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Animal intake of DCD for delivery in urine to achieve cost-effective reduction in nitrous oxide emissions from soil in grazed livestock systems

Key external stakeholders:
Grassland farmers, Agricultural and environmental policy makers, EPA emissions inventory, dairy industry

Practical implications for stakeholders:
Reduction of nitrogen loss to the environment is a pressing national and international need to improve water quality and reduce greenhouse gas emissions. Feeding DCD was cost effective at reducing emissions of the potent greenhouse gas nitrous oxide (N_2O).

Main results:
Nitrification inhibitors have been found to reduce nitrate leaching and greenhouse gas emission. Previously DCD has been sprayed to soil but incorporating DCD in feed might be more cost effective. The inclusion of DCD in three feeds (barley concentrate, maize silage or grass silage) was effective at delivering high DCD rates to urine patches where large losses can occur. The DCD excreted in the cow urine was effective at reducing nitrous oxide emissions from urine patches by between 34 and 64%. Larger reductions were observed from urine patches with DCD at a rate of 30 kg ha^{-1}. Incorporation of DCD into animal feeds is an effective measure to reduce nitrous oxide emissions and costs compared with blanket spraying of DCD. No negative impacts on cow liveweight or body condition score were observed.

Opportunity / Benefit:
Inclusion of DCD in animal feed was found to a very effective mitigation option but further work on residues of DCD in animal products is required.

Collaborating Institutions:
AgResearch, New Zealand

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1. Project background:
The project aimed to investigate the feeding of the nitrification inhibitor DCD for delivery in urine to achieve cost-effective reduction in nitrous oxide emissions from soil in grazed livestock systems. DCD has been proven to be a highly effective nitrification inhibitor that dramatically reduces emissions of the greenhouse gas nitrous oxide and nitrate leaching to water. Heretofore DCD has been blanket sprayed on to grazed pastures in New Zealand as a practical management practice to reduce both nitrous oxide and nitrate

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leaching loses from urine effected soils in grazed pasture. This practice applied DCD to both urine and non-urine effected soil. There is a large potential to reduce the amount of DCD used and cost reduction if DCD could be targeted directly to urine patches, thereby avoiding the need to spread it across large areas unaffected by urine deposition.An alternative, untested approach to targeting DCD would be to provide the DCD in feed supplemented to grazing animals (sprayed on the surface of the feed or dried with the feed). This approach would complement existing farm management practises as the key time for DCD application is over autumn and winter (when losses by leaching and N2O emissions are dominant) when supplementary feed is commonly provided for grazing animals due to low pasture growth and reduced pasture availability. Thus, in practical terms, it would be a simple, lower cost mitigation measure to provide DCD-amended feed to animals to achieve significant reductions in emissions.

2. Questions addressed by the project:

The hypothesis was provision of the nitrification inhibitor DCD in feed results in a cost-effective method of delivery of the DCD in animal urine that is effective in decreasing nitrous oxide emissions and nitrate leaching from grazed pastoral soils.

3. The experimental studies:

The experiment was set up in a Latin Square design, where three groups of five non-lactating dairy cows were subject in rotation to one of three feeding treatments during three phases of 21 days. Each phase was divided between pre-conditioning (4 days), sampling (5 days) and resting periods (12 days). During pre-conditioning and sampling, groups were evening-fed daily one of three treatments (3 kg dry matter cow-1 of grass silage GS, maize silage MS or barley concentrate BC) that was manually mixed with DCD (30 g cow-1). During resting, cows were fed with GS without DCD. In the sampling periods, groups were brought out daily to graze fresh pasture. A representative soil sample was collected from each urine patch and analysed for DCD concentration by HPLC analysis (Minet et al 2016). The effect of differing urine DCD concentrations (10 and 30 kg ha-1) on N2O emissions was evaluated over 2 years. The efficacy of excreted urinary DCD to reduce nitrous oxide (N_2O) emissions was investigated in a two-year study carried out on simulated urine patches in three application seasons (spring, summer, autumn) from grazed pasture soil in a heavy-textured soil under temperate climatic conditions. In each application season, the following treatments were applied: untreated control (C), urine (U), urine + 10 kg DCD ha^{-1} (U+DCD10), urine + 30 kg DCD ha^{-1} (U+DCD30) and urine + 30 kg DCD-fed ha^{-1} (U+DCD30-f). Nitrous oxide emissions were measured using the static chamber method and air samples were analysed by gas chromatography (Minet et al. 2018).

4. Main results:

There was no significant effect of feed type on the urine patch DCD equivalent application rate with a mean excretion rate of 27 g DCD cow^{-1} day^{-1}. This suggests that the ingestion of any of the three supplementary feeds mixed with DCD should be similarly effective at delivering DCD to urine patches. There was a highly significant positive relationship between urine patch DCD and N content which resulted in higher DCD application rates at higher urine patch N loading. This could be important as previous research has indicted that DCD has a higher effectiveness and persists longer in soil at higher loadings. Importantly, no negative impacts on cow liveweight or body condition score were observed during these feeding trials. Added to the fact that DCD and urinary N are both deposited at the same time and intimately mixed in urine patches, feeding DCD to dairy cows after mixing with different feeds could represent a more effective and practical DCD application strategy than a DCD broadcast application at a single rate (Minet et al. 2016).

