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Effects of oral administration of dicyandiamide to lactating dairy cows on residues in milk and the efficacy of delivery via a supplementary feed source

B.G. Welten*, S.F. Ledgard, S.F. Balvert, M.J. Kear, M.M. Dexter

AgResearch Ruakura Research Centre, Private Bag 3123, Hamilton, New Zealand

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ABSTRACT

A metabolism stall study examined the fate of dicyandiamide (DCD) administered to dairy cows by either oral drenching or via a supplementary feed source (pasture silage) as a practical method to achieve targeted DCD excretion in individual urinations to reduce nitrogen (N) losses from grazed pasture systems. The study consisted of two experiments; firstly, lactating dairy cows were orally administered an aqueous solution of DCD at two rates (3 or 30 g cow^{-1} day^{-1}) to examine the output in urine, faeces and milk, and secondly, non-lactating dairy cows were fed pasture silage amended with fine-crystalline DCD powder (30 g DCD cow^{-1} day^{-1}) to investigate concentrations of DCD in excreta (urine and faeces) and the subsequent inhibition of nitrification of urinary-N in soil. Administration of DCD to lactating dairy cows in solution resulted in DCD being predominantly recovered in urine at 61% relative to 19% in faeces and 1.2% in milk (SEM 2.3, 1.0 and 0.08, respectively). Increased DCD administration rate led to higher ($P < 0.01$) concentrations of DCD in urine, faeces and milk, but had no significant effect on the total daily proportion recovered (percentage of that administered). After ceasing administration, concentrations of DCD in milk and excreta (urine and faeces) declined to undetectable levels after 5 days. In the second experiment, recovery of DCD in urine from cows fed DCD-treated pasture silage was higher at 82%, with 10% in faeces (SEM 1.9 and 0.6, respectively) and markedly inhibited nitrification of urine-N in soil. This study highlights that oral administration of an aqueous DCD solution to lactating dairy cows is predominantly eliminated in urine with relatively low amounts voided in milk. Furthermore, provision of fine-crystalline DCD powder in supplementary feed is also a viable delivery method for excretion in urine to potentially reduce environmental N losses from grazed pasture systems.

1. Introduction

Losses of nitrogen (N) from agricultural systems are an important contributor to global greenhouse gas (GHG) emissions and can have a deleterious impact on water quality (Kroeze and Bouwman, 2011). The principal source of N loss from grazed pasture systems is from urine excreted by grazing ruminants in small localised patches at very high N rates of up to about 1000 kg N ha^{-1} (e.g. Ledgard et al., 2009). The surplus urinary-N that is not utilised by plants or immobilised in soil is susceptible to N loss processes through nitrate leaching and gaseous N emissions (primarily nitrogen gas, nitrous oxide and ammonia gas; Cameron et al., 2013).

Research has focused on developing a range of technologies to mitigate urinary-N losses that include strategic grazing practices, low-N feed supplements to reduce concentration of urinary-N and improved plant and animal breeding for increased N use efficiency (Ledgard et al., 2011; Luo et al., 2010). A recent review of N mitigation technologies in grazed pasture systems by Cameron et al. (2013) highlighted the use of soil nitrification inhibitors, particularly dicyandiamide (DCD), as one of the key practical mitigation strategies to reduce losses of urinary-N by leaching and nitrous oxide emissions from grassland soils.

The conventional method of DCD application is to surface broadcast over the entire grazed area within 7 days of grazing during the main period of N loss (e.g. late-autumn-winter period; Di and Cameron, 2007). For example, broadcast application of DCD to urine- affected pastures has been shown to reduce nitrous oxide emissions and nitrate leaching losses by about 60% across a range of soil types and climatic regimes (Di et al., 2007, 2009). However, this uniform method of application is non-specific at targeting

* Corresponding author. Fax: +64 7 838 5117.
E-mail address: brendon.welten@agresearch.co.nz (B.G. Welten).

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individual urine patches that only represent a small proportion of the grazed area (e.g. <5% in a single grazing or about 20% annually; Haynes and Williams, 1993). Alternatively, DCD can be orally-administered to grazing ruminants for excretion in the urine (Ledgard et al., 2008), which could reduce the total amount of DCD required compared with conventional broadcast application. Ledgard et al. (2008) carried out a metabolism stall study using sheep directly infused with a DCD solution over a 5 day treatment period and found that 86% was excreted in the urine and was effective in inhibiting nitrification in incubated soil. Similarly, O'Connor et al. (2013) recovered 82% of DCD in urine when DCD was infused in the rumen of non-lactating dairy cows in a 6-day metabolism stall study. These studies have established that DCD is predominantly excreted in the urine in an unaltered form. Adoption of practical methods of DCD delivery to ruminants (e.g. dairy cows) in farm systems as an N mitigation technology requires a range of delivery methods to be evaluated (e.g. daily oral drenching, delivery in animal drinking water systems). Welten et al. (2014) administered DCD in drinking water to dairy cows and showed a reduction in nitrate leaching and nitrous oxide emissions by 40% under an intensive grazing system. While this approach has demonstrated potential effectiveness in reducing N losses, an alternative delivery method could be to provide DCD in supplementary feed for grazing animals. The advantage of this delivery method is that supplementary feed is typically provided to grazing animals during the main period of N loss in year-round grazing systems (late-autumn-winter period; e.g. Holmes et al., 2002). However, uncertainty exists on the fate of DCD in dairy cows when delivered in fine-granular powder form with supplementary feed. Furthermore, a critical issue with delivery of DCD to dairy cows that requires investigation is the potential for DCD to be voided in milk when administered during the lactation period.

