Agriculture, Ecosystems and Environment 186 (2014) 23–32

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Effect of cattle urine addition on the surface emissions and subsurface concentrations of greenhouse gases in a UK peat grassland☆

A. Boon[a,b,*], J.S. Robinson[a], D.R. Chadwick[b,c], L.M. Cardenas[b]

[a] Department of Geography and Environmental Science, University of Reading, Whiteknights, P.O. Box 233, Reading, RG6 6DW, United Kingdom
[b] Rothamsted Research North Wyke, Okehampton, Devon, EX20 2SB, United Kingdom
[c] Environment Centre Wales, Deiniol Rd., Bangor University, Bangor LL57 2UW, United Kingdom

ARTICLE INFO

Article history:
Received 5 June 2013
Received in revised form 2 January 2014
Accepted 10 January 2014
Available online 7 March 2014

Keywords:
Greenhouse gases
Cattle urine
Peatlands
Nitrous oxide
Carbon dioxide
Methane

ABSTRACT

Grazing systems represent a substantial percentage of the global anthropogenic flux of nitrous oxide (N_2O) as a result of nitrogen addition to the soil. The pool of available carbon that is added to the soil from livestock excreta also provides substrate for the production of carbon dioxide (CO_2) and methane (CH_4) by soil microorganisms. A study into the production and emission of CO_2, CH_4 and N_2O from cattle urine amended pasture was carried out on the Somerset Levels and Moors, UK over a three-month period. Urine-amended plots (50 g N m^{-2}) were compared to control plots to which only water (12 mg N m^{-2}) was applied. CO_2 emission peaked at 5200 mg CO_2 m^{-2} d^{-1} directly after application. CH_4 flux decreased to −2000 μg CH_4 m^{-2} d^{-1} two days after application; however, net CH_4 flux was positive from urine treated plots and negative from control plots. N_2O emission peaked at 88 mg N_2O m^{-2} d^{-1} 12 days after application. Subsurface CH_4 and N_2O concentrations were higher in the urine treated plots than the controls. There was no effect of treatment on subsurface CO_2 concentrations. Subsurface N_2O peaked at 500 ppm 12 days after and 1200 ppm 56 days after application. Subsurface $NO_3{}^-$ concentration peaked at approximately 300 mg N kg dry soil^{-1} 12 days after application. Results indicate that denitrification is the key driver for N_2O release in peatlands and that this production is strongly related to rainfall events and water-table movement. N_2O production at depth continued long after emissions were detected at the surface. Further understanding of the interaction between subsurface gas concentrations, surface emissions and soil hydrological conditions is required to successfully predict greenhouse gas production and emission.

1. Introduction

Nitrous oxide (N_2O) is an important greenhouse gas (GHG) with 298 times the Global Warming Potential (GWP) of CO_2 (Forster et al., 2007). N_2O is produced as a result of microbial processes operating in the soil profile, whereby it is a by-product of the reduction of nitrate ($NO_3{}^-$) to nitrogen gas (N_2) (denitrification), the ammonification of nitrate and the oxidation of ammonium ($NH_4{}^+$) to $NO_3{}^-$ (nitrification) (Firestone et al., 1980; Baggs, 2011). Agricultural systems, comprising both livestock and arable production, return substantial amounts of mineral N to the soil and therefore contribute significantly to global emissions of N_2O (IPCC, 2001). Grazing systems are thought to represent 16% of the global anthropogenic flux of N_2O (IPCC, 2001) as livestock add nitrogen (N) to the soil in the form of excreta.

