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Short-term effects of single or combined application of mineral N fertilizer and cattle slurry on the fluxes of radiatively active trace gases from grassland soil

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Abstract

After implementation of legislative measures for the reduction of environmental hazards from nitrate leaching and ammonia volatilisation when using organic manures and fertilizers in Europe, much attention is now paid to the specific effects of these fertilizers on the dynamics of global warming-relevant trace gases in soil. Particularly nitrogen fertilizers and slurry from animal husbandry are known to play a key role for the CH_4 and N_2O fluxes from soils. Here we report on a short-term evaluation of trace gas fluxes in grassland as affected by single or combined application of mineral fertilizer and organic manure in early spring. Methane fluxes were characterised by a short methane emission event immediately after application of cattle slurry. Within the same day methane fluxes returned to negative, and on average over the 4-day period after slurry application, only a small but insignificant trend to reduced methane oxidation was found. Nitrous oxide emissions showed a pronounced effect of combined slurry and mineral fertilizer application. In particular fresh cattle slurry combined with calcium ammonium nitrate (CAN) mineral fertilizer induced an increase in mean N_2O flux during the first 4 days after application from 10 to 300 μg N_2O–N m^{-2} h^{-1}. ^{15}N analysis of emitted N_2O from ^{15}N-labelled fertilizer or manure indicated that easily decomposable slurry C compounds induced a pronounced promotion of N_2O–N emission derived from mineral CAN fertilizer. Fluxes after application of either mineral fertilizer or slurry alone showed an increase of less than 5-fold. The NO_x sink strength of the soil was in the range of −6 to −10 μg NO_x–N m^{-2} h^{-1} and after fertilization it showed a tendency to be reduced by no more than 2 μg NO_x–N m^{-2} h^{-1}, which was a result of both, increased NO emission and slightly increased NO_2 deposition. Associated determination of the N_2O:N_2 emission ratio revealed that after mineral N application (CAN) a large proportion (c. 50%) was emitted as N_2O, while after application of slurry with easily decomposable C and predominantly NH_4^+–N serving as N-source, the N_2O:N_2 emission ratio was 1:14, i.e. was changed in favour of N_2. Our work provides evidence that particularly the combination of slurry and nitrate-containing N fertilizers gives rise to considerable N_2O emissions from mineral fertilizer N pool.

Keywords: Nitrous oxide; Dinitrogen emission; N_2; Methane; Nitric oxide; NO_x; Greenhouse gases; Nitrification; Denitrification; Organic manure; Interaction organic: mineral fertilizer

1. Introduction

Organic and mineral fertilizers are known to be key variables in the regulation of trace gas emissions from soils (IPCC, 1996; Mosier et al., 1998; Dobbie and Smith, 2003). Among agricultural landuse systems, grassland soils are important systems, as they are rich in organic matter, and they often receive high rates of mineral fertilizers and organic returns from animal husbandry. Here, fertilization measures in early spring are of particular relevance, because raising soil temperatures and highly water-saturated conditions favour N_2O emissions (Dobbie and Smith, 2003).

Production and consumption of radiatively active trace gases in soils differ greatly in their dynamics and effects on

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global warming. While CO_2, CH_4, and N_2O contribute directly to the greenhouse effect through increased absorption of infrared radiation (Crutzen, 1981; Robertson, 1993), N_2O, NO and NO_2 (the latter two often summed up as NO_x) interact with ozone, leading either to destruction of stratospheric ozone, or increase of tropospheric ozone. Both processes are detrimental, as the protection exerted by ozone in the stratosphere is reduced, and oxidative stress to flora and fauna is increased through raising levels of tropospheric ozone. NO_x furthermore causes acid rain and thus, contributes to ecosystem degradation.

In this study, the effects of organic or mineral fertilizer application and the combinations of both were examined in a short-term measuring campaign using a fully automated mobile measuring system in the field over the period before and after fertilizer application to a grassland soil in early spring. These field measurements were complemented by soil core incubation experiments for determination of the effect of fertilizer application on N_2 and N_2O fluxes, as these are the major products of denitrification, which was identified as a process of major relevance after fertilizer application to humid soils. The objective of this study was to identify relevant processes and conditions, that lead to trace gas emissions from grassland soil immediately after application of mineral and organic fertilizers in spring.

