Because of this European farmers are being increasingly regulated to reduce nitrate losses. Dicyandiamide (DCD) has been shown to reduce nitrate losses from grazed pastures in New Zealand, and could potentially be used to satisfy European regulations. In this trial DCD was applied in autumn to urine-treated lysimeters in Ireland and leachate was collected for 12 months following urine application. DCD reduced peak nitrate concentrations by up to 55 %, and reduced total annual nitrate losses by up to 45 %. These results confirm that DCD application has the potential to be a useful tool for Irish farmers to satisfy their environmental obligations.

Key Words
Dicyandiamide (DCD), nitrate, Ireland, leaching, grazed pasture, urine.

Introduction
Nitrate leaching is a concern around the world, as nitrate can contribute to eutrophication, and may also cause health problems in formula-fed infants. Agricultural industries around the world are becoming increasingly regulated to reduce the losses of nitrate and other nutrients. Stocking and fertilizer application rates in Ireland and other European countries are being restricted, which could have severe financial implications for farmers. Dicyandiamide (DCD) has been shown to reduce nitrate and nitrous oxide losses from grazed pastures in New Zealand (Di and Cameron 2002; 2004; 2005). If it is also effective in Europe, it could potentially be used by farmers to reduce nitrate losses while maintaining higher stocking rates than would otherwise be permitted. Alternatively it could be used in some circumstances to reduce nitrate losses further than could be achieved through the current regulations and thus provide greater protection for sensitive catchments. This study investigated the effectiveness of a DCD application regime developed in New Zealand (Di and Cameron 2005) on three Irish soils, under the climatic conditions of Wexford, Ireland.

Methods
A field lysimeter facility was established at the Johnstown Castle Environment Research Centre in Wexford, Ireland, in 2003. Undisturbed monolith lysimeters (0.8 m diameter, 1 m deep) representing three soil classes used for dairy farming in Ireland (well drained Clonakilty, moderately drained Elton, poorly drained Rathangan) were collected following the method of Cameron *et al.* (1992) and installed in a randomised complete block design. Urine was applied to the lysimeters in November 2006 and 2007. Urine was collected from dairy cows and standardised to the desired concentrations by the addition of deionised water or urea. In 2006, 3 L of 5.1 g N/L urine was applied to each lysimeter, providing an equivalent application rate of 306 kg N/ha. In 2007, 2 L of 8.6 g N/L urine was used, providing 344 kg N/ha.

Nitrogen fertiliser was applied as Calcium Ammonium Nitrate (CAN) and Urea, at 141 and 291 kg N/ha, referred to as ‘Low Fertiliser’ and ‘High Fertiliser’, respectively. There were three replicates, giving a total of 36 lysimeters. DCD was applied at a rate of 10 kg/ha in solution. DCD was applied once immediately following urine application, and again in the following March, for a total application rate of 20 kg/ha. DCD was applied in drops evenly spread across the surface of the lysimeter in 2006, and in a fine mist spray in 2007. Leachate was collected for twelve months after application and analysed for nitrate using standard methods (Standing Committee Of Analysts 1982). Grazing was simulated by harvesting herbage on a 30-day rotation. Data were analysed using ANOVA and orthogonal contrasts in R (R Development Core Team 2008).

Results
Total rainfall was 1406.8 and 1233.4 mm in the twelve months following the 2006 and 2007 treatment applications, respectively. Total annual drainage was 645, 626 and 503 mm from the Clonakilty, Elton and Rathangan soils following the 2006 treatments, and 677, 622 and 374 mm following the 2007 treatments.

The total annual nitrate-N losses with urine and 141 and 291 kg fertiliser N/ha, averaged across both urine and urine + DCD treatments, are shown in Table 1. When losses were averaged across all soils, there were higher losses from the high fertiliser rate than the low in both 2006 ($P < 0.05$) and 2007 ($P < 0.001$). When the soils were analysed individually this effect was only visible on the Clonakilty soil in 2006 ($P < 0.05$), and the Clonakilty ($P < 0.001$) and Elton ($P < 0.01$) soils in 2007.

Table 1.Total annual nitrate-N losses with urine and fertiliser applied at 141 or 291 kg N/ha. SEM in brackets.

