Transformation and loss of excretal nitrogen under winter management systems

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Abstract

Excreta from cattle animals contain large amounts of nutrients, particularly nitrogen, which could lead to substantial gaseous losses of ammonia and nitrous oxide to the atmosphere, as well as nitrogen leaching. These losses are greatest during wet conditions in winter. However, the situation could be improved through moving cows off grazing paddocks to a stand-off pad or housing system. Therefore, it is necessary to quantify ammonia emissions and evaluate denitrification potential (which leads to emission of N_2O) through various winter management systems in order to determine methods and technologies for efficient and effective mitigation of gaseous emissions.

To understand the mechanism of nitrogen transformation and of reduction on gaseous emission from excreta in various winter management systems, a series of incubation studies and a field study were carried out investigating the suitability of several natural materials with absorbent properties, as media to reduce gaseous emission of ammonia and nitrous oxide.

The incubation studies were undertaken using cow excreta that consisted of a 1:1 (v:w) mixture of fresh urine and dung collected from a dairy farm. A lab incubation study was conducted using excreta, and excreta amended with soil and sawdust treatments. A further lab incubation study was carried out using different levels of natural materials. The field study consisted of two stand-off pads in which crushed pine bark or sawdust were used as bedding materials.

In the incubation study, ammonification was rapid in the case of excreta, compared to excreta amended with addition of natural materials. Whereas nitrification was very slow in the all treatments, only a small amount of nitrate ions could be detected till the end of incubation study.

In the incubation study, both soil and sawdust appeared to significantly reduce ammonia emission. In comparison to excreta, amendment with soil (excreta: soil=1:2, w:w) and sawdust (excreta: sawdust=1:2, w:v) reduced ammonia loss by 32.9% and 19.5%,

respectively. Excreta amended with a combination of soil and sawdust (1:1:1, w:w:v) was most effective, reducing ammonia emission by 34% under aerobic conditions.

Nitrate concentration was found to be the crucial limiting factor affecting the denitrification rate in the incubation studies. When KNO_3 was added to the excreta, the denitrification rate was 43.8μg N_2O-N/g excreta/hour. However, the denitrification rate of the excreta amended with both glucose-C and KNO_3 was 114.4μg N_2O-N/g excreta/hour. Denitrification potential followed: excreta> excreta with sawdust> excreta with soil.

On a field-scale stand-off pad, the carbon-rich natural materials pine bark and sawdust were shown to retain nitrogen effectively. After nine months of use, the bark retained 78% of the deposited excreta-N, while the sawdust pad retained 51%.

Therefore, it can be concluded that reduction of nitrogen losses can be achieved by using stand-off pad or housing systems (herd homes) which incorporate the use of a carbon rich natural material or soil in winter.

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Chapter 1 Introduction

1.1 The issue

Over the last few decades there has been concern in New Zealand at the extent of environmental contamination associated with pastoral farming; particularly the adverse effects on water and atmospheric quality (Bolan *et al.*, 2004a; Parliamentary Commissioner for the Environment Report, 2005). From 1994 to 2002 the number of dairy cows in New Zealand increased by 34% from 3.8 to 5.1 million; (Statistics New Zealand, 2004). Inevitably this large increase in cows has increased the impact of dairy farming on the environment. Feeding this large number of dairy cows has required high rates of fertiliser application, particularly of nitrogenous formulations. As well, the widely adopted policy of irrigating dairy farm effluent to land has meant that all manure nitrogen is returned to pasture. If nitrogen is applied to pasture in excess of plant uptake, the consequences can include nitrate leaching to surface and ground water, volatilisation of ammonia and emission of the greenhouse gas nitrous oxide (Muck and Richards, 1983; Buijsman *et al.*, 1987; Oosthoek *et al.*, 1991; Asman, 1992; Haynes and Williams, 1993; Bolan *et al.*, 2004a).

