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Nitrous oxide, its formation and place in farm green house gas balances

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ABSTRACT

Nitrous oxide is a troublesome greenhouse gas for New Zealand's agricultural sector to deal with. It is formed by a naturally occurring soil process that is fundamental to the global nitrogen cycle. Quantities emitted are very small in a productive sense but very significant in New Zealand's greenhouse gas inventory. Increasing protein production from land carries an associated risk of increasing N_2O emission because increased inputs of N are usually required. Attention to the detail of whole system N cycling and greenhouse gas balances is therefore necessary if the challenge of increasing population and food demand is to be met without incurring hidden costs from atmospheric change.

Keywords: nitrogen cycle; denitrification; inventory.

INTRODUCTION

Nitrous oxide is a potent greenhouse gas (GHG) that is mostly derived from soils in agricultural systems. In the New Zealand GHG inventory it ranks third in importance behind CO_2 and methane; this is unusual as it generally ranks as a minor gas in national budgets. Nitrous oxide concentrations in the atmosphere have been rising since the middle of last century and the increased nitrogen flow in agricultural systems is believed to be the driver for this (Mosier *et al.*, 1998). The production of N_2O by soils is of little consequence in productive terms because it amounts to a few kilograms of nitrogen at most, a quantity that falls within the error term of nitrogen balances for intensive production systems. Little attention was paid to the process before 1990 because of that and as a result there is limited information to inform the policy decisions and inventory processes that are now necessary. In this paper I will discuss the issues surrounding the production of N_2O , at the global, the molecular and the farm scale. The data presented in the conference are drawn from the references cited in this manuscript.

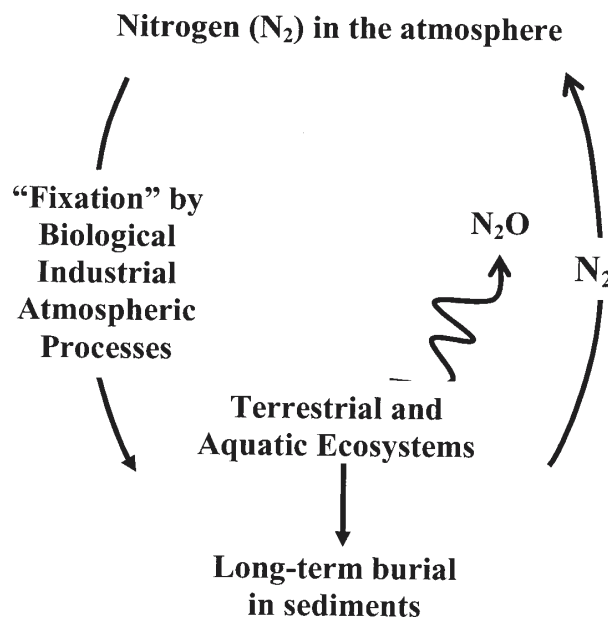
The global scale

Atmospheric N_2 enters terrestrial and aquatic ecosystems through biological fixation, synthesis of nitrogen fertilisers and by lightning discharge. Within oxygen rich environments N may be stored in organic forms that turn over slowly (half lives may be thousands of years), cycle and recycle through plants and animals and be oxidised to nitrate (NO_3^-). Where soils or sediments are anaerobic, reduction reactions occur and these produce almost exclusively N_2 which returns to the atmosphere completing the cycle. Some N will be effectively removed from the cycle through long term burial in deep sediments (Fig 1).

A very small proportion of the cycling nitrogen can be incompletely reduced and enter the atmosphere as N_2O . The concentration of N_2O in the atmosphere is small, about 360 parts per billion by volume, it is however very efficient in storing heat and persists for a long time before being converted to N_2 in the stratosphere. One molecule of N_2O has the same Global Warming Potential (GWP) as about 300 molecules of CO_2 .

This large-scale view of the nitrogen cycle has two

FIGURE 1. A generalised global nitrogen cycle showing the escape of N_2O from the denitrification process to the atmosphere.



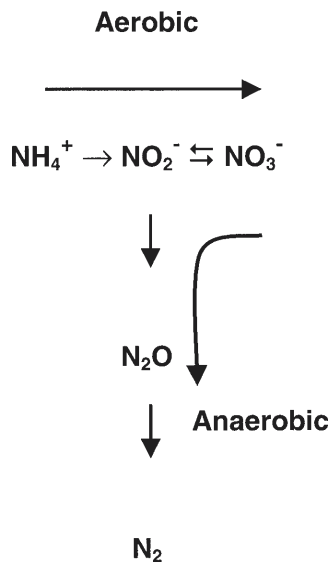
important features that underlie the methodology used to draw up national inventories for N_2O . The first is time independence. Nitrogen entering the ecosystems today may be recycled to the atmosphere in minutes or millennia. Second is place independence. Nitrogen leaving the site at which it is used for productive purposes has any associated emissions counted against the site of first use. This can have important consequences for reduction in emissions on farms and is discussed further below.

