Agriculture, Ecosystems and Environment 189 (2014) 171–180

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Seasonal nitrous oxide emissions from field soils under reduced tillage, compost application or organic farming

Bruce C. Ball[a,*], Bryan S. Griffiths[a], Cairstiona F.E. Topp[a], Ron Wheatley[b], Robin L. Walker[c], Robert M. Rees[a], Christine A. Watson[c], Helen Gordon[a], Paul D. Hallett[d], Blair M. McKenzie[b], Ian M. Nevison[e]

[a] SRUC Crop and Soil Systems Research Group, West Mains Road, Edinburgh EH9 3JG, UK
[b] James Hutton Institute, Dundee DD2 5DA, UK
[c] SRUC Crop and Soil Systems Research Group, Craibstone Estate, Aberdeen AB21 9YA, UK
[d] Institute of Biological and Environmental Sciences, University of Aberdeen, Aberdeen AB24 3UU, UK
[e] Biomathematics and Statistics Scotland, James Clerk Maxwell Building, The King's Buildings, Edinburgh EH9 3JZ, UK

ARTICLE INFO

Article history:
Received 15 October 2013
Received in revised form 12 March 2014
Accepted 16 March 2014
Available online 16 April 2014

Keywords:
Soil management
No-tillage
Compaction
Greenhouse gas
Biological N-fixation
Green-waste compost
Rainfall

ABSTRACT

Soil management practices shown to increase carbon sequestration include reduced tillage, amendments of carbon and mixed rotations. As a means to mitigate greenhouse gases, however, the success of these practices will be strongly influenced by nitrous oxide (N_2O) emissions that vary with soil wetness. Few seasonal data are available on N_2O under different soil managements so we measured seasonal N_2O emission in three field experiments between 2006 and 2009 in eastern Scotland. The experimental treatments at the three sites were (1) tillage: no-tillage, minimum tillage, ploughing to 20 cm with or without compaction and deep ploughing to 40 cm, (2) organic residue amendment: application of municipal green-waste compost or cattle slurry and (3) rotations: stocked and stockless (without manure) organic arable farming rotations. Most seasons were wetter than average with 2009 the wettest, receiving 20–40% more rainfall than average. Nitrous oxide emissions were measured using static closed chambers. There was no statistical evidence, albeit with low statistical power, that reduced tillage affected N_2O emissions compared to normal depth ploughing. With organic residue amendments, only in the wet season in 2008 were emissions significantly increased by high rates of green-waste compost (4.5 kg N_2O-N ha^{-1}) and cattle slurry (5.2 kg N_2O-N ha^{-1}) compared to the control (1.9 kg N_2O-N ha^{-1}). In the organic rotations, N_2O emissions were greatest after incorporation of the grass/clover treatments, especially during conversion of a stocked rotation to stockless. Emissions from the organic arable crops (1.9 kg N_2O-N ha^{-1} in 2006, 3.0 kg N_2O-N ha^{-1} in 2007) generally exceeded those from the organic grass/clover (0.8 kg N_2O-N ha^{-1} in 2006, 1.1 kg N_2O-N ha^{-1} in 2007) except in 2008 when the wet weather delayed manure applications and increased emissions from the grass/clover (2.8 kg N_2O-N ha^{-1}). Nevertheless, organic grassland was the land use providing the most effective overall mitigation. Although the magnitude of fluxes did not relate particularly well to rainfall differences between seasons, greater rainfall received during some growing seasons increased the differences between tillage, organic residue and crop rotation phase treatments, negating any possible mitigation by timing management operations in dry periods. This was partly attributed to applying tillage and manures late and/or in wet conditions. Of benefit would be different sampling strategies including closed chambers or eddy covariance with standardised methodology. Controlled soil management experiments with a wide geographic spread to specify land management for mitigation also important.

1. Introduction

Soil used for arable and grassland production is a major source of nitrous oxide (N_2O) emission, mainly in response to the application of inorganic and organic nitrogen as fertilisers, crop residues and manures. Changes in crop and soil management form

* Corresponding author. Tel.: +44 1315354379; fax: +44 1315354144.
E-mail address: bruce.ball@sruc.ac.uk (B.C. Ball).

http://dx.doi.org/10.1016/j.agee.2014.03.038
0167-8809/

important strategies to decrease N_2O emissions (Mosier et al., 1998). The main processes producing N_2O are microbial and vary with soil water status (Bateman and Baggs, 2005). For example, seasonal N_2O emissions in fertilised grassland are highly dependent on soil water and rainfall along with soil temperature (Flechard et al., 2007).

Interactions between soil water content and tillage (Ball et al., 2008; Rochette, 2008) and soil water content and compaction (Beare et al., 2009) are also very important in regulating the production and emission of N_2O. Mitigation strategies for emissions from soil that have been identified as potential win-win options include more efficient use of N inputs and greater recycling of residues (MacLeod et al., 2010). Three such strategies are increased use of organic residues, decreased overall fertiliser N application rates and reduced tillage. The effectiveness of these mitigation strategies is currently in doubt in temperate Europe. For example, organic fertilisers can give very high N_2O fluxes in wet conditions (Jones et al., 2005). Even without the use of inorganic fertilisers, as in organic farming, fluxes can be similar to those from arable cropping under average fertiliser applications due to the release of available nitrogen from ploughed-in organic materials and decomposing legume residues (Ball et al., 2007). The use of no-tillage in well aerated soils can decrease N_2O emissions or have only a minor effect (Soane et al., 2012). However, no-tillage in fine textured soils can result in substantial fluxes of N_2O due to soil compaction preventing drainage and thus increasing soil wetness and concentration of carbon, nitrogen and microbial activity near the surface (Vinten et al., 2002).

