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Effect of slurry dry matter content, application technique and timing on emissions of ammonia and greenhouse gas from cattle slurry applied to grassland soils in Ireland

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ABSTRACT

Agriculture contributes to 98% and 33% of ammonia and greenhouse gas (GHG) emissions in Ireland, respectively. Those emissions are mainly associated with livestock production. The Gothenburg Protocol and the EU National Emissions Ceilings Directive are policy drivers which set new and more demanding targets from 2020 to reduce these gaseous emissions. A field experiment was set up in Wexford (Ireland) between April 2009 and August 2010, on a grassland site established with a uniform ryegrass (*Lolium perenne*) sward for more than ten years. The objective was to investigate the impact of slurry dry matter (DM) content, application technique and timing of application on the overall GHG balance from cattle slurry applied to grassland soils. The treatments on plots were a control, calcium ammonium nitrate (CAN) and cattle slurry, either grass-based or maize-based and with varying DM contents, applied by mimicking trailing shoe and splash plate application. The dry matter contents were varied by mixing different ratios of faeces and urine. The results showed that, while ammonia (NH_3) volatilisation losses were significantly increased on slurry spread plots, cumulative direct nitrous oxide emissions, and corresponding emission factors, were significantly higher when applying CAN. In terms of GHG field balance, the potential decrease in indirect nitrous oxide (N_2O) emissions, calculated from a reduction of ammonia volatilisation losses using trailing shoe as opposed to splash plate, could be easily offset by an increase in direct N_2O emissions and ecosystem respiration. Switching from summer to spring application was much more efficient for mitigation of both NH_3 and GHG emissions, due to favourable soil and climatic factors which enhanced crop growth. Any potential trade-off between NH_3 and N_2O emissions was cancelled, leading to an overall positive effect on reactive nitrogen losses and offering agronomic benefits to farmers.

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1. Introduction

Agriculture in Ireland is the main source of ammonia (98% of NH_3 emissions) and contributes to 33% of greenhouse gas (GHG) emissions with the majority of these associated with livestock production (Duffy et al., 2013).

Ireland is a Party to the Convention on Long-Range Transboundary Air Pollution (CLRTAP, also known as "Gothenburg Protocol"), under which certain transboundary air pollutants (including NH_3) are targeted for control (UNECE, 1999). As a member of the European Union (EU), the country is also subject to the National Emission Ceilings (NEC) Directive (EU, 2001), which implements the Gothenburg targets for member states. Target emissions for Ireland to be achieved by 2010, under the NEC Directive, were 116 kt (Humphreys, 2008). NH_3 emissions reached 130 kt in 1998 but declined to 113 kt in 2005, because of a smaller ruminant livestock population and reduced use of fertiliser nitrogen (N). However, both the Gothenburg Protocol and the EU National Emissions Ceilings Directive were reviewed with a new target of 0.5% reductions on 2005 levels by 2020 (DAFM, 2013).

NH_3 emissions from manure spreading to land contribute about a third of the total N emissions from agriculture in industrial countries (Misselbrook et al., 2000). Hyde et al. (2003) estimated that spreading of cattle slurry on grassland is the source of approximately 25% of NH_3 emissions in Ireland. Therefore, there is a need to develop NH_3 abatement strategies to reduce volatilisation losses when applying cattle slurry to grassland. This can be achieved by modifying the method of slurry application as well as optimising

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the timing of application or modifying slurry characteristics (Brink et al., 2001). However, reduced NH_3 losses from manure spreading are likely to increase N availability in agricultural soils and this may, in turn, affect the production and release of nitrous oxide (N_2O) (Brink et al., 2001). As N_2O is a potent GHG with a global warming potential 298 times that of carbon dioxide (CO_2) (IPCC, 2007), this could be regarded as pollution swapping (Stevens and Quinton, 2009) where attempts to abate the release of one ecologically harmful gas result in an increase in the emissions of another.

In Ireland, N_2O represented, in 2011, 13% of national GHG emissions and 40% of GHG emissions from agriculture. Manure management accounted for 6% of those emissions while N_2O sourced from manure application to land comprised 9% of agricultural N_2O emissions and 24% of direct N_2O emissions from agricultural soils (Duffy et al., 2013).

Methane (CH_4) is another potent GHG, with a global warming power 25 times that of CO_2 (IPCC, 2007), which represented 20% of national GHG emissions and 60% of GHG emissions from agriculture (Duffy et al., 2013). Those CH_4 emissions have decreased since 1998 mainly as a result of lower CH_4 losses from enteric fermentation which was a consequence of a gradual reduction in sheep numbers. Hence CH_4 from manure management has remained relatively static over the same period (Duffy et al., 2013).