Year	Treatment	NO_3^--N loss (kg/ha)		
		Clonakilty	Elton	Rathangan
2006	Urine + Low Fertiliser	159.0 (33.5)	185.1 (17.2)	66.9 (35.1)
	Urine + High Fertiliser	210.8 (14.6)	195.2 (24.1)	43.9 (6.6)
2007	Urine + Low Fertiliser	100.9 (24.4)	149.8 (26.2)	44.7 (32.7)
	Urine + High Fertiliser	148.3 (25.3)	159.3 (8.8)	11.5 (2.5)

Graphs of the nitrate-N concentration versus drainage for urine and urine + DCD following the 2007 treatments, averaged across both fertiliser rates, are shown in Figure 1. Similar results were seen following the 2006 treatments. The peak concentration following urine application was higher from the Clonakilty and Elton soils than from the Rathangan. DCD reduced the mean peak nitrate concentration from all soils by 32.8 and 55.2 % in 2006 and 2007, respectively ($P < 0.001$). In 2007 (Figure 1), DCD reduced peak concentrations by 49.6 and 48.7 % on the Clonakilty and Elton soils respectively ($P < 0.05$), but the 90.0 % reduction on the Rathangan soil was not significant ($P = 0.14$).

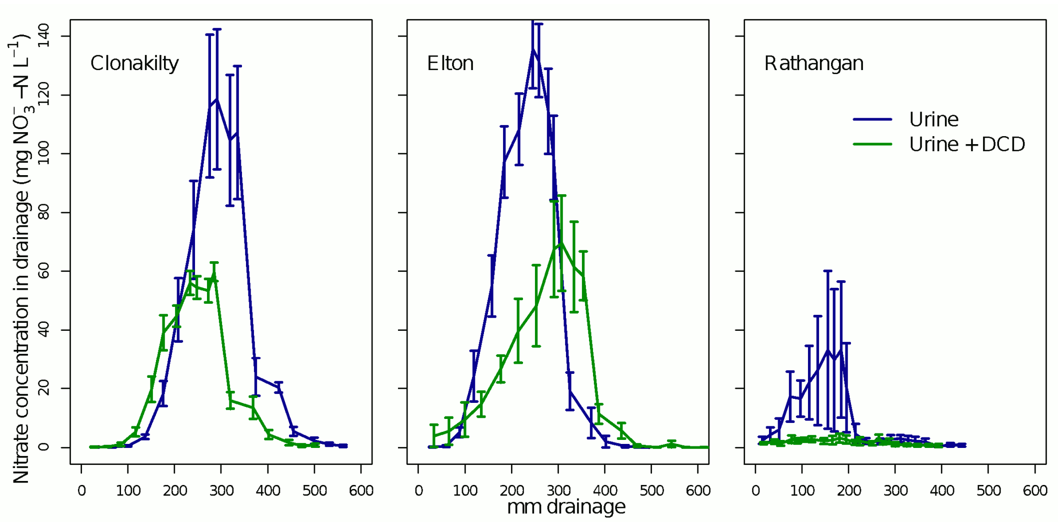

Figure 1. Nitrate-N concentration over mm drainage from urine with or without DCD in 2007. Error bars = 1 SEM.

The total annual nitrate-N losses with urine and urine + DCD, averaged across both fertiliser rates, are shown in Figure 2. When losses were averaged across all soils, DCD reduced nitrate losses by 21.8 % in 2006, and 45.3 % in 2007 ($P < 0.001$).

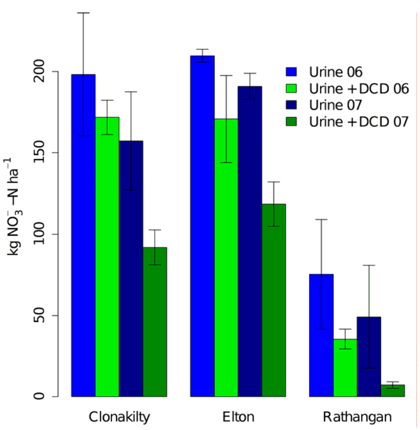

Figure 2. Total annual nitrate-N losses with urine and urine + DCD. Error bars = 1 SEM.

When the soils were analysed individually, this reduction in losses was only significant on the Rathangan soil in 2006 (52.8 % reduction, $P < 0.01$), although reductions in losses from the Clonakilty (13.4 %, $P = 0.078$) and Elton (18.5 %, $P = 0.105$) were nearly significant. Following the 2007 treatments, DCD significantly ($P < 0.001$) reduced losses on the Clonakilty and Elton soils by 41.5 and 38.0 %, respectively, however the apparent 85.6 % reduction in losses from the Rathangan soil was not significant ($P = 0.228$).

Discussion

Doubling the N fertiliser rate had a minor effect on N losses from most soils, except the Clonakilty soil. For this reason the fertiliser rate results were combined to test the effects of the DCD treatment. The total nitrate losses of 16 – 233 kg nitrate-N/ha were in most cases higher than the 59.7 kg nitrate-N/ha observed by Di and Cameron (2007) following a similar rate of urine application in New Zealand. This is most likely due to the higher total drainage from this trial (374 – 677 mm as opposed to around 300 mm in Di and Cameron 2007). Peak nitrate concentrations were observed at 200 – 300 mm of drainage, comparable to previous results from New Zealand (Di and Cameron 2004; Fraser *et al.* 1994). However as the total annual drainage was considerably higher than in New Zealand, these peaks occurred earlier in the drainage season – in January, i.e. in the middle of winter. The majority of the nitrate that was leached was therefore lost before pasture growth picked up in spring, and before the spring DCD application. This could explain not only the higher total losses than in the previous New Zealand work, but may have also contributed to the apparent lower efficacy of DCD in this trial than in the New Zealand work.