Cattle urine has been shown to stimulate N_2O production to a larger extent than dung due to the dual effect of a large pool of readily available N and C and increased soil water content (e.g. Allen et al., 1996; van Groenigen et al., 2005a). Cattle urine supplies greater amounts of N to the patch than the pasture N demand, thereby facilitating losses through leaching and gaseous emissions (Di and Cameron, 2002). Cattle urine N content varies between 1 and 20 g L^{-1} due to differences in water intake and diet (Oenema et al., 1997; Leterme et al., 2003) and is on average 6 g N L^{-1} (Leterme et al., 2003; Bristow et al., 1992). Urine patch radius is generally around 0.32–0.35 m but ranges between 0.1 and 0.6 m for dairy cattle (Moir et al., 2011). The surface area of urine patches is generally between 0.34 and 0.40 m^2 (Moir et al., 2011; Oenema et al., 1997) giving rise to an N deposition of 20–80 g N m^{-2} (200–800 kg N ha^{-1}) on each urination event (Oenema et al., 1997;

* Corresponding author at: Department of Meteorology, University of Reading, Earley Gate, Reading, RG6 6BB, United Kingdom. Tel.: +44 0 118 378 7060.
E-mail addresses: alex.boon@reading.ac.uk (A. Boon), j.s.robinson@reading.ac.uk (J.S. Robinson), d.chadwick@bangor.ac.uk (D.R. Chadwick), laura.cardenas@rothamsted.ac.uk (L.M. Cardenas).

0167-8809/$ – see front matter © 2014 The Authors. Published by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agee.2014.01.008

Whitehead, 1986). For beef cattle urine the typical N loading is 700 kg N ha^{-1} (Haynes and Williams, 1993).

On contact with the soil, urea-N is rapidly hydrolysed to ammonia (NH_3), catalysed by the enzyme urease which is ubiquitous in soils as a result of microbial activity. This process is dependent. The hydrolysis process also reduces the available carbon from the urea, as CO_2 is a by-product of the reaction. Hydrolysis can account for over 50% of the added urine-C depending on soil moisture (Lambie et al., 2013). The remaining C provides a substrate for respiration (and therefore emission of CO_2) or for CH_4 production in anoxic soils (Yamulki et al., 1999; Liebig et al., 2008). Studies have also shown that addition of cattle urine can increase the solubility of soil C, leading to increased soil C decomposition and therefore potentially increased CO_2 emission (Clough et al., 2003a) and leaching (Lambie et al., 2012). In addition to potential for increased N_2O and CO_2 production in urine patched, NH_4^+ is known to inhibit oxidation of CH_4 and therefore promote increased CH_4 emission (Mosier et al., 1991; Dobbie and Smith, 1996).

Studies indicate that even short-term grazing can cause a significant increase in N_2O emissions, particularly when combined with compaction and seasonal water-table rise (van Groenigen et al., 2005b; van Beek et al., 2011). There is a wide body of research into the effect of cattle excreta on soils, with focuses on soil moisture, N content, urine volume and interactions with dung and fertilisers (e.g. Allen et al., 1996; Velthof et al., 1996; van Groenigen et al., 2005a,b; Maljanen et al., 2007) but few focus exclusively on peat soils (Koops et al., 1997; van Beek et al., 2011) and few include observations of all three greenhouse gases under urine patches (Liebig et al., 2008; Lin et al., 2009). Peat soils by definition have higher organic matter content than mineral soils. This leads to physical differences between peat and mineral soils; in particular higher porosity and gas diffusion coefficient (Boon et al., 2013). Additionally, due to the tendency of peat soils shrink and swell with changing soil moisture, they exhibit strong variations soil hydraulic properties such as moisture retention (Kechavarzi et al., 2010) compared to mineral soils. Peat soils also generally have higher mineralisation rates than mineral soils leading to higher available N, which combined with higher moisture retention leads to increased N_2O emission through denitrification (Koops et al., 1997). Peat soils have been shown to have increased N_2O emissions with respect to mineral soils as a result of a combination of these factors, particularly when amended with fertilisers or livestock excreta (Velthof and Oenema, 1995). Due to the increased availability of soil organic carbon, peat soils are substantial sources of CH_4 when in an anaerobic state and CO_2 when in an aerobic state (Moore and Dalva, 1993).

Subsurface concentrations of greenhouse gases, when combined with measurements of soil nitrogen and carbon, can be used to identify the key processes contributing to the accumulation of gases that may be subsequently emitted to the surface (Li and Kelliher, 2005; Li and Kelliher, 2007). These measurements can be used to determine zones of production and storage of greenhouse gases in the soil, particularly when combined with soil physical measurements such as bulk density, air-filled porosity and the gas diffusion coefficient, all important predictors of greenhouse gas emissions (Ball, 2013; Balaine et al., 2013). Measurements of subsurface greenhouse gases are currently limited from peat soils (e.g. Clark et al., 2001; Elberling et al., 2011), particularly when these soils are subjected to agricultural amendments, and especially where measurements have been made of soil physical parameters.

