Nitrous oxide emissions from grazed grassland: effects of cattle management and soil conditions

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1 Introduction

Traditionally, dairy cattle spend a substantial part of the year on pastures. For organic farming within EU it is specified that ”all mammals must have access to pasturage or an open-air exercise area” which they must be able to use whenever ”weather conditions and the state of the ground permits” (Council Regulation [EEC] No 2092/91[1]).

Dairy production systems are characterized by a considerable N surplus, and N deposited during grazing represents a significant risk for environmental losses, including N_2O emissions. Excess N is excreted mainly in the urine, the composition of which is influenced by factors such as lactation stage, sward quality and intake of supplements. Resulting N concentrations in urine patches can range from 20 to 80 g N m^{-2}, and soil environmental conditions associated with such a range of N inputs could affect the potential for N_2O production via nitrification and denitrification. Soil properties and fertilization also influence N_2O emissions.

This presentation shows results from a work package within the MIDAIR project which aimed to describe known sources of variability within the grazing system, and their impact on N_2O emissions. The objective was to evaluate if management changes can be proposed that will reduce the risk for N_2O emissions associated with grazing. Field studies have addressed the heterogeneity of soil physical, chemical and microbiological properties, while plot-scale and laboratory experiments have examined the fate of urinary C and N and the microbial response to urine deposition.

[1] http://europa.eu.int/eur-lex/en/consleg/main/1991/en_1991R2092_index.html

2 Impact of animal traffic and excretal returns

During two winter seasons, N_2O emissions and several soil characteristics were monitored in an over-wintering area (sandy loam) with 22 animals ha^{-1}. There were strong gradients of all soil chemical and microbiological properties, indicating that deposition of excreta was highest near the barn and feeding site. For soil physical variables no clear patterns were identified. Nitrous oxide emissions were greatest from sections of the pasture with an intermediate level of impact, whereas N_2 appeared to be the main product of denitrification in areas with the highest animal impact. The mole fraction of N_2O (N_2O/N_2+N_2O) was probably determined by the combination of soil pH, mineral N availability and soil diffusivity in the different sampling locations. Nitrous oxide emissions during the six-month periods constituted around 0.5% of the N excreted.

In measurement campaigns, new approaches for describing field-scale heterogeneity of pastures have been investigated. These include image analysis of photosynthetic activity to indicate soil N distribution (i.e., N deposition); electrical conductivity (EC) measurements by time domain reflectometry as a point measure of soil N status; and soil density measurements with narrow-probe gamma ray transmission. All approaches hold promise as non-destructive methods for characterizing within-field variation. In one campaign, systematic measurements of EC and soil density were used to identify a smaller number of sampling points, covering the ranges of both variables, for subsequent N_2O measurements. The results confirmed that there is no simple relationship between animal impact, as reflected in soil compaction and N deposition, and N_2O emissions.

3 Fate of urea-C and-N in urine patches

Excess N in the diet is mainly excreted as urea in the urine, and it was hypothesized that conditions in urine patches with high urea levels can result in microbial stresses with possible impact on soil N transformations. In a field plot study, cattle urine amended with ^{13}C- and ^{15}N-labelled urea at two concentrations was added to sandy loam pasture soil at rates of 23.3 and 39.8 g urea-N m^{-2}. Gaseous emissions, as well as plant retention and soil content of ^{13}C and ^{15}N, were monitored during 14 days. Urea-derived C in above-ground plant parts was <0.5% after 3 h and decreased rapidly, indicating that little urea-C was incorporated in plant material. In contrast, the proportion of plant N derived from urea increased to >20% during the experiment.