Under wet conditions high rates of nitrogen loss mainly through nitrate leaching have been reported from dairy farms; these conditions also enhance the emission of nitrous oxide (Luo *et al.*, 2000; De klein *et al.*, 2001). As these conditions are more frequent in colder months, attention is being given to mitigation through winter management systems (Luo *et al.*, 2000; Bolan *et al.*, 2004a). A successful winter management system will maintain satisfactory animal condition and pasture production while preventing adverse environmental effects. Desirable environmental outcomes under winter management systems include maintenance of soil structure and prevention of nutrient leaching and of emissions of ammonia and nitrous oxide. As adverse environment effects are not permitted under the Resource Management Act (1991) the Ministry for the Environment has issued regulations and guidelines for effluent management (MFE, 1995) and these apply to the manures and effluents collected from winter management systems. Guidelines for winter management pads have been produced in consultations with farmers (Dexcel and Environment Waikato, 2005) that include a requirement for an appropriate effluent collection and retention systems. Although winter management systems are designed to improve environmental outcomes there could be some adverse effects from them, particularly those associated with undesirable gaseous losses. For example, de Klein and Ledgard (2001) suggested that the total NH_3 losses in the nil grazing system (housing shed) were higher than that in the conventional grazing system, with total nitrogen losses being 10-35% higher than under conventional grazing system. It has been reported that about 70% of the excreted nitrogen is transformed to ammonia gas over 9 months storage of manure in herd home bunkers (Longhurst *et al.*, 2006). Therefore it is necessary to understand nitrogen transformation processes and develop optimum mitigation technologies to reduce gaseous losses from winter management systems.

1.2 Winter management systems

Four winter management systems are used commonly on New Zealand dairy farms (Dexcel, 2005; Longhurst *et al.*, 2006): feed pads, stand-off pads, herd homes (wintering barns) and sacrificial paddocks. In the first three systems cows are physically removed from wet pasture for varying periods each day during the winter periods. In the sacrificial paddock system cows are generally left on the same paddock(s) throughout a wet period.

- Feed pads usually consist of a hard surface constructed from permanent materials, requiring an initial capital outlay. When conditions are wet, cows are held on the pad for 1 to 2 hours and are given supplementary feed. The principal purpose is to ensure the efficient consumption of feed without losses due to trampling of feed into wet soil. Urine and dung must be removed from the pad to an appropriate holding facility.

- Stand-off pads are used by cows for up to 20 hours a day which means that they need to be constructed from materials that do not adversely affect hooves and legs. A range of pad materials are in use including sawdust, bark, woodchips, either separately or mixed; sometimes with the addition of suitable proportions of lime or soft rock chip. Pads need to be large enough, usually 8 to 10 m^2 per cow, to accommodate cows for extended periods. Although the initial capital cost is relatively low, pad materials require frequent replacement, at least once a year; and some on-going maintenance to ensure that the surface is not covered with a deep layer of manure. Due to the length of time that cows spend on the pad a properly designed manure collection and storage system is an integral requirement of pad design.

- Herd homes (wintering barns) are a sophisticated design that provide shelter and incorporates a feeding platform and stand-off facility; together with a bunker to contain manure. The structure is made from permanent materials so that the initial cost is high (about $1000 per cow) (Pow T, personal communication). As cows can be maintained in a herd home for 24 hr a day they must be large enough to allow for cows to lie down. The platform needs specialised construction so that hooves and legs are not stressed and the design needs to ensure good airflow while maintaining shelter from adverse weather. The bunker system must be large enough to contain all the manure collected during wet periods.

- Sacrificial paddocks are a traditional wintering system that may have the feature of convenience but that has some undesirable environmental features. Cows remain on the same paddock(s) continuously throughout the wet period and this leads to pasture loss, soil damage and high rates of nutrient leaching and runoff. This sacrificed paddock is usually located close to the feed storage facility and milking yard. The condition of cows may deteriorate from the prolonged holding on wet soil (Longhurst R.D, personal communication).

1.3 Research objective

The overall objective of the study was to investigate nitrogen losses and nitrogen transformation from cow excreta. The research was aimed at selecting natural amendments with strong nutrient retention properties that are suitable for slowing down the transformations, thereby reducing gaseous emissions.

1.4 Layout of thesis

This thesis is comprised of seven chapters.

- Chapter 1 gives an overview of environmental issues and winter management systems.
- Chapter 2 reviews the scientific literature relating to dairying particularly under wet conditions and winter management systems; with emphasis on nitrogen cycle processes including mineralisation, ammonia volatilisation and denitrification potential.
- Chapter 3 describes the experimental design, materials and analytical methods used in the study.
- Chapter 4 reports the findings of laboratory scale investigations carried out to understand nitrogen transformations and ammonia volatilisation in excreta.
- Chapter 5 reports the findings of laboratory scale investigations of nitrification rates and denitrification potential in excreta amended with various natural materials.
- Chapter 6 reports the results of a field-scale investigation of emissions of ammonia and nitrous oxide from stand-off pads constructed from natural materials and of nitrogen transformations in pad leachate.
- Chapter 7 draws conclusions from the study findings and discusses their implications.