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Review

Assessment of the application of gibberellins to increase productivity and reduce nitrous oxide emissions in grazed grassland

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ABSTRACT

Emissions of nitrous oxide from grassland systems are attributable largely to the use of nitrogen fertilisers and the excreta deposited by grazing animals. There is increasing interest in using gibberellins as a naturally-occurring growth promotant of herbage that could be used to reduce the use of nitrogen fertilisers while leading to similar or greater increases in dry matter. This may provide practical opportunities to reduce nitrogen intake by ruminants and extend the seasonality of herbage growth in spring and autumn while reducing nitrogen losses, resulting in lower rates of nitrogen excretion by grazing animals and reduced nitrous oxide emissions. Our findings from a review of previous studies confirm that gibberellins promote dry matter production, especially when applied in early spring or late summer/early autumn. When gibberellins are applied alone without nitrogen fertiliser, the nitrogen concentration of herbage is reduced and the impacts on forage quality are small and often not significantly different from those for untreated controls. We calculated the consequences of enhanced herbage production on nitrogen excreta returned to the soil as urine by a grazing dairy cow and estimated that one application of gibberellins will result in a relative reduction in nitrous oxide emission per urination event of 18% when compared with emissions from using nitrogen fertiliser. We used the OVERSEER® model and nitrous oxide emissions factors to estimate the impacts of changing herbage dry matter production, foliage nitrogen concentration and timing of one application of gibberellins on annual nitrous oxide emissions for a dairy farm. For one application of gibberellins in late summer and early spring, we estimate reductions in nitrous oxide emissions of 1.6% and 1.3%, respectively, relative to the response for an untreated control. Incorporating the effects of reduced use of nitrogen fertiliser by substituting one split application of fertiliser in late summer or autumn with gibberellins, we estimate reductions on nitrous oxide emissions of between 5 and 6% relative to the response for the untreated control. We conclude that the use of gibberellins with reduced addition of nitrogen fertiliser has the potential to reduce nitrous emissions from grazed grassland. However, acceptance of widespread use of gibberellins will be dependent on cost benefit analysis for farmers.

Contents

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1. Introduction

Despite its low concentration of 319 ± 12 ppbv in the atmosphere, nitrous oxide is the fourth most potent greenhouse gas because its high global warming potential associated with its long lifetime in the atmosphere of 120 years (Ramaswamy et al., 2001) is 298 times that for carbon dioxide (Forster et al., 2007). Globally, more than 40% of the emissions of nitrous oxide are attributable to agricultural systems managed for grazing animals (Denman et al., 2007) and emissions have continued to increase during the last two decades. Nitrous oxide is derived from microbiological processes in the soil acting on nitrogen that is applied as fertiliser, mineralised from stored organic sources or biologically fixed from atmospheric nitrogen. Grazing livestock are responsible for additional emissions from dung and urine deposited by the animals directly or from controlled application of stored waste.

New Zealand's greenhouse gas inventory is unique among OECD (Organisation for Economic Co-operation and Development) countries in that agricultural emissions of methane from enteric fermentation in the rumen of grazing animals (37.0% of gross emissions) and nitrous oxide (14.2% of gross emissions) are high relative to the emissions from carbon dioxide (Ministry for the Environment, 2013). This is attributable to the large surface area of land (42%) devoted to grazed grasslands with agricultural products being the dominant contributor to the economy (DairyNZ and LIC, 2012).

Increasing intensification of livestock farming on grasslands is facing a growing challenge. Most notable is the recent widespread increases in the scale and intensity of the conversion of dryland to irrigated grassland to support dairy farming. Economic pressures to increase the supply of forage for animals and associated agricultural products are colliding with growing concerns of increased requirements for resources (e.g. nitrogen and water) and the impact of high resource use on the environment. In New Zealand, particular concerns are the increases in nitrous oxide emissions and nitrate leaching. There are similar concerns in northern Europe, even though nitrous oxide emissions have reduced in some countries with decreased intensity of grassland production following the implementation of agri-environmental policies (European Environment Agency, 2014).

