Impacts of soil moisture on trace gas emissions from grassland: a case study on grassland in Northern Ireland

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Abstract
The impacts of soil moisture on trace gas emissions from grassland were investigated by an *in situ* measurement conducted over two sampling periods from 2008–2009 in a typical agricultural ecosystem of Northern Ireland. Gas samples were taken with the closed chamber technique and analysed for carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Wet soil conditions led to high emissions of CH_4 and N_2O and a loss of applied nitrogen (N) fertilizer. These results are valuable toward the development of practical measures for reducing greenhouse gas emissions from agriculture.

Key Words
Grasslands, greenhouse gases, fertilizer.

Introduction

With rising global demand for food production, the area of land under cultivation and inputs of chemical fertilizers into agricultural ecosystems are expected to further increase (Galloway *et al.* 2008). As a result, the emission of greenhouse gases (GHGs) from agriculture may be intensified and their impact on global climate may become more serious. Therefore, greater understanding of the processes of trace gas emissions from agriculture must be developed (Batjes and Bridges 1992). This understanding will result in the development of practical measures for reducing trace gas emissions from agriculture.

Agriculture is estimated to contribute approximately 25%, 65% and 90% of global anthropogenic emissions of CO_2, CH_4, and N_2O, respectively (Duxbury 1994). Carbon dioxide is taken up by plants during photosynthesis and released through respiration processes from vegetation and soil organisms (Byrne *et al.* 2007). The CO_2 released from respiration depends on decomposition processes, which are affected by soil water status (Parton *et al.* 1987). Methane is commonly oxidized into CO_2 in unsaturated soils leading to an uptake of atmospheric CH_4 (Del Grosso *et al.* 2000). Soil production of CH_4 is associated with poorly drained areas (Gregorich *et al.* 2005). Synthetic N fertilizer application is the main source of N_2O emissions from agriculture (Smith *et al*. 1997). N_2O is produced via nitrification and denitrification processes (Wrage *et al.* 2004).

The impact of soil moisture on N_2O and CH_4 emission from grasslands and forest soil has been well discussed (Zheng *et al.* 2002) and is considered a significant factor for regulating N_2O emissions. However, land management can affect sources and sinks of GHGs in grasslands in opposing manners. For example, increased fertilizer input generally leads to an increase in N_2O emissions, but can also contribute to increased C sequestration in the soil (Conant *et al.* 2005). Therefore, it is important to examine the impact of soil properties on all significant GHGs simultaneously to determine a net GHG effect from various agricultural management practices. The objective of this study was to determine the effect of soil moisture on trace gas emissions from a grassland system in Northern Ireland.

Methods

Site and Experimental Design

The experimental field site was located in Crossnacreevy, Northern Ireland (54°32’ N, 05°52’ W; 390 m above sea level) as part of the Agri-Food and Bioscience Institute in Northern Ireland (AFBINI). The soil is a medium loam soil. Two nitrogen fertilizer treatments, high (420 kg N/ha/y) and low (105 kg N/ha/y), were applied to three replicates of three different grass species (*Lolium perenne*, *Phleum pratense*, *Dactylis glomerata*) combined with clover (*Trifolium repens)*. Each year fertilizer was applied directly after harvest (nine times on high N, three times on low N). The data described in this paper were obtained during the last fertilizer application (40 kg N/ha) for the high N site in September of each year (2008 and 2009). Measurements were taken simultaneously at the low N sites, though no fertilizer was applied to these sites at that time.

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Sampling and flux calculation
For obtaining the gas samples the closed chamber technique (Hutchinson and Mosier 1981) was used (chamber size: 40x40x10 cm). Three samples were taken with 60 ml plastic syringes, closed with a 3-way stopcock over a period of 30 minutes immediately (t_0), 15 minutes (t_{15}), and 30 minutes (t_{30}) after the chamber was closed. Air pressure was obtained from the Aldergrove weather station (Latitude: 54.65; Longitude: -6.217), approximately 30 km from the field site. Temperature in the chambers was measured with a thermometer. Soil moisture was measured by soil probes buried at approximately 7 cm depth at the low N site. Analysis for CO_2, N_2O and CH_4 was carried out on a gas chromatographer (Shimadzu GC-2024) with automated injection system (Loftfield *et al.* 1997). The flux rates were calculated by using the ideal gas law and linear regression with chamber temperature and average air pressure during cover period. An exponential equation (Hutchinson and Mosier 1981) was used if R-squared was greater than 0.985 but less than 1.