The objectives of this study were to (1) examine the fate of DCD administered to lactating dairy cows including the level voided in milk and, (2) to determine the efficacy of delivering fine-crystalline DCD powder via a supplementary feed source (pasture silage) as a practical method to deliver inhibitors to grazing animals. The study consisted of two experiments. The first experiment examined the fate of DCD orally-administered to lactating dairy cows at two dose rates (3 or 30 g cow^{-1} day^{-1}) by assessing DCD output in urine, faeces and milk. The second experiment, examined the fate and effectiveness of amending fine-crystalline DCD powder (30 g cow^{-1} day^{-1}) in pasture silage to non-lactating dairy cows on excretion in urine and subsequent inhibition of urinary-N in soil.

2. Methods

2.1. Animal housing

The experiments were undertaken in a metabolism stall facility located at DairyNZ Lye Research Farm in Hamilton, New Zealand (NZ). The indoor facility consisted of stalls that housed individual dairy cows and each cow was fitted with a standard harness for separate collection of urine and faeces. Each stall had individual feed and water access facilities. All experimental dairy cows had been previously trained for use in metabolism stalls and had been blood tested prior to commencing each experiment to ensure blood metabolite parameters were consistent with normal renal and hepatic function (data not presented). At the conclusion of each experiment the dairy cows were returned to standard grazing.

Regulatory approval for the experiments was obtained from the Ruakura Crown Research Institute Animal Ethics Committee and the Agricultural Compounds and Veterinary Medicines group (ACVM) of the NZ Ministry for Primary Industries. The latter imposed default withholding periods for milk and meat of at least 35 and 91 days, respectively.

2.2. Experiment 1

2.2.1. Experimental design

Eight lactating Friesian dairy cows (508 (SEM 13) kg initial live-weight) at the same stage of early lactation with similar preceding daily milk yields (averaged 23.9 (SEM 1.5) L cow^{-1} day^{-1}) were randomly allocated to the following two treatments (four cows per treatment);

(1) Low DCD—3 g DCD dissolved in 150 ml water daily
(2) High DCD—30 g DCD dissolved in 1200 ml water daily

The low-DCD dose was based on the conventional field application rate of 10 kg DCD ha^{-1} and average dairy cow excretion data (Di and Cameron, 2007; Haynes and Williams, 1993). The high-DCD dose was calculated to achieve 10 times the per-hectare field rate.

The experiment was comprised of 3 days for acclimatisation to the metabolism stalls (to diet and housing) followed by a 5-day treatment period and a 7-day non-treatment clearance period.

2.2.2. Treatment administration

An aqueous solution of DCD was prepared daily during the 5-day treatment period for each individual cow by dissolving fine-crystalline DCD powder (>99.8% purity; Ningxia Darong Chemicals & Metallurgy Co., Ltd., China) in deionised water to achieve stock solution concentrations of 20 and 25 g DCD L^{-1} for the low and high DCD treatments, respectively. The latter used a higher DCD concentration to avoid an excessive total volume of solution being administered on a per cow basis for animal welfare reasons. The aqueous DCD solutions were orally administered to the designated dairy cows in three equal aliquots (each 50 and 400 ml for the low and high-DCD treatments, respectively) at 0900, 1300 and 1700 h to achieve the required total daily volume.

2.2.3. Animal management and sampling

The eight lactating dairy cows were housed in individual metabolism stalls and offered freshly cut perennial ryegrass pasture as two equal meals at approximately 0900 and 1600 h at a rate of 25 kg dry matter (DM) cow^{-1} day^{-1}. Herbage DM content and total N concentration of the offered pasture averaged 17.3% and 3.1% N, respectively. Any feed refusals were recorded and collected for determination of herbage DM content and total N concentration. Daily cow water consumption was recorded at 0900 h daily throughout the duration of the experiment.

Dairy cows were milked twice daily at approximately 0830 and 1530 h throughout the duration of the experiment. Milk yields from individual dairy cows were weighed at each milking event, thoroughly mixed, and sub-sampled. A composite milk sample was prepared for each individual dairy cow according to the milk yield by proportionally bulking the two milking events for each day. The composite milk sample was sub-sampled (50 ml) in duplicate and frozen at −20 °C prior to analysis for total N and DCD concentration. The remaining milk was discarded and did not enter the human food chain.

The total amount of urine voided over a 24 h period was determined at approximately 0900 h daily for the duration of the experiment. The total urine output was weighed, and thoroughly mixed prior to being subsampled (50 ml) in duplicate. This consisted of one non-acidified urine sample for DCD analysis, and one acidified sample (*via* HCl addition to achieve pH < 4) to minimise ammonia volatilisation for total-N analysis. All urine samples were frozen at −20 °C prior to analysis.

Total faecal output over a 24 h period was determined at approximately 0900 h daily for the duration of the experiment. Total output of faeces was weighed and duplicate sub-samples