The cumulative N_2O-N emissions and the N2O-N emission factor (EF3, expressed as % of N applied) were not significantly different for the U+DCD30 and U+DCD30-f treatments. Thus the DCD excreted in urine was not significantly different to the DCD mixed with urine post excretion. DCD significantly reduced N_2O emissions by 34 and 64% for the U+DCD10 and U+DCD30 treatments compared to the no DCD urine treatment (U). Increasing the DCD loading from 10 to 30 kg ha^{-1} significantly improved efficacy by reducing the EF3 from 34% to 64%. This highlights that under local conditions, 10 kg DCD ha^{-1} (the recommended rate for commercial use in New Zealand) was not the optimum DCD rate to curb N_2O emissions on this specific soil (Minet et al. 2018).

The results of the research were also integrated into the €rin model (Hoekstra et al. 2020) which integrates an agronomic dairy production model with an environmental model. The integrated model was then used to test a range of production scenarios to balance increased milk production with nitrogen loss to the environment. The model was used to simulate increasing milk production from 8.3 to 12 ton ha^{-1} which resulted in increasing farm net profit from 301 to 1,574 € ha^{-1}. Inclusion of mitigation options such as inhibitors and low emission slurry spreading reduced losses of ammonia, nitrate, N_2O and N_2 by 12%, 37%, 29% and 57%, respectively compared to the baseline. The also reduced the milk nitrogen foot print from 12.9

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to 10.4 kg N per ton milk, compared to the control. There was a cost of using inhibitors was low and reduced farm net profit from 1,574 to 1,500 € ha^{-1}. The intensification scenarios all led to increased ammonia emissions completely wiping out the combined N loss savings from nitrate, N_2O and N_2. There is a need to holistically consider additional ammonia abatement techniques coupled with the use of inhibitors to offset increasing nitrogen emissions associated with increased milk production (Hoekstra et al. 2020).

5. Opportunity/Benefit:

Inclusion of the nitrification inhibitor dicyandiamide (DCD) in animal feed is an effective method of delivering the required DCD concentration in urine patches to effectively reduce nitrification and emissions of the potent greenhouse gas N_2O.

6. Dissemination:

Main publications:

1. Minet E.P., Ledgard S.F., Lanigan G.J., Murphy J.B., Hennessy D., Lewis E., Forrestal P., Grant J., Richards K.G. (2016) Mixing dicyandiamide (DCD) with supplementary feeds for cattle: an effective method to deliver a nitrification inhibitor in urine patches. Agriculture Ecosystems and the Environment Agriculture, Ecosystems and Environment 231 114–121.
2. Minet E.P., Ledgard S.F., Grant J., Murphy J.B., Krol D.J., Lanigan G.J., Luo J., Richards K.G. (2018) Feeding dicyandiamide (DCD) to cattle: An effective method to reduce N2O emissions from urine patches in a heavy-textured soil under temperate climatic conditions, Science of the Total Environment 615 1319–1331.
3. Hoekstra, N.J., Schulte, R.P.O., Forrestal, P.J., Hennessy, D., Lanigan, G.J., Müller, C., Shalloo, L., Wall, D.P., Richards, K.G. (2020) Modelling the effect of sustainable dairy intensification on farm scale nitrogen flows and economic performance. Science of the Total Environment 707 134606

Popular publications:

1. Minet E., Ledgard S., Murphy J., Lanigan G., Hennessy D., Lewis E., Forrestal P., Richards K. (2016) Mixing dicyandiamide (DCD) with supplementary feeds for cattle: an effective method to deliver a nitrification inhibitor to urine patches, Greenhouse Gas and Animal Agriculture Conference, Melbourne, Australia 14-18 February 2016, P.28-29.
2. Richards K., Minet E., Ledgard S., Luo J., Lanigan G. (2017) Inclusion of nitrification inhibitor in animal feed to reduce environmental N losses. . In: Dalgaard et al. Innovative Solutions for sustainable management of nitrogen. Proceedings from the International Conference, Aarhus, Denmark 25-28 June 2017, p 93.
3. Hoekstra, N.J., Schulte, R.P.O., Forrestal, P.J., Hennessy, D., Lalor, S.T.J., Lanigan, G., Müller, C., Shalloo, L., Wall, D. , Richards, K.G. (2016) A model for upscaling disaggregated emissions from grazed grasslands. Greenhouse Gas and Animal Agriculture Conference, Melbourne, Australia 14-18 February 2016, p. 135.
4. Hoekstra, N.J., Schulte, R.P.O., Forrestal, P.J., Hennessy, D., Lanigan, G., Müller, C., Shalloo, L., Minet E., Richards, K.G. (2017) Assessment of options to support sustainable intensification of grazed grasslands. In: Dalgaard et al. Innovative Solutions for sustainable management of nitrogen. Proceedings from the International Conference, Aarhus, Denmark 25-28 June 2017, p 128.
5. Hoekstra, N.J., Schulte, R.P.O., Forrestal, P., Hennessy, D., Lanigan, G., Müller, C., Shalloo, L., Minet, E., Richards, K (2018) Assessment of options for sustainable intensification of grassland-based dairy farms European Grassland Federation, 17 to 21 June 2018 Cork Ireland.

7. Compiled by: Karl Richards, Gary Lanigan and Eddy Minet.

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