Results
Data from all three grass varieties were averaged for the high and low N sites because there was no significant difference in emissions between grass species. Figure 1a presents the fluxes for CO_2, which were in 2008 higher on high N plots (mean = 173.6 ± 30.1mg CO_2-C/m^2/h) before and after cutting compared to low N sites (mean = 144.1 ± 26.9 mg CO_2-C/m^2/h). Similar results, though slightly lower, were found for 2009 after harvesting the plots.

Figure 1b presents high N_2O emissions after fertilizer application on high N plots in both years. In both 2008 and 2009, the highest fluxes were measured one day after fertilizing the site. The maximum N_2O emissions from the high N plots were 1280.7 ± 606.7 µg N_2O-N/m^2/h and 2015.2 ± 763.4 µg N_2O-N/m^2/h, for 2008 and 2009 respectively.

Figure 1c presents soil moisture and CH_4 emissions which were both lower in September 2009 than in September 2008. In 2008, the highest average value of methane production was higher on the low N site (50.5 ± 42.9 µg CH_4-C/m^2/h) compared to the high N site (18.3 ± 17.5 µg CH_4-C/m^2/h). This correlation, though lower, was also observed in 2009. Due to heavy rainfall in September of both years, the soil was completely saturated to the soil surface during the measurement period. Therefore, soil moisture data should also apply to the soil layers above 7 cm depth as the spot for main microbial activity was found to be in the top soil layers just a few centimeters thick (Koschorreck and Conrad 1993). Slightly higher soil moisture was observed in 2008, due to heavier rainfall in the weeks before the sampling period (data not shown).

Conclusion
N_2O fluxes
As in previous research, the present study found that N_2O production was enhanced by reduced aeration via soil saturation (Wrage *et al.* 2004) and large N-input. This emission can be caused not only by denitrification via microbial activity but also by fungal denitrification (Laughlin 2002). Due to the Nitrates Action Programme Regulations for Northern Ireland (DOE 2006), the fertilizer in this experiment had to be applied before the 15th of September even though the site was very wet. Therefore, it was hypothesised that the site would lose high amounts of N. Glatzel and Stahr (2001) found lower emissions of N_2O (50 and -20 µg N_2O-N/m^2/h) after application of cattle slurry (200 kg/ha/y) on a well aerated grassland site. Lower fluxes than in the present study (489 µg N_2O-N/m^2/h) were also found by Lampe *et al*. (2006), who investigated the effect of mineral fertilizer and slurry application on N_2O emissions (489 µg N_2O-N/m^2/h) on aerated grazed grassland.

CH_4 fluxes
In this experiment, temporarily high rainfall events caused anaerobic soil conditions leading to CH_4 emissions. Well-aerated grassland usually shows a net uptake of CH_4 (Mosier *et al.* 1991, Kammann *et al.* 2001). Induced CH_4 emission in grassland has also been observed in 5cm soil depth after autumn rainfall (Kammann *et al*. 2001). In addition, lab experiments have verified an increase in CH_4 production after a long lag phase either due to flooding (Wang and Bettany 1997) or anaerobic incubation (Peters and Conrad 1995). Similar results were observed in the present study during the first measurement period in 2008, when a slight but steady increase in CH_4 production on already CH_4 emitting plots was found over 12 days of sampling. The effect of higher emissions from the low N plots could be a reason of higher water content on the low N site, as this effect is enhanced under slightly higher soil moisture in 2008.

CO_2 fluxes
A correlation was observed between higher CO_2 emissions and lower CH_4 emissions on the high N site and

conversely lower CO_2 efflux and higher CH_4 production on the low N site. This could also be explained by higher soil moisture content on the low N site which could be observed indirectly through the higher production of methane. This effect was more distinct in 2008 with slightly higher measured water content. High water content leads to a limitation of soil respiration through a slower diffusion rate of oxygen in water (Conant *et al.* 2004).