Many lowland peatland environments in the UK are under seasonal grazing management, often as a contribution to conservation management schemes on tenanted farmland or nature reserves. Sheep production is regularly practiced on 85% of UK upland peat; but cattle and ponies are being introduced to manage fen vegetation in lowland peatland and little study of the potential effect on GHG budgets for these environments has been conducted (Worrall et al., 2011). In this study, we aim to simulate small urination events on an area of UK peat grassland that is intensively grazed by beef steers for short period of time during autumn seasonal water-table rise. The main objective of this experiment was to quantify the difference between subsurface concentrations and surface fluxes of CO_2, CH_4 and N_2O in plots treated with cattle urine and control plots treated with water. Secondary objectives were to examine the relative importance of water-table depth (WTD), water soluble (available) carbon (WSOC) and soil NO_3^- and NH_4^+ concentrations on CO_2, CH_4 and N_2O production and emission and thereby draw conclusions on the dominant greenhouse gas producing processes during short term cattle grazing on peat soils. We also consider the importance of measured soil physical parameters (porosity, bulk density and gas diffusion coefficient) for transport of greenhouse gases from the surface layers of soil to the atmosphere. We hypothesise that addition of cattle urine to the soil will produce significant differences in GHGs relative to the control plots and that water-table depth is the key control on these processes throughout the autumn rewetting period.

Table 1
Characterisation of field soil (dry weight basis) between 0 and 30 cm depth (averaged data ± SE) (data collected May 2009–June 2010).

	Soil depth		
	0–10 cm	10–20 cm	20–30 cm
Texture	Clay loam	Loamy clay	Peat
Total C (%)	23.84 ± 0.74	16.08 ± 0.75	26.35 ± 2.08
Total N (%)	2.05 ± 0.05	1.54 ± 0.04	2.02 ± 0.12
C/N ratio	11.63 ± 0.15	10.41 ± 0.21	12.84 ± 0.48
SOM content (%)	48.57 ± 2.09	63.07 ± 1.45	43.13 ± 3.98
pH	5.05 ± 0.14	5.46 ± 0.15	5.57 ± 0.15
Bulk density (g soil cm^{-3})	0.44 ± 0.01	0.40 ± 0.01	0.14 ± 0.002

2. Materials and methods

2.1. Site description

The experimental site was located at West Sedgemoor, Somerset in SW England, UK (51°0.1.11′N, 2°55.16′W); a 1035 ha peatland site that forms part of the Somerset Levels and Moors Environmentally Sensitive Area (ESA). The site is managed by the Royal Society for the Protection of Birds (RSPB) for wetland bird conservation with the majority of land grazed in rotation with hay cutting a minimum of one year in three. The land is grazed by mixed breed beef steers belonging to a single tenanted farm holding. Approximately 30 animals graze 4.2 ha of land in rotation for two weeks in early autumn. It is known that little or no organic or inorganic fertiliser has been applied to the site for over 20 years.

The climate of the region is characterised by warm winters and cool summers with an average rainfall of 1005 mm annually and an average annual temperature of 10 °C. According to Findlay et al. (1984) and Heathwaite and Ross (1987), the soil profile of West Sedgemoor comprises three clear horizons within the surface 0–30 cm. The uppermost horizon between 0 and approximately 10 cm is loamy clay, resulting from the decay of surface vegetation and is significant despite cutting/grazing activity. Beneath this is a deposit of silty clay arising from periodic inundation by the nearby River Parrett. Below the clay, at between 25 and 30 cm depth in most cases, is black fibrous sedge peat (fibric histosol) of up to 8 m depth. Characterisation of the soil is given in Table 1. These data were collected as part of a separate field trial conducted between May 2009 and June 2010.

The selected field has its water-table controlled by two different drainage ditch management practices. The north and west ditches