Typical annual emissions of N_2O from arable crops in Scotland range from 0.6 to 6.6 kg N_2O-N ha^{-1} yr^{-1}. Within that range, emissions are predicted to increase with the duration of soil wetness (Lilly et al., 2009) and, although this relationship is supported by a large body of experimental evidence (Dobbie and Smith, 2001; Guo et al., 2010; Kliewer and Gilliam, 1995), verification with field data has been variable (Dobbie and Smith, 2003a). In this paper we present results for greenhouse gas emissions from field experiments on tillage, organic residue amendment and rotation and relate these to climate. For tillage, we compare no-tillage and minimum tillage with conventional plough tillage with or without regular compaction under spring barley. For organic materials we report on the influence of additions of green-waste compost and slurry combined with irrigation under spring barley. The tillage and organic materials trials received manufactured N fertilisers. For N source, we report on organic farming where a stockless rotation was introduced in a long-term, stocked, ley-arable experiment. The N source in this rotation was exclusively biologically-fixed N as legume residues from clover and beans in the stockless rotation and from clover residues, applications of farmyard manure and grazing in the stocked rotation.

2. Materials and methods

2.1. Sites and experimental treatments

Treatments were tested in three field experiments at two sites (Table 1). The sites where tillage and organic amendments were tested, Mid Pilmore and Low Pilmore respectively, were at the James Hutton Institute, Invergowrie, Dundee, UK (56°27′N, 3°W). The soil is a Dystric-Fluvic Cambisol according to the World Reference Base (WRB) classification with a sandy loam texture and free drainage. The Tillage Experiment at Mid Pilmore evaluated the impact of a range of cultivation, with the following main plot treatments (1) no tillage, (2) minimum tillage (3) normal plough (4) normal plough and compaction and (5) deep plough treatments (Table 1) sampled for N_2O emissions in this study. Each tillage treatment was replicated 3 times in a split-plot design, where each main plot was 33 m × 33 m (Table 1). Treatment plots were split with half planted with a range of winter barley (*Hordeum vulgare* L.) varieties and the other half a range of spring barley varieties. Sub-plots with different varieties were 1.55 m × 6 m and our study was limited to the spring barley variety Optic. Inorganic compound fertiliser was applied such that 77 kg N ha^{-1} was drilled with the spring barley and an additional 33 kg N ha^{-1} was broadcast at mid-tillering. Further details of the site and treatments were given by Sun et al. (2011) and Newton et al. (2012).

The data reported here from the Amendment Experiment at Low Pilmore, adjacent to Mid Pilmore, are from part of a slightly larger experiment involving an additional slurry treatment and some extra control plots but from which no N_2O flux data were collected. The full trial was arranged in the field as a rectangular matrix of 6 rows × 9 columns of plots (15 m × 30 m). All six residue treatments (including the control receiving inorganic N & K fertiliser only) on which data were collected are listed in Table 1. All treatments were applied annually in every row and half of the rows were irrigated. There was an additional constraint on allocation of residue treatments to plots within columns. Each individual column contained only plots with either varying levels of slurry or varying levels of compost or control plots. No column contained plots of all treatments. The compost contained 52% dry matter with a total N concentration of 1.39% and the slurry was 4.9% solids with a total N concentration of 3.65% (Paterson et al., 2011). The total N in the slurry corresponded to 7 kg ha^{-1} t^{-1} applied of which *ca.* 40% was readily available. The organic materials were spread on the surface and incorporated using two passes of a disc and tine cultivator operating to 10–15 cm depth. Plots were sown with spring barley.

Irrigation of the three rows occurred overnight from crop emergence until anthesis with a moving linear irrigator at a rate sufficient to maintain the soil close to field capacity. This was to simulate the wet soil conditions that may be associated with climate change. Inorganic compound fertiliser was applied to all treatments, including the control, such that the rate of application of N was 87 kg N ha^{-1}.

The Rotation Experiment was at Tulloch, near Aberdeen, UK (57°11′N, 2°15′W) on a Leptic Podsol according to the WRB classification with a sandy loam texture. Drainage varies from free to impeded across the site. The experiment contained two rotations chosen to typify local six-year farming rotations, called Rotations 1 and 2. Every course in each rotation was present each year. Each course occupied a plot (27 m × 30 m) and there were two replicate blocks of each rotation. In the first year (2006), Rotation 1 was 3 years grass/white clover (*Trifolium repens* L.) and 3 years arable whereas Rotation 2 was 4 years grass/white clover and 2 years arable (Fig. 1A). In the second and third years (2007–2008) the experimental design was changed so that Rotation 1 included barley and Rotation 2 was made stockless (Table 1 and Fig. 1B and C). The addition of extra crops necessitated splitting plots in 2007 and in 2008 that were formerly third-year grass in Rotation 1 and that were formerly first- and second-year grass in Rotation 2 (Fig. 1B and C). Split plots were 27 m × 15 m. Sheep grazed the grass/clover at a rate of 1.7 livestock units ha^{-1} when herbage was available. The sequence of cropping in individual plots is shown in Fig. 1 from top (2006) to bottom (2008). The stockless rotation was introduced in response to the two demands from the farming and food trades for more organic food direct from the field and for more organic animal fodder. In Rotation 1 95, 59 and 71 kg total N ha^{-1} were applied as manure to the second year grass/clover, the third year grass clover and the swedes (*Brassica napobrassica* L.) respectively. In Rotation 2, in 2006, 136, 89 and 71 kg total N ha^{-1} were applied as farmyard manure to the second year grass/clover, the fourth year grass/clover and the oats (*Avena sativa* L.) preceding grass/clover (oats undersown). The other crops received no manure. After