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The effect of the nitrification inhibitor dicyandiamide (DCD) on herbage production when applied at different times and rates in the autumn and winter

P.J. O'Connor[a,b], D. Hennessy[a,*], C. Brophy[c], M. O'Donovan[a], M.B. Lynch[b]

[a] Teagasc, Animal & Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland
[b] UCD School of Agriculture and Food Science, University College Dublin, Belfield, Dublin 4, Ireland
[c] Department of Mathematics & Statistics, National University of Ireland Maynooth, Maynooth, Co. Kildare, Ireland

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ABSTRACT

The high rate of urine excreted during animal grazing in late autumn provides a source of nitrogen (N) to the growing sward and also provides the potential for losses of N over the winter months. This study was established to evaluate the potential of applying a nitrification inhibitor, dicyandiamide (DCD), to urine patches to increase N use efficiency in grassland. Four simulated grazing plot experiments were undertaken across two experimental sites, one a free-draining acid brown earth (Experiments 1 and 3) and the other a moderate to heavy brown earth soil (Experiments 2 and 4). Experiments 1 and 2 received no fertiliser N application, and Experiments 3 and 4 received a split application of 350 kg N fertiliser ha^{-1} $year^{-1}$. The effect of applying the nitrification inhibitor dicyandiamide (DCD) at 5 or 10 kg DCD ha^{-1} in autumn and winter to plots receiving synthetic urine or zero urine on spring and annual herbage production was examined in all experiments. The application of DCD did not increase spring herbage production in any of the experiments. Over the two years, the application of 5 or 10 kg DCD ha^{-1} increased annual herbage production in Experiment 1 when applied to October and November deposited urine patches. Urine application increased herbage production in spring and annually in Experiments 1 and 2, and increased herbage crude protein content and herbage N uptake in all experiments. The application of urine increased soil ammonium and TON content in the 0–100 mm horizon at both sites. The application of 10 kg DCD ha^{-1} reduced surplus N in Experiment 1 when applied to October and November deposited urine. Overall the effects of DCD on herbage production, surplus N and other parameters in this study were not consistent.

1. Introduction

Increasing the proportion of grazed grass in the diet of the dairy cow, particularly in early spring, reduces milk production costs and can increase the profitability of grass based milk production systems in Ireland and other temperate climates (Shalloo et al., 2004; Dillon et al., 2005; Kennedy et al., 2005). Nitrogen (N) availability is one of the key factors driving grass growth. Increasing N availability in spring through fertiliser or slurry application can result in increased grass growth and therefore herbage availability for grazing. Urine and dung are also sources of N in grazed swards, although their deposition is localised. Nitrogen concentration under urine patches is very high, equivalent to a fertiliser N application rate of up to 1000 kg N ha^{-1} (Whitehead, 1995). The majority of this N is in excess of sward requirements and is often lost by nitrate (NO_3^-) leaching through the soil profile or nitrous oxide (N_2O) emissions, particularly over winter when grass growth rates are low.

Nitrification inhibitors are being investigated in many countries as a strategy to mitigate NO_3^- leaching, denitrification and N_2O emissions under urine patches (Serna et al., 1995). They therefore have the potential to increase N availability in the soil for grass growth, thereby increasing the N use efficiency of grazed swards, as well as reducing N losses to the environment (O'Connell et al., 2004). Dicyandiamide (DCD; $C_2H_4N_4$) is one such nitrification inhibitor. It is a white crystalline nitrogenous powder naturally broken down in the soil, with no traces of residue remaining beyond the cropping year (Amberger, 1989). Dicyandiamide slows the conversion of ammonium (NH_4^+) to NO_3^- in the soil by interfering with the cytochrome oxidase in the respiratory electron transport system of *Nitrosomonas* bacteria, which are responsible for the first step of the nitrification process (Serna et al., 1995). Reductions in NO_3^- leaching and N_2O emissions following the application of DCD have been reported by many authors including Moir et al. (2007) and Dennis et al. (2008). Di and Cameron (2002) reported reductions in annual NO_3^- leaching of 59% from urine

* Corresponding author. Tel.: +353 025 42297; fax: +353 025 4234.
E-mail address: deirdre.hennessy@teagasc.ie (D. Hennessy).

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patches (lysimeter study) following DCD application; in addition Di and Cameron (2005) reported a 68% reduction in NO_3^- leaching from dairy cow urine N when DCD was applied in autumn (Di and Cameron, 2005). Selbie et al. (2011) reported that DCD (10 kg ha^{-1}) reduced NO_3^- leaching by 45% and N_2O emissions by 70% on dairy cow urine (1000 kg N ha^{-1}) treatments on Irish soils. Richards et al. (2008) also reported that DCD application on urine patches reduced NO_3^- leaching, especially on Irish soils.

In addition to the reductions in environmental N losses, Di and Cameron (2002) also observed an 18% increase in herbage production following DCD application to spring deposited urine patches, and an average increase in herbage production of 49% following DCD application to autumn deposited urine patches. The same authors observed that the application of DCD to autumn deposited urine patches, followed by a second application in spring, increased herbage production by 33% annually (Di and Cameron, 2005). Zaman and Blennerhassett (2010) reported that the application of DCD to spring deposited urine increased herbage production by an average of 12%.

An N balance can be used to describe the potential for N loss to the environment; it gives an indication of the quantity of N that may be lost through leaching, denitrification and volatilization or immobilization into soil organic N. Research has identified the importance of some individual loss processes, such as N losses by ammonia volatilization in pastures grazed by dairy cows (Bussink and Oenema, 1996), NO_3^--N leaching (Scholefield et al., 1993), N_2O emissions and N removal by immobilization (Ledgard et al., 1999).

