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Research paper

Renovation and conversion of permanent grass-clover swards to pasture or crops: Effects on annual N_2O emissions in the year after ploughing

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ABSTRACT

The need for improved herbage yield and forage quality, on intensively managed grassland, in dairy farming systems, often results in land being brought into tillage, either by grassland reseeding or conversion to arable cropping (particularly maize (*Zea mays* L.) for silage). However, both options are likely to increase the greenhouse gas emissions (GHG) after grassland cultivation, particularly when this involves ploughing, although there is limited information about the level of emissions. In order to estimate whether the time of ploughing and type of forage crop would affect the annual emissions of the important GHG nitrous oxide (N_2O) in the year after soil disturbance of grassland, a field experiment was established on a *Eutric Luvisol* in northern Germany. The three factorial experiment comprised the effect of land use management (four treatments: ploughing and reseeding in autumn; ploughing and reseeding in spring, ploughing and conversion to maize in spring; control treatment of intact permanent grassland); the effect of nitrogen (N) fertilizer input (two treatments: 0 and 240 kg N ha^{-1} $year^{-1}$ applied as cattle slurry); and the experimental year (two years). Treatments were arranged with three replicates in a randomized block design. N_2O emissions were measured on a weekly basis with the static chamber method and N drainage during winter was estimated using suction cups. Thus, direct and indirect N_2O emissions (via N leaching) were calculated per ha as well as per unit of forage yield. Results showed that ground-frost and freeze-thaw cycles were major drivers of enhanced N_2O fluxes during the winter following ploughing and reseeding of grassland in autumn, resulting in the highest direct emissions of 21.31 kg N_2O-N ha^{-1} $year^{-1}$. Emissions following grassland ploughing in spring were mainly driven by high soil mineral N-concentrations but with maximum figures of 3.90 and 6.32 kg N_2O-N ha^{-1} $year^{-1}$ after reseeding and conversion to maize respectively. Emissions in the intact permanent grassland were lowest in both years. Forage yield related emissions were also highest for grassland ploughing and reseeding in autumn and lowest for intact permanent grassland, but with no significant differences for reseeding and maize cultivation after grassland ploughing in spring. Application of slurry increased annual N_2O emissions, particularly when applied in the year of reseeding, but with a lower calculated emission factor as advised by the IPCC guidelines for N fertilizers. We conclude that sustaining highly productive permanent grass-clover swards with moderate N fertilization and without tillage is the best option for 'climate-smart forage production' followed, when unavoidable, by tillage operations only in early spring for direct grassland reseeding, or delayed reseeding using a high yielding forage crop like maize.

1. Introduction

Greenhouse gas (GHG) inventories identify nitrous oxide (N_2O) as one of the major greenhouse gases of agricultural land. Its global warming potential is almost 300-fold higher than CO_2 over a 100-year time horizon (IPCC, 2007) and it contributes 6% of total annual anthropogenic greenhouse gas emissions, with atmospheric concentrations currently increasing by 0.73 ppb each year. More than 60% of N_2O emissions are soil derived (Thomson et al., 2012), mainly produced as a by-product of soil nitrification and denitrification processes (Wrage et al., 2004). Global agriculture is responsible for the largest proportion, and increasing share, of anthropogenic N_2O emissions; these are mainly derived from nitrogenous inputs including mineral and organic nitrogen (N) fertilizers and from the use of legumes (Ussiri and Lal, 2013). Moreover, soil tillage practices can cause N losses due to enhanced mineralization of soil organic N, with the risk of additional gaseous emissions and N leaching. Conversely, the absence of soil tillage and year-round plant cover are the main reasons why permanent

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grassland systems store comparatively high concentrations of carbon (C) and N in the soil organic matter (Johnston et al., 2009). Thus, these stores are likely to be sensitive to occasional tillage events associated with grassland reseeding, leading to C and N losses (Conijn et al., 2004). Although the IPCC (2006) guidelines for calculating GHG inventories for agricultural activities provide emission factors for different land use practices, in addition to the quantification of losses of SOM, there remains large uncertainty about the effects of occasional soil tillage practices on grasslands, particularly in their effect on non-CO_2 GHG emissions. These predominantly concern both direct N_2O losses and indirect N_2O losses.

From the perspective of agricultural land use in northwest Europe there is a need for good estimations of N_2O emissions because forage production for dairy farming has undergone continuous intensification over the last decades. As a consequence, permanent grassland, which covers more than 59 million hectares of the utilized agricultural area in Europe (EUROSTAT, 2016), was often converted to arable land (Taube et al., 2014) and the remaining grassland areas are now primarily managed under high management intensities, predominantly with heavily fertilized three- to four-cut systems for silage making. Due to management shifts towards cutting-only strategies without grazing, sward deterioration occurs with reductions in the proportion of the main sown grass, perennial ryegrass (Lolium perenne). Repeated reseeding is therefore required to maintain high performance from swards, in terms of their yield and quality, and the cultivations associated with reseeding are often associated with mechanical soil disturbance. Ploughing, as the most common soil cultivation technique used for renovation of permanent grassland, often causes a rapid loss of soil C (Linsler et al., 2013; Necpálová et al., 2013b) in particular when old swards are renewed. Hence, N_2O emissions are likely in the short-term because of high concentrations of available reactive N (Whitmore et al., 1992) and easily degradable organic matter (Six et al., 2000), enhancing N_2O production, mainly due to soil heterotrophic denitrifiers (Senbayram et al., 2012). Summarizing the findings of these studies, which estimated short-term emissions following different soil tillage methods for grassland renovation and conversion to arable respectively, revealed the highest emissions of up to 29 kg N_2O-N per ha occurred during the six months following tillage (Merbold et al., 2014). Another potential pathway for high N losses is leaching (Whitmore et al., 1992), which has to be considered in terms of GHG inventories for indirect N_2O emissions. The time of year that ploughing occurs can have a substantial effect on total N losses because of different environmental conditions in autumn and spring. Most available studies found a decrease in N leaching when ploughing was conducted in early spring (e.g. Seidel et al., 2009) but there was a higher risk of N_2O emissions compared with ploughing in autumn (Velthof et al., 2010).