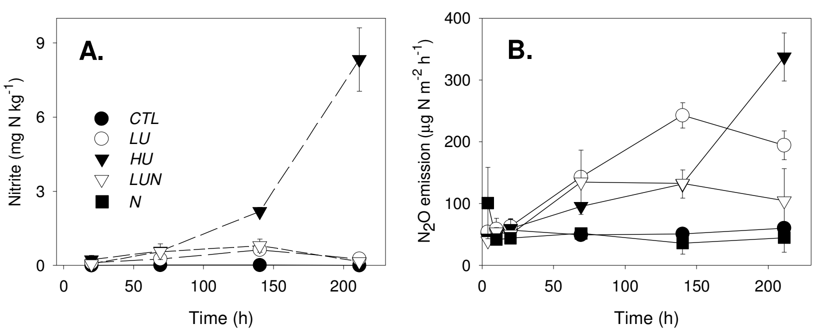
Incorporation of ^{13}C in the microbial biomass was examined via PLFA fingerprints of the microbial community analyzed by GC-IRMS. Since urea-C is hydrolyzed to CO_2, any labelling was expected to be dominated by the fatty acid profiles of autotrophs. The incorporation of ^{13}C in membrane lipids was low, but significant, and consistent with labelling of both ammonium oxidizing and nitrite oxidizing bacteria. Nitrate accumulation was initially delayed, but then proceeded almost linearly. Nitrous oxide emissions increased during the 14-d period, as did the proportion derived from urea-N. Cumulative N_2O losses corresponded to approximately 0.10% of the N input at both urea levels.

4 Regulation of N_2O emissions from urea-amended soil

The regulation of N_2O emissions may vary with urine composition and soil conditions. This laboratory study was undertaken to describe short-term N_2O emissions and the associated soil conditions and microbial dynamics after deposition of urea at two different rates (22 and 43 N g m^{-2}). The lower urea concentration was also combined with elevated soil NO_3^- in order to simulate conditions in overlapping urine patches. ^{15}N-labelled urea solutions were surface-applied to repacked pasture soil and incubated for up to 9 d under constant conditions (60% WFPS, 14°C). Soil inorganic N (NH_4^+, NO_2^- and NO_3^-), pH, electrical conductivity and dissolved organic C were quantified. Microbial dynamics were followed by measurements of N_2O, N_2 and CO_2 evolution, and by PLFA analyses of the microbial community. Also, potential ammonium oxidation and denitrifying enzyme activity were quantified after 3 days.

Nitrification was delayed at the highest urea concentration, and accumulation of NO_2^- was observed (Fig. 1A). Nitrous oxide emission was also delayed

Fig. 1. Concentrations of NO_2^- (A) and N_2O (B) in the five treatments of the incubation study. Key to legend: *CTL*—control; *LU*—low urine; *HU*—high urine; *LUN*—low urine w. high soil NO_3^-; and *N*—high soil NO_3^-.



initially at the highest urea level, but accelerated towards the end of the study, concomitant with the increase in NO_2^- concentration (Fig. 1B). In this treatment, soil pH interacted with NH_4^+ to produce concentrations of free ammonia of up to 58 mg L^{-1} which have previously been shown to give a >50% inhibition of nitrification. There was also evidence for adverse effects of soil environmental conditions on denitrifying bacteria in urea-amended soil, and PLFA profiles showed several indications of accelerated microbial turnover. Nitrifier denitrification is proposed to be the main source of N_2O with the experimental conditions used.

5 Cattle management and N_2O emissions

Several experimental approaches have been used to describe sources of variability within grazed pastures which may be linked with N_2O emissions. Macro-scale variations of animal impact could be identified, but there was no simple relationship with N_2O emissions. Management practices which regulate animal impact, such as rotational grazing or relocation of feeding and drinking sites, can reduce environmental losses by counteracting nutrient overload. However, if N_2O emissions peak at an intermediate level of animal impact, then it is doubtful if a management strategy can be devised that will significantly reduce emissions of N_2O while ensuring a uniform load of nutrients.

In urine patches, the microbial response and N transformations are influenced by urea-N concentration, and high levels of excess N in the diet could stimulate N_2O emissions from grazed pastures due to microbial stresses, although conclusive evidence for this was not obtained in the short-term studies presented here. Optimized feeding may thus be able to reduce N_2O emissions, although this is complicated by the effects of sward quality, lactation stage, climatic conditions and soil type. The most efficient strategy for reducing N_2O emissions from grazing systems is likely to be optimization of N use efficiency by such actions as control of the protein intake to more precisely meet the requirements of the animals, restricted access to grazing in order to collect manure N for use in crop production, measures to reduce ammonia volatilization during storage, and improved synchronization between energy and nitrogen intake.