2. Sources of nitrous oxide from grazed grassland

Countries that are signatories to the United Nations Framework Convention on Climate Change (UNFCCC) are required to provide annual inventories of greenhouse gas emissions and removals. Data for New Zealand show that nitrous oxide emissions increased by 29% from 25.4 to 32.8 Gg N $year^{-1}$ between 1990 and 2011 (Ministry for the Environment, 2013). Nitrous oxide emissions from grazed grassland, notably dairy farms, occur because the inputs of nitrogen fertiliser to maintain high herbage and animal productivity exceed the ability of soils to retain the nitrogen. Surplus nitrogen is lost through nitrate leaching and emissions of gaseous nitrogen in the forms of ammonia, nitric oxide, nitrous oxide and nitrogen gas (Luo et al., 2010).

Emissions of nitrous oxide are regulated by interactions between soil physical and chemical properties, soil microbiological populations, climate, and animal management practices. Emissions are enhanced by the deposition or controlled application of animal excreta to the soil especially during anaerobic conditions resulting from wet soil conditions and soil compaction from animal treading (Saggar et al., 2004, 2009; de Klein and Ledgard, 2005; van der Weerden et al., 2014). The potential for emissions is thus higher in winter when soils are wet and more vulnerable to compaction.

For inventory purposes, it is necessary to calculate nitrous oxide emissions from each source independently. The UNFCCC (United Nations Framework Convention on Climate Change) approach is to apply relative direct emission factors (EFs) to each source that expresses the proportion of the quantity of nitrogen applied to soils that is emitted to the atmosphere as nitrous oxide. Emission factor EF_3 is used to estimate nitrous oxide emissions from urine and dung deposited during grazing. Values for EF_3 are obtained from measurements of nitrous oxide emissions when known amounts of urine and dung are applied to soils (van der Weerden et al., 2014). Emission factor EF_1 refers to nitrous oxide emissions from the addition of nitrogen fertiliser to grassland. In a recent statistical analysis of measurements of nitrous oxide emissions from 185 field sites in New Zealand, Kelliher et al. (2014) concluded that the appropriate (mean ± standard error) values of EF_3 for dairy cattle urine and dung, and sheep urine and dung are 1.16 ± 0.19%, 0.23 ± 0.05%, 0.55 ± 0.19% and 0.08 ± 0.02%, respectively. The higher values of EF_3 for both dairy cattle and sheep urine compared with those for dung are attributable to the higher concentrations of mineral nitrogen that are deposited in a small area. Analysis of New Zealand's available data for the emission factor from the addition of nitrogen fertiliser as urea, EF_1, by Kelliher et al. (2014) showed that the value is 0.48 ± 0.13%. We have used this value in anticipation that it will replace the current value of 1% used in the national inventory (Ministry for the Environment, 2013).

3. Mitigation of nitrous oxide emissions

Various approaches have been identified to mitigate greenhouse gas emissions associated with grazed grassland systems (de Klein and Ledgard, 2005). These include soil management, animal management using feed pads or housing systems, controlled application of effluent, reductions in nitrogen fertiliser, lowering the amount of nitrogen excreted by animals, use of feed with low nitrogen content, selecting animals with high nitrogen use efficiency, and the use of chemical inhibitors that block the conversion of urea to ammonium and ammonium nitrate in soils (Luo et al., 2010). Rates of nitrous oxide production are dependent on complex interactions between soil properties, soil microbiology, climate and management practices (Saggar et al., 2009). Rather than the supply of nitrogen from urine and dung deposits and nitrogen fertiliser, in New Zealand grasslands nitrous oxide emissions are regulated primarily the rates of denitrification and its dependence on soil water content (Müller and Sherlock, 2004; van der Weerden et al., 2014).

To reduce nitrous oxide emissions from grassland, in terms of animal-based approaches, there is a need to focus on the root cause