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Managing fertiliser nitrogen to reduce nitrous oxide emissions and emission intensities from a cultivated Cambisol in Scotland

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ABSTRACT

Emissions of nitrous oxide (N_2O) were measured from an arable site in south east Scotland for twelve months during 2011–2012 using an intensive sampling strategy. This fully replicated and blocked field experiment aimed to provide accurate measurements of N_2O emissions from one of the UK's principle geoclimatic zones supporting agricultural production and to produce robust N_2O emission factors (EFs). Calculated EFs were compared to the IPCC's default Tier 1 EF of 1.25%, and the new value of 1%, to assess their suitability for use in locations throughout the UK. Emissions from ten treatments fertilised with either ammonium nitrate or urea at rates of 0 kg N ha^{-1} to 200 kg N ha^{-1}, and sown with spring barley, were measured using the static closed chamber technique. Potential N_2O mitigation options were investigated; these included the use of a nitrification inhibitor (NI), split fertiliser applications and variations in the form and quantity of fertiliser applied. Crop yields were measured to enable calculation of N_2O emission intensities for each treatment; this is an important factor to consider when assessing N_2O mitigation options due to the need to maintain crop yields. Cumulative N_2O emissions varied between 1.32 kg N_2O-N ha^{-1} and 3.82 kg N_2O-N ha^{-1} with a mean 42% decrease in emissions associated with the use of the NI. Increases in crop yield were associated with increases in N fertiliser application, and the amendment of treatments with a NI and the use of a split fertiliser application significantly decreased crop yields by approximately 10% and 5% respectively. Annual EFs ranged between −0.28% to 1.35%. Emission intensities decreased with increasing fertiliser application at low N application rates, and the optimum fertiliser application rate to obtain minimum emissions but maximum crop yield was 160 kg N ha^{-1}.

1. Introduction

Nitrous oxide (N_2O) is a powerful greenhouse gas (GHG) which accounts for 8% of total global GHG emissions (Reay et al., 2012) and has a global warming potential 298 times greater than that of CO_2 (Forster et al., 2007). The breakdown of N_2O to NO in the stratosphere also results in the depletion of stratospheric ozone (Crutzen and Lelieveld, 2001). Although N_2O is a naturally occurring gas, there has been an increase in atmospheric concentration of 16% since 1750 which is primarily attributed to emissions from fertilised agricultural soils (Davidson, 2009). Global annual emissions from agricultural soils are currently estimated to be around 4 Tg of N_2O-N (Reay et al., 2012).

The production of N_2O by fertilised arable soils is associated with the application of inorganic N fertilisers and manures or soil disturbance, which cause an increase in soil concentrations of ammonium (NH_4^+) and nitrate (NO_3^-); which is responsible for the subsequent production of N_2O as a byproduct of the microbial processes of nitrification and denitrification (Chapuis-Lardy et al., 2007; Inselbacher et al., 2011). Emissions from fertilised soils have high spatial and temporal variability (Flechard et al., 2007; Lilly et al., 2003) due to the influence of multiple factors such as soil water filled pore space (WFPS), soil compaction, pH and temperature on the N_2O source processes (Bessou et al., 2010; Castellano et al., 2010; Pierzynski et al., 2005; Smith et al., 2003). The high spatial and temporal variability of N_2O emissions from agricultural soils makes it difficult to accurately assess annual fluxes. It has been suggested that a solution to this problem is the use of high frequency long path length measurement techniques such as eddy covariance (Flechard et al., 2007). However, such methods require large areas and are typically of limited value in plot based field experiments where manipulation treatments are compared, and emission factors (EFs) need to be calculated (as an unfertilised control area is needed too). An alternative approach, used in this study, is the use of static chambers with high temporal and spatial replication (Chadwick et al., 2014). Previous studies of N_2O emissions from agricultural soils using the static closed chamber technique often involved the use of only a small number of replicate chambers per treatment and a low sampling frequency over a short period of time. For example, a number of studies have used six or less static chambers per treatment (Ball et al., 1999; Clayton et al., 1997; Dobbie et al., 1999; Dobbie and Smith, 2003; Smith et al., 2012). Previous

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studies have also often been based on short measurement periods ranging from 5 days to 6 weeks after fertiliser application (Skiba and Ball, 2002; Skiba et al., 2002; Smith et al., 2012). Furthermore, previous studies have not always adequately captured temporal dynamics where gas samples were taken at intervals of 2–4 weeks (Rees et al., 2013).

