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Greenhouse gas emissions from temperate permanent grassland on clay-loam soil following the installation of artificial drainage

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ABSTRACT

Shallow drainage (e.g. mole and gravel mole drainage installed at 0.55 m below soil surface) is used on pasture-based farms to reduce soil moisture, deepen water table depth and thus increase grass utilization on soils with impeded drainage. There is, however, a lack of research on the effect that these drainage techniques have on soil greenhouse gas (GHG) emissions. Hence the objective of this study was to investigate the effects of mole and gravel mole drainage on soil GHG fluxes. Soil nitrous oxide (N_2O), soil root respiration (CO_2) and soil methane (CH_4) fluxes were measured in two experiments conducted over a 36 month period. The experiments were conducted on permanent grassland with impeded drainage on a eutric gleysol (humic) in Ireland (52°30′N, 08°12′W). Both experiments were arranged in randomized complete block design. There were three treatments: (i) undrained control, (ii) mole drainage and (iii) gravel mole drainage. Soil GHG fluxes, soil water filled pore space (WFPS) and soil temperature were measured on a weekly basis and soil mineral nitrogen (N), herbage N uptake, soil organic carbon (SOC) and soil total N (TN) were measured seasonally and annually over the sampling period. Drainage treatments ($P < 0.05$) deepened (mean ± SE) the water table by 0.17 ± 0.03 m and decreased WFPS by 7 ± 0.2%. However no ($P > 0.05$) impact of drainage treatment was detected on soil average daily GHG fluxes (9.84 ± 6.34g N_2O-N $ha^{-1}day^{-1}$, 34.05 ± 12.90 kg CO_2-C $ha^{-1}day^{-1}$ and −0.91 ± 3.70 g CH_4-C $ha^{-1}day^{-1}$), soil N mineralisation, soil N nitrification, SOC and TN in both experiments. The results indicate that mole and gravel mole drainage can be installed on farms with similar management and soil type to that described in the present study without impact on the soil GHG emissions.

1. Introduction

Permanent grassland accounts for 68% of agricultural land globally (FAO, 2014). Pasture-based systems are, in general, concentrated in temperate grassland regions. In temperate zones, pasture-based systems predominate in areas with high rainfall, low evapotranspiration and with soils with poor-drainage characteristics- often unsuitable for other forms of agricultural production (Humphreys et al., 2009). Such conditions coincide with poor soil trafficability by livestock and machinery, and poor grass utilization by grazing livestock (Keane, 1992; MacEwan et al., 1992; Drewry, 2006; Fitzgerald et al., 2008; Tuohy et al., 2016). Grass utilization under grazing is one of the main components underpinning the profitability in these systems (Dillon et al., 2005). Mole and gravel mole drainage have been used widely as shallow drainage techniques in these areas and have been found to reduce soil moisture content by lowering the watertable depth (WTD) and improving surface water infiltration (Burke et al., 1974; Sharpley and Syers, 1979; Haygarth et al., 1998; Ibrahim et al., 2013; Tuohy et al., 2015)

Soil greenhouse gas (GHG) fluxes are a major contributor to global GHG emissions (Robertson et al., 2000). Grasslands have been reported to account for between 16% and 33% global agricultural N_2O emissions and are also an important carbon sink (De Klein et al., 2008). Soil GHG emissions are highly dependent on soil microbial activity, which is regulated by soil moisture content, soil temperature, soil pH and available soil organic carbon (SOC). Previous research has shown that soil disturbance, for example by ploughing, decreases soil moisture content and increases soil temperature (Davidson et al., 2000a, b; Lal, 2004; Angers et al., 2010), and significantly increases soil N_2O and soil carbon dioxide (CO_2) fluxes (Schlesinger and Andrews, 2000; Ruan and Robertson, 2013; Garcia-Marco et al., 2016). At present, there is very

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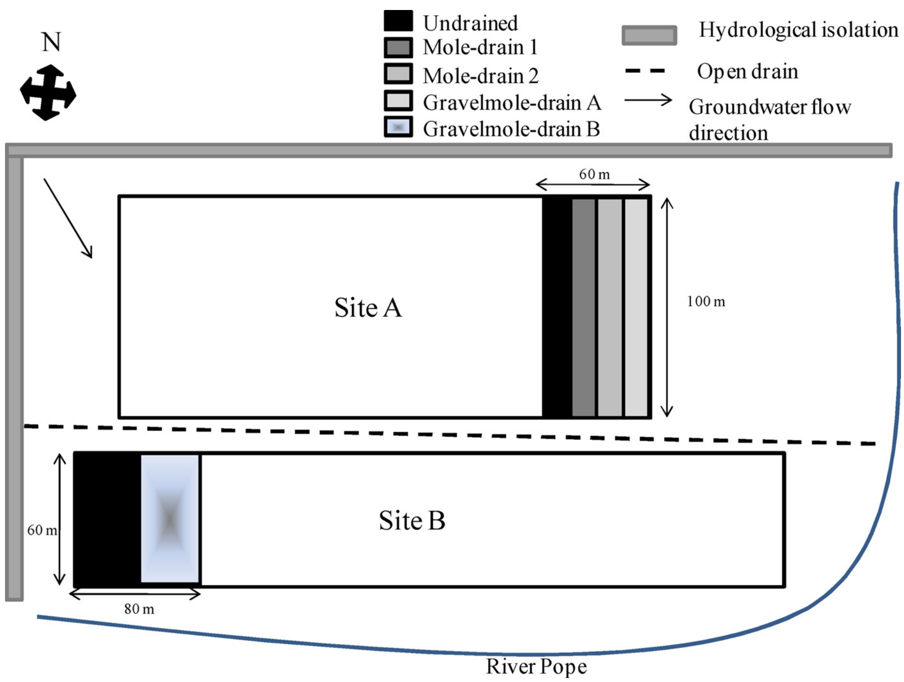