The overall reductions in loss with DCD (21.8 and 45.3 %) were not as high as the reductions of 68 % or more that have been observed following DCD application in New Zealand (e.g. Di and Cameron 2002; 2004; 2005). However these reductions are still considerable, and show DCD to have potential as a mitigation technology to counter nitrate leaching losses in Europe. Although not all the individual soil reductions with DCD were significant, it appeared to consistently have the greatest effect on the poorly drained Rathangan soil. This may be due to the slower drainage of this soil retaining N in the soil for longer, and allowing the DCD to continue to act for longer. There may also have been lower quantities of DCD lost in drainage from this heavy soil compared the lighter soils.

The greater effectiveness of DCD following the 2007 treatments may be due to the improved application regime used that year (fine mist application). Liquid DCD appears to be slightly more effective at reducing N losses than granular DCD (presumably spread less evenly), however this difference was not significant at a rate of 18 kg DCD per hectare (Menneer *et al.* 2008). Given that the DCD application rate in this trial was lower than that used by Menneer *et al.* this difference may have been enhanced, and it is possible that the less even spread of DCD in 2006 could have reduced its effectiveness compared to the 2007 results and previous NZ work. The higher rainfall and total N losses in 2006 may also have contributed to this result. The DCD application regime used was that developed under Canterbury, New Zealand drainage conditions (Di and Cameron 2005). It may be necessary to modify the DCD application regime to better suit Irish leaching conditions, by changing the timing of applications, adding extra applications (as Monaghan *et al.* 2009 suggest), or increasing the DCD application rate.

Conclusion

DCD significantly reduced both the concentration and total losses of nitrate from three very different Irish soils. Although the results were not as impressive as previous work in New Zealand, considerable reductions in total nitrate loss of up to 45% were observed. These results may be able to be improved by tailoring the application regime to better suit Irish conditions. DCD shows potential as a useful technology to help Irish farmers meet their environmental obligations.

Acknowledgements

This research was funded through the Teagasc Walsh Fellowship Scheme.

References

Cameron KC, Smith NP, McLay CDA, Fraser PM, McPherson RJ, Harrison DF, Hardbottle P (1992) Lysimeters without edge flow: an improved design and sampling procedure. *Soil Science Society of America Journal* **56**, 1625-1628.

Di HJ, Cameron KC (2002) The use of a nitrification inhibitor, dicyandiamide (DCD), to decrease nitrate leaching and nitrous oxide emissions in a simulated grazed and irrigated grassland. *Soil Use and Management* **18**, 395-403.

Di HJ, Cameron KC (2004) Treating grazed pasture soil with a nitrification inhibitor, eco-n, to decrease nitrate leaching in a deep sandy soil under spray irrigation - a lysimeter study. *New Zealand Journal of Agricultural Research* **47**, 351-361.

Di HJ, Cameron KC (2005) Reducing environmental impacts of agriculture by using a fine particle suspension nitrification inhibitor to decrease nitrate leaching from grazed pastures. *Agriculture, Ecosystems and Environment* **109**, 202-212.

Di HJ, Cameron KC (2007) Nitrate leaching losses and pasture yields as affected by different rates of animal urine nitrogen returns and application of a nitrification inhibitor - a lysimeter study. *Nutrient Cycling in Agroecosystems* **79**, 281-290.

Fraser PM, Cameron KC, Sherlock RR (1994) Lysimeter study of the fate of nitrogen in animal urine returns to irrigated pasture. *European Journal of Soil Science* **45**, 439-447.

Menneer JC, Sprosen MS, Ledgard SF (2008) Effect of timing and formulation of dicyandiamide (DCD) application on nitrate leaching and pasture production in a Bay of Plenty pastoral soil. *New Zealand Journal of Agricultural Research* **51**, 377-385.

Monaghan RM, Smith LC, Ledgard SF (2009) The effectiveness of a granular formulation of dicyandiamide (DCD) in limiting nitrate leaching from a grazed dairy pasture. *New Zealand Journal of Agricultural Research* **52**, 145-159.

R Development Core Team (2008) 'R: A language and environment for statistical computing.' (R Foundation for Statistical Computing: Vienna, Austria).

Standing Committee Of Analysts (1982) Oxidised Nitrogen in Waters 1981. In 'Methods for the Examination of Waters and Associated Materials (Blue Book)'. (HMSO: London).