The relationship between the amount of N fertiliser applied and the magnitude of N_2O emissions is quantified through the use of an EF (EF1) which expresses the quantity of N_2O-N emitted as a proportion of the N fertiliser applied. The EF calculation also accounts for background emissions which are largely due to mineralisation of crop residues (IPCC, 2006). Bouwman (1996) reviewed experiments of at least a year in length and recommended an EF (EF1) of 1.25% of the N applied to express the relationship between applied N fertiliser and N_2O emissions. The IPCC subsequently used this as a “default EF” to enable calculation of countries' N_2O emissions from soils receiving inorganic fertiliser N (IPCC, 1996). This value has since been revised downwards on the basis of more recent evidence to give an EF of 1% of N applied for use in the Tier 1 methodology for calculating N_2O emissions (IPCC, 2006). However many countries including the UK have not yet adopted the 1% EF in their national inventory calculations. This default EF attempts to estimate typical emissions across large spatial areas and time periods, however there is concern that local soil and climatic conditions, and the type and rate of fertiliser used can lead to significant variance from average conditions (Smith et al., 2012). The use of a 1.25% EF has been controversial in Scotland where it has been demonstrated that large changes in soil WFPS may result in Scottish EFs which are atypical of the whole of the UK (Dobbie et al., 1999; Dobbie and Smith, 2003). This is reflected in calculated N_2O EFs ranging from 0.17 to 7% for a range of N sources for Scottish agricultural soils (Clayton et al., 1997; Dobbie et al., 1999; Smith et al., 1998a). To improve the accuracy of agricultural N_2O reporting it is necessary for investigation into the effects of controlling variables on N_2O emissions and the appropriateness of utilising a 1.25% EF, or the new 1% EF, regardless of location, and this is particularly relevant in areas of the UK which may experience extreme or unusual climatic conditions.

Mitigation of agricultural N_2O emissions is necessary if we are to limit the contribution of agriculture to climate change. The use of nitrification inhibitors (NIs) such as dicyandiamide (DCD) which act to decrease N_2O emissions by deactivating the ammonia monooxygenase enzyme used in the primary stage of nitrification (Amberger, 1989) have proved successful in mitigating agricultural N_2O emissions (Di and Cameron, 2003; Di et al., 2007) and have also demonstrated the potential to increase crop yields (Abalos et al., 2014). However, there has been little investigation into the effectiveness of DCD in UK agricultural systems and more research in this area is required. Another N_2O mitigation option which requires further investigation is the use of split applications of N fertiliser. Split applications result in the application of smaller individual doses of fertiliser, which reduces surplus N in the soil and decreases the potential for loss of N via transformation to N_2O or leaching, in addition to being more suitable for crop requirements (Burton et al., 2008), potentially increasing the nitrogen use efficiency of fertilisers. Reducing the amount of surplus N is an important method of decreasing N_2O emissions as it not only has positive impacts on the environment but is also financially beneficial for the farmer. Altering the amount or type of fertiliser applied is another means by which surplus N may be decreased, and research has indicated that the use of urea rather than ammonium nitrate (AN) fertiliser may result in lower N_2O emissions (Dobbie and Smith, 2003; Smith et al., 2012).

Although it is important to minimise N_2O emissions from agricultural soils, it will also be necessary in the future to produce greater quantities of food, meaning that crop yield must not be negatively impacted by mitigation options. Emission intensities i.e. the amount of N_2O produced per unit of crop yield, are therefore a vital indicator of the potential of any N_2O mitigation option (Van Groenigen et al., 2010), although research into this area has thus far been limited.

This work forms part of a nationwide project to assess the effect of a range of organic and inorganic nitrogen fertiliser treatments on N_2O emissions from agricultural soils with the results being used to improve agricultural management systems and to reduce uncertainty in the UK agricultural greenhouse gas inventory (GHG, 2013). More specifically, the aims are to:

i). Compare N_2O emissions, calculated EFs and emission intensities from different inorganic fertiliser treatments.
ii). Investigate the efficacy of potential N_2O mitigation options.
iii). Assess the appropriateness of the use of the standard 1.25% or 1% EF for the area under investigation.

2. Materials and methods

2.1. Site description

The experiment began in April 2011 at Gilchriston in south east Scotland (Grid reference: NT479658). Gilchriston is a commercial arable farm, selected for its location in one of the principal geoclimatic zones which support arable production in the UK. The site characteristics are described in Table 1. Soil pH, organic matter and bulk density were calculated using field measurements, other soil information was obtained from Hipkin (1989).

2.2. Experimental design

Nitrogen fertiliser treatments were compared that ranged from a control (0 kg N ha^{-1}) to 200 kg N ha^{-1} and included the recommended application rate for the area of 120 kg N ha^{-1} (Defra, 2010). The fertiliser was applied either in the form of ammonium nitrate (AN) or urea. Fertiliser was applied in two doses (three doses for one treatment) in April and May 2011, by hand to the entire plot, to simulate agronomic practice. The NI DCD was applied at a rate of 10 kg ha^{-1} as a spray an hour after the application of AN and urea. Further details of treatments are presented in Table 2. The experimental layout consisted of 10 m × 3 m plots replicated three times for each treatment in a randomized block design. For the duration of the experiment, pesticides were applied according to standard recommendations, and P_2O_5 and K_2O were applied to all plots at rates of 60 kg ha^{-1} and 90 kg ha^{-1}, respectively, in order to satisfy crop demand.

2.3. Gas and soil sampling, measurements and analysis

Nitrous oxide fluxes were measured at the experimental site over a 347 day period (19th April 2011–30th March 2012) using the static closed chamber technique (Chadwick et al., 2014; Clayton et al., 1994) and with a methodology that was consistent with Global Research Alliance guidelines