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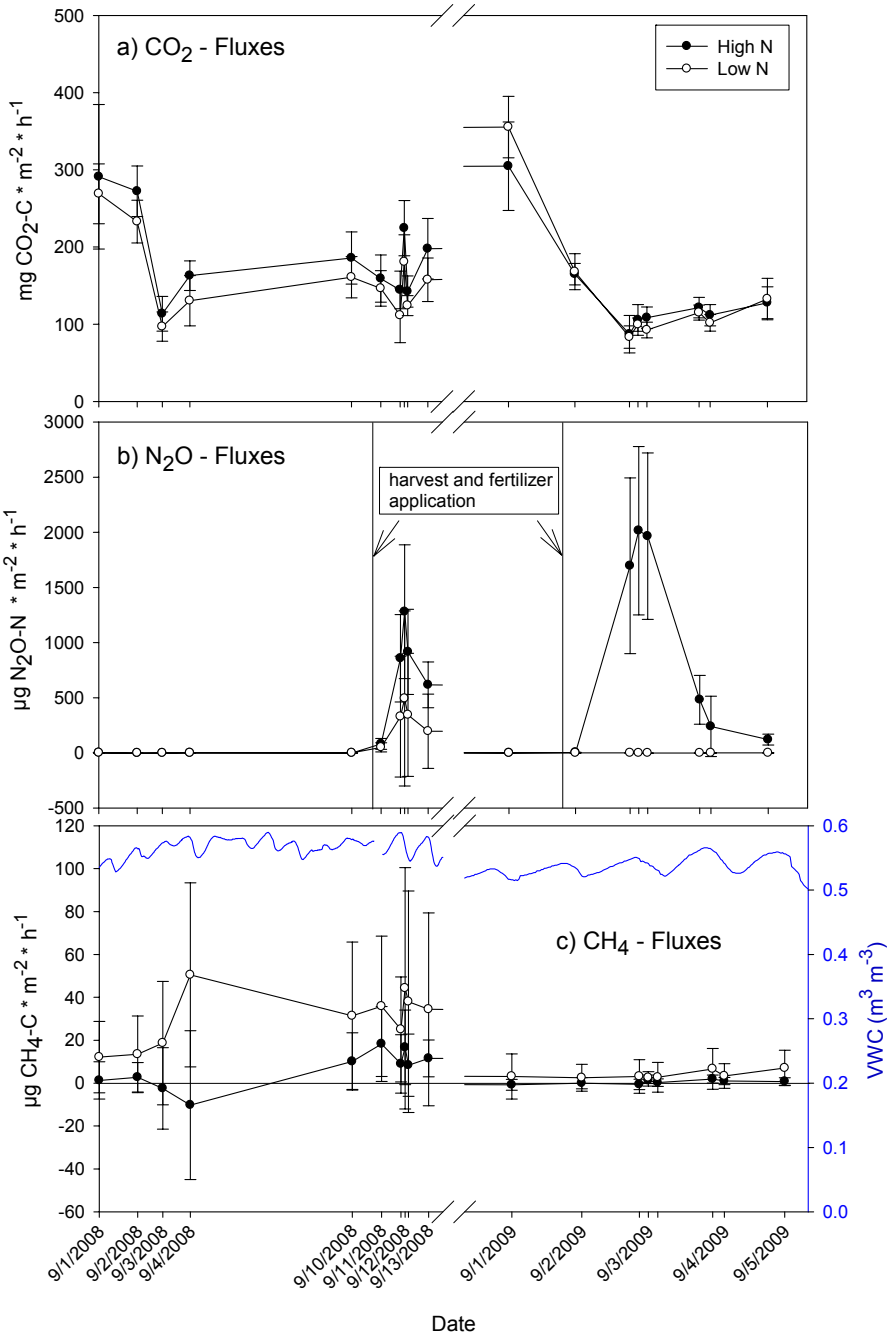

Figure 1. Fluxes for a) carbon dioxide (mg CO_2-C/m^2/h), b) nitrous oxide (µg N_2O-N/m^2/h) and c) methane (µg CH_4-C/m^2/h) from Crossnacreevy, Northern Ireland during measurement periods in September 2008 and 2009 compared to c) vwc, volumetric water content (m^3/m^3)

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