The efficacy of DCD is influenced by several factors, including soil and environmental factors. Temperature is the most influential environmental factor; an increase in temperature can have a negative effect on the persistence of DCD in the soil, reducing the time frame in which it can provide effective nitrification inhibition. The half life of DCD at 6 °C is 100 days (Williamson et al., 1996), and 18–25 days at 20 °C (Di and Cameron, 2004). As a consequence, DCD should be applied in cool conditions such as late autumn, winter and early spring in temperate climates to maximise its potential effectiveness in inhibiting nitrification in the soil (Kelliher et al., 2008). Therefore, the hypothesis of this experiment was that the application of DCD in autumn and winter will increase N availability for grass growth in spring and, therefore, increase spring herbage production.

The objective of this study was to establish if herbage production was increased following the application of DCD to autumn and winter deposited urine patches, and to determine the appropriate rate and time of application of DCD on grass swards receiving zero or 350 kg N ha^{-1} $year^{-1}$.

2. Materials and methods

2.1. Soil type and pasture

Four experiments were undertaken using simulated grazing plots at the Animal and Grassland Research and Innovation Centre, Teagasc, Moorepark, Fermoy, Co. Cork, Ireland, on two contrasting soil types. The soils were a free-draining acid brown earth of sandy loam to loam in texture with a pH of 6.02 and bulk density of 1.00 g cm^3 at Moorepark Research Farm, hereafter referred to as MPK (50°07′N, 08°16′W) in Experiments 1 and 3 and a moderate to heavy brown earth with evidence of an iron pan with a pH of 5.52 and bulk density of 0.83 g cm^3 at Ballydague Research Farm, hereafter referred to as BD (52°12′N, 08°13′W) in Experiments 2 and 4. Ballydague Research Farm is approximately 8 km from MPK. Swards were predominately perennial ryegrass (*Lolium perenne* L.) and were previously rotationally grazed by dairy cows at MPK and by dairy heifers at BD. In Experiments 1 and 2 no fertiliser N was applied, and in Experiments 3 and 4 split applications of N fertiliser (total 350 kg N ha^{-1} $year^{-1}$) were applied between mid–January and mid September (as specified in the Irish Governments Nitrates Action Plan (S.I. 378, 2006)) as urea (46% N) from February to April (120 kg N ha^{-1} $year^{-1}$), and calcium ammonium nitrate (CAN; 27% N) from May to September (230 kg N ha^{-1} $year^{-1}$).

2.2. Experimental design

Apart from the N fertiliser application strategy (zero N in Experiments 1 and 2, and 350 kg N ha^{-1} in Experiments 3 and 4), all experiments had the same design. Each experiment had three replications (blocks), and within each replication five factors (details below) were manipulated resulting in 28 treatments in total. The 28 treatments were each applied to one plot within each block; plots were 5 m × 1 m at BD and 5 m × 1.5 m at MPK. Experiments were established in September 2008 and completed in November 2010. A cleaning cut was undertaken in November 2008 and the recording of experimental data began in February 2009. Each plot was harvested ten times in year 1 (2009) and eight times in year 2 (2010).

2.3. Treatments

Within each experiment, the five factors manipulated were urine rate, date of application of urine, DCD rate, date of first application of DCD and date of second application of DCD (Table 1). The two urine application rates were 0 and 1000 kg N ha^{-1} (0U or U, respectively) applied on one of three occasions in autumn – late September, October or November. Synthetic urine was used (urea and water mix) so that a known quantity of N was applied. Synthetic urine was deposited using 10 L watering cans with rose caps (cap with small openings). Dicyandiamide was applied at rates of 0, 5 and 10 kg ha^{-1} to all designated plots within 24 h of urine application in either late September, October or November. Of the plots that received a first application of DCD > 0 kg ha^{-1}, half received a second application of the same rate approximately 90 days later. The DCD was applied as a fine particle suspension (FPS) using a walk behind sprayer (Kestrel Spray-Master Sprayer, R&J Hay, St Johnston, Cavanacaw, Co. Donegal, Ireland).

Plots receiving DCD at rates of 0, 5 and 10 kg ha^{-1} will hereafter be referred to as 0, 5 and 10. Plots receiving a single application of urine and DCD in late September, October or November will hereafter be referred to as S, O or N, and those receiving a second application of DCD 90 days later will hereafter be referred to as S + 90, O + 90 and N + 90. Plots that received zero urine and zero DCD are called control and hereafter be referred to as C. In total there are 28 unique combinations of factor levels or treatments (including control) listed in Table 1. Treatments applied in year 1 were applied between September 2008 and March 2009 and treatments applied in year 2 were applied between September 2009 and March 2010.

2.4. Measurements

2.4.1. Herbage production

Herbage was mechanically harvested every four weeks from February to November 2009 and in 2010 using an Agria auto-scythe mower (Agria Werke GmbH, Bittelbronnerstr 42, Moeckmuehl 74219, Germany) at MPK and a Honda rotary blade lawnmower (Honda HRH 536 HX Pro Hydrostatic 4-wheel mower, Honda, Swepsonville, NC, USA) at BD. The Honda lawnmower was used at BD due to the heavy soil at the site (Hennessy et al., 2008). All fresh samples were weighed and a sub-sample (100 g) was dried at 40 °C for 48 h to determine dry matter (DM) content. Dry matter yield was calculated by multiplying DM% of the subsample by