2. Material and methods

2.1. Study site

The field experiment was conducted at the experimental grassland farm ‘Karkendamm’ of the University of Kiel, northern Germany (53°55′N, 9°55′E; 14 m asl), which contributed to a larger evaluation program of grassland management systems (Trott et al., 2004). The soil was a coarse-sandy Treposol, which developed from a gleyic Podzol by deep ploughing in 1980. It was rich in humus (4% C_{org}), showing a soil pH of 5–5.5. Soil parameters are given in Table 1. The climate at this site is humid-temperate with mild winters and usually sufficient summer rainfall. The mean annual air temperature and precipitation (1980–1999) were 8.4 °C and 824 mm. During winter 2001/2002 precipitation was in typical range, so in the experimental period the ground water table was shallow, at a depth of 0.7–1.0 m.

Prior to the onset of the experiment in 1995, a 4-year old grassland sward was ploughed and re-sown with White Clover (*Trifolium repens* cv. Milkanova sown at 2 kg ha^{-1}) and a custom grass mixture consisting of 16 kg Perennial Ryegrass (*Lolium perenne*, early, intermediate and late cultivars in equal proportions), 4 kg Timothy Grass (*Phleum pratense*) and 2 kg Smooth Meadow Grass (*Poa pratense*) per hectare. Due to poor clover establishment, the sward was oversown with White Clover (3 kg ha^{-1}, cv. AberHerald) and Perennial Ryegrass (22 kg ha^{-1}, cv. Fennema) in 1996. Fertilization and slurry application treatments were set on in spring 1997 and remained constant on the same plots to the beginning of the present experiment. The swards were managed as a mixed system (two silage cuts and two cattle grazings afterwards).

2.2. Experimental

The 5-day measuring campaign started on March 20, 2002. On March 21, 2002, cattle slurry at a rate of 82 kg N ha^{-1} and mineral fertilizer at a rate of 70 kg N ha^{-1} were applied to the soil. Measurements were conducted on the grassland site (total area: 0.2 ha) with control and four different fertilizer treatments, each treatment having three replicates. N input rates of the treatments are shown in Table 2. 15 micro-plots of 2.25 m^2 (1.5 m × 1.5 m) each were located randomly on the grassland site. N fertilizer was distributed by hand using either $^{15}NH_4^{15}NO_3$ (2.0 atm% ^{15}N) or unlabelled calcium ammonium nitrate (CAN). ^{15}N-labelled cattle slurry (0.73 atm% ^{15}N), produced in March 2001, or fresh, unlabelled cattle slurry were evenly applied in the respective treatments using watering cans. ^{15}N-labelled slurry had been produced by feeding two steers with ^{15}N-labelled hay and maize silage that were produced from grass and maize that were grown with ^{15}N-labelled mineral N fertilizer. Dung and urine were collected and mixed. The total carbon (C_t) and total nitrogen (N_t) contents

Table 1
Soil properties at the Karkendamm experimental site

Horizon	Depth (cm)	Soil bulk density (g cm^{-3})	Pore volume (cm^3 cm^{-3})	Plant available soil water at field capacity (mm cm^{-1})	Total organic carbon (%)	Total nitrogen (%)	C/N ratio
A_h	0–6	1.30	49.3	2.83	4.1	0.23	18.1
R_{ap}	6–27	1.16	51.3	3.26	3.8	0.21	18.3
R/A_p	27–80	1.22	54.3	2.23	5.6	0.27	20.9
R/B_{sh}	–	1.22	54.3	2.03	3.9	0.17	22.7
R/B_{hs}	–	1.20	54.3	2.50	1.2	0.11	10.7
R/G_{ro}	–	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
G_{ro}	80–109	1.45	47.4	1.02	0.3	0.06	5.9

n.d. = not determined.