In the intensively managed grassland systems in northwest Europe, where high inputs of mineral and organic fertilizers typically supply 240–400 kg N ha^{-1} $year^{-1}$, there are also direct N_2O emissions that arise from these N sources. If these direct N_2O emissions are taken into account the additional emissions from frequently renewed grassland may negate the C sequestration benefit of grassland, at the field-scale (Merbold et al., 2014; Skiba et al., 2009). However, in addition to estimation of emissions on an area basis, the supposed advantages of improved yield associated with cultivation and sowing must also be taken into account. Climate has to be addressed as a global environmental good, and the yield performance of a specific system is also relevant in order to derive product carbon footprints (PCF) per unit of a specific agricultural commodity as an indicator for the eco-efficiency of a production system (Basset-Mens et al., 2009). Adopting this approach to forage requires the selection of a functional unit that reflects its production potential as a feedstuff for ruminants, e.g. Metabolizable Energy (ME) expressed as Gigajoules (GJ) per ha. Reasonably high yielding production systems that have moderate emissions might thus be superior to a low emission reference system in terms of their PCF (Lemaire et al., 2014). In regions where ley systems are commonly used, like Scandinavia and northern Germany, forage crop rotations are based on maize for silage that follows the grass or clover-grass ley. Thus, tillage of grassland might be an option for direct grass-to-grass reseeding, as mentioned above, or it may be considered as an option for a short-term land use change for an arable crop such as maize, before reseeding to grassland again.

There are few sources of data regarding the eco-efficiency parameters of short-term effects following the ploughing of permanent grassland for grassland renovation or conversion to arable crops. Against this background the aim of this study was to determine the effect of different management options regarding grassland renovation on the total N_2O emissions and to address the following hypotheses: (i) ploughing for grassland renovation causes substantial emissions of N_2O; (ii) the magnitude of N_2O emissions is affected by the time of the year when ploughing takes place (spring or autumn); (iii) N_2O emissions are enhanced by N fertilization following grassland reseeding; and (iv) the functional unit used (per ha; per GJ ME) triggers the range of treatments regarding N_2O emissions.

2. Methods

2.1. Experimental site

The field experiment was conducted at the experimental farm "Lindhof" (54°27′N, 9°57′E; elevation 27 m above sea level) of Kiel University in northern Germany. The farm is located close to the Baltic Sea with a long-term mean annual temperature of 8.9 °C and an average annual rainfall of 768 mm (1981–2010). The soil type is classified as a *Eutric Luvisol* (FAO, 2006) with a pH of 5.7 and a soil organic carbon concentration of 170 g kg^{-1}. The soil texture comprised 11% clay, 29% silt and 60% sand in the 0–30 cm soil depth, respectively. The historical management of the experimental field was arable cropping with a 5-year crop rotation until 1993. Since 1993, the experimental farm is managed according to the German organic growers association "Bioland" prohibiting the use of chemical fertilizers or pesticides. In 1994, a grass-clover mixture was undersown in a cereal crop and it was subsequently managed as grassland. Before the experiment started, the grassland was managed in a mixed system (1–2 silage cuts followed by 3–4 grazing cycles by cattle).

2.2. Experimental design and treatments

The experiment started in autumn 2010 and was repeated in 2011. To estimate N_2O-emissions and yield performance in the 12 months after grassland renovation in autumn (AR), grassland renovation in spring (SR) and grassland conversion to maize (CM), the 1994-sown permanent grassland sward was mown, rotovated and mouldboard ploughed to a soil depth of 25 cm in Sep 2010 and 2011 (AR) and May 2011 and 2012 (SR + CM), respectively. For the grassland renovation (AR + SR) the ploughed treatments were harrowed and sown with 30 kg ha^{-1} of a grass-clover mixture. The commercial seed mixture used contained, by weight, *Lolium perenne* (70%), *Poa pratensis* (12%), *Phleum pratense* (12%) and *Trifolium repens* (6%). For the CM treatment, maize (*Zea mays* L.) seeding (cv. Ronaldinio, mid-early) was conducted in a row width of 0.75 m with a plant density of 10 plants per m^2. Intact permanent grassland served as a control (PG). The PG and AR tratments were cut four times during the growing seasons of 2011 and 2012, respectively, while SR treatments were cut three times following reseeding in spring. Cattle slurry provided the N fertilizer. This was applied using trailing hoses for each of the four cuts in the 'N-fertilized treatments'. Based on the total N content, the amounts of slurry applied provided 80 kg N ha^{-1} for the first cut, 60 kg N ha^{-1} for the second and third cut and 40 kg N ha^{-1} for the last cut. An unfertilized treatment served as the control. The maize treatments received the same total amount of slurry N as the grass treatments, but for maize it was applied as two or three equal applications. Dates of management