The molecular scale

The key chemical reactions that occur in aerobic parts of the system are the oxidation of ammonium ions (NH_4^+) to nitrite (NO_2^-) and nitrate (NO_3^-). In anaerobic sites the reduction of NO_3^- to NO_2^- and then N_2O and ultimately N_2 occurs completing the cycle:

These two zones may be in different locations and ecosystems, as in anaerobic estuarine sediments and aerobic well-drained soils of upland regions. Soils often contain micro zones that are aerobic and anaerobic and

FIGURE 2.



in close proximity and thus allow both processes to occur simultaneously.

Soil

Strong *et al.* (1998) present a clear account of pore space in relation to microbial habitats and redox reactions that is useful in understanding the spatial variability that N_2O emissions show. The key factor in determining the rate of N_2O emission is the proportion of the soil that is anaerobic at any given time. In practical terms this relates strongly to water content of the soil. Soils that have less than about 80% of the pore spaces filled with water tend to emit only small amounts of N_2O . Soils with smaller volumes of air filled pores are generally anaerobic enough to allow substrate concentration, temperature, pH and available carbon to be expressed as regulators of N_2O emission. In any rainfall regime, well drained soils will emit less N_2O than poorly drained soils even when substrates are abundant. Animal treading damage, and cultivation or traffic can compact soils and create the anaerobic conditions that favour N_2O emission whereas drainage may reduce emission of N_2O .

Abundant substrates, NO_3 or NO_2 -N (or materials that yield these) seem to be a prerequisite for high rates of N_2O to occur as this ensures that the most anaerobic sites in the soil are active as these are, by definition, often at the end of tortuous diffusion pathways. In pasture soils an abundance of substrate can occur in areas where urine has been voided, animal manures spread or nitrogen fertiliser spread at high rates. Because of this it is unusual for high rates of emission to occur right across the landscape or at paddock scale and obtaining accurate average emission rates is therefore difficult.

Modification of the underlying reactions by inhibitors, mostly of the nitrification reactions, has attracted attention and been publicised throughout the world. This approach to restricting N_2O emissions has its greatest chance of success in heavily N fertilised systems but has direct costs and a range of possible undesirable effects in agricultural systems.

Annual estimates of direct N_2O emission from pastures in New Zealand, which are mostly from the Manawatu

region, range from a few hundred grams of N/ha on steep, low fertility hill country to 4 kgN/ha (equivalent to $(4 \times 44/28) \times 310 = 1.95$ tonnes CO_2 /ha) on intensively farmed (30 stock units/ha) Kairanga soils (Carran *et al.*, 1995). That range also includes emission estimates of about 1 kgN/ha from highly productive stock camp areas in hill country. Total N flow through the pasture-animal system was similar to the Kairanga site and the soil generally wetter. This suggests that there can be substantial environmental modification or limitation of emissions and the causes and mechanisms are not always obvious.

The farm

Animals play a key role in the New Zealand N_2O inventory for pastoral agriculture. In Figure 1 the generalised N cycle was shown. Nitrous oxide escaped from the return processes and the amount of nitrogen entering was seen as the key driver for the increase in emission rate. In grassland systems, N enters largely *via* biological N fixation or nitrogen fertiliser. The inventory process calculates the amount of N eaten by livestock, the proportion excreted and attaches factors to calculate emission. Additional estimates of the amount of N moving off site as excreta, as ammonia or as nitrate are made and emission factors attached to these. In this way the land user accepts responsibility for the ultimate fate of the N used in his production system. The other key N component, that in product, essentially becomes the responsibility of the consumer since N in human excreta enters the inventory through the waste management systems in the country of consumption.

The detail of how N stocks and flows are calculated and used for inventory purposes is laid out by the Intergovernmental Panel on Climate Change (IPCC, 2000) and a useful account of how these can be used in a farm setting is given in Brown *et al.* (2001).

Maximising the efficiency with which nitrogen is used, seems to provide the best opportunity to mitigate N_2O emissions from animal production systems. The effects on CH_4 and CO_2 emissions will need to be included in any assessment of N_2O mitigation methods. Attempts to modify N excretion patterns through diet for instance or to substitute feeding on pads during periods of high risk for N_2O emission, may effect all three gases and it is the net effect that has to be the overriding concern.

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