Fig. 1. Location of the study area, experimental sites, groundwater flow direction and open drain. North is upslope position and south is down slope. Hydrological isolation consisted on a 1 m deep by 0.5 m wide ditch filled with gravel (20–30 mm grade).

little research on how mole drainage techniques impact on soil GHG fluxes, despite the wide application of mole drainage techniques on grasslands and their impact on soil microbial environment.

Hence the objective of this study was to investigate the effects of mole and gravel mole drainage on soil GHG emissions. We examined the soil cumulative (kg ha^{-1} $year^{-1}$) and daily (g ha^{-1}) GHG fluxes from mole and gravel mole drainage systems throughout their life-span i) immediately after drainage installation, ii) during first drainage season and iii) three years after drainage installation.

2. Materials and methods

2.1. Site description

This study was conducted on a grassland site (4 ha) at Solohead Research Farm in Ireland (52°30′N, 08°12′W), with a gentle slope (1.4%) and bounded on the south and east by the river Pope (Fig. 1). The average annual rainfall in the preceding 10 years was 1089 mm with annual potential evapotranspiration of approximately 510 mm. Mean daily soil temperature at 10 cm depth ranged from 3.3 to 13.9 °C between November and January and from 10.1 to 20.0 °C between May and July. The WTD fluctuates seasonally from < 1.0 m to > 2.5 m below ground level (Tuohy et al., 2015). The soils are classified as eutric gleysol (humic) under the 2014 World Reference Base (WRB, 2014). Soil physical and chemical properties are presented in Table 1.

The grassland site was reseeded with perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) in August 2010. During the study the swards were predominantly perennial ryegrass with 20% white clover on a dry matter (DM) basis. In August 2010 a large open V-shaped drain (2 m depth and 4 m wide at ground level) was excavated along a natural depression in the site running along a west-east axis with water exiting into the river Pope from the eastern end of the open drain (Fig. 1). The large open drain separated the study area into two sites: site A and site B (Fig. 1) where experiments A (Expt A) and B (Expt B) were conducted. All the runoff and drainage flow originating in both sites was discharged to the open drain and then to the river Pope. The experimental site was hydrologically isolated from external lateral water movement by an isolation ditch, comprising a 1 m deep trench filled to the soil surface with stone aggregate (Fig. 1).

2.2. Experimental layout and design

2.2.1. Experiment A

In January 2011, the area was divided into four blocks; each 60 m wide and 100 m long, with the long axis of each block running from north to south. Each block was subdivided into four plots (100 m long and 15 m wide), with the long axis of each plot running perpendicular to the open drain. One of four treatments was imposed in each plot in a randomised complete block design with four replicates. The four treatments were (i) undrained control (C), (ii) mole drainage installed in January 2011(M1), (iii) mole drainage installed in July 2011(M2) and (iv) gravel mole drainage installed in July 2011 (GM). Treatment installation dates were chosen in order to evaluate the drainage treatments performance with different soil conditions at installation. Soil

Table 1
Soil properties at Solohead Research Farm at four different depths. All values are means of at least three determinations. Bulk density (BD), hydraulic conductivity (HD), total nitrogen (TN), total carbon (TC), and soil organic carbon (SOC).

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	BD (g cm^{-3})	HD (mm h^{-1})	Total porosity (%)	pH	TN (t ha^{-1})	TC (t ha^{-1})	Total inorganic C (t ha^{-1})	SOC (t ha^{-1})
0–10	40	29	29	1.01	0.0012	61.71	6.5	12.7	119.7	2.4	117.3
10–30	41	20	39	1.05	0.0020	60.32	6.8	8.8	91.4	2.5	80.6
30–60	34	20	46	1.21	0.0016	54.31	7.5	3.3	7.3	0.7	6.5
60–80	11	31	58	1.33	0.0028	49.81	7.5	2.4	6.8	0.8	6.0