Under the Kyoto Protocol (UNFCCC, 1997), Ireland was limited to an increase in GHG emissions by 13.5% for the period 2008–2012 (relative to 1990 levels). Whilst these emissions are just on target, the country has been set, under the EU 2020 Climate and Energy Package and its associated Effort-Sharing Decision, a further 20% reduction target for its non-Emission Traded Sectors (EU, 2009). As agriculture comprises over 40% of this category of emissions, there will be sustained pressure into the future to reduce GHG emissions.

Research on abating NH_3 emissions from manure spreading has primarily focused on comparing the NH_3 and N_2O emissions from surface (conventional or band spreading) and injection application methods (e.g. Weslien et al., 1998; Sistani et al., 2010; Velthof and Mosquera, 2011). Injection methods have been shown to reduce NH_3 volatilisation losses up by up to 90% (Dendooven et al., 1998) but they can also lead to an increased release of N_2O from soils in the weeks following slurry application (Wulf et al., 2002; Velthof and Mosquera, 2011). However, observations of this increase in N_2O emissions are inconsistent and some studies report no effect of application technique (Dendooven et al., 1998; Weslien et al., 1998). Sistani et al. (2010) also showed contrasted results, when comparing both surface application and injection of swine effluent, as they observed lower N_2O emission from injected plots during the first year of their experiment, but they found higher emissions from the same plots in the second year.

Trailing-shoe application of slurry to grassland soils has been shown to be an efficient NH_3 abatement technique (Misselbrook et al., 2002); it is considered to be the most effective way to lower NH_3 losses for many grassland areas, especially where a high stone content of soils and undulating topography make injection unsuitable. However, only a few studies have compared N_2O emissions from low trajectory slurry applications (e.g. with a trailing-shoe) with those from the broadcast method.

Timing of manure application affects NH_3 emissions as they increase with temperature and wind speed (Sommer et al., 2003). Timing is also likely to affect N_2O emissions since N_2O production is mainly driven by N availability, temperature and soil aeration, which vary temporally. Most studies investigating the impact of timing of slurry applications on NH_3 and N_2O emissions have focused on comparing autumn and spring applications, as reviewed by VanderZaag et al. (2011). However, slurry in Ireland is applied mainly in the summer (Hyde and Carton, 2005) when N volatilisation losses are likely to be enhanced by higher soil temperatures. Spreading of slurry in the spring is restricted if soils remain above field capacity and rates of infiltration are low, even although uptake by herbage is high and lower soil temperatures reducing volatilisation losses. However, after applying pig and dairy slurries onto perennial ryegrass, Chadwick et al. (2000) observed higher N_2O losses in spring than in summer suggesting that, while spring application may reduce NH_3 losses to the atmosphere, this may be offset by higher N_2O emissions.

One possible way to reduce NH_3 volatilisation from spreading of manures could be by dilution. NH_3 fluxes have been shown to increase with increasing dry matter (DM) content in liquid manures (Sommer and Olesen, 1991). A higher content of solids can lead to sealing of soil pores, reducing the rate of infiltration into the soil and potentially increasing NH_3 volatilisation (Donovan and Logan, 1983; Dosch and Gutser, 1996). Sommer and Olesen (1991) observed that dilution of slurry from 12% to 4% DM content could reduce NH_3 losses. Mkhabela et al. (2009) showed similar results on NH_3 losses after diluting swine slurry and investigated the effect of such dilution on N_2O losses post-application, finding no significant effect of slurry dilution. Gregorich et al. (2005) found that N_2O emissions from liquid manure application were increased up to three fold compared to solid manures, with a much larger N fraction lost as N_2O.

The objective of this study was to investigate the impact of slurry application technique and timing of application, as well as the influence of slurry type (defined by parameters such as its DM and N content or its C:N ratio), on the overall GHG balance from cattle slurry applied onto grassland soils. The hypotheses formulated for this experiment are:

- Any reduction in NH_3 losses, following an alteration of slurry DM content, a switch from splash-plate to trailing-shoe or from summer to spring/autumn application will increase soil N pools, leading to an increase in measured N_2O emissions (as a result of the trade-off between NH_3 and N_2O fluxes).
- The supply of extra N to the soil (following the implementation of one of the NH_3 abatement strategies tested in this experiment), coupled with an input of organic carbon (C), will enhance soil microbial activity, increasing soil (and ecosystem) respiration.

2. Materials and methods

2.1. Site characteristics

The experiment was undertaken between April 2009 and August 2010, on a grassland site in Johnstown Castle, Wexford, Ireland (52°18° N; 6°30° W). The field is under an established (>10 years) and uniform ryegrass (*Lolium perenne*) sward. The mean annual rainfall and temperature, averaged over 25 years (Rosslare weather station, Met Eireann, 1978–2003), are 1044 mm and 10 °C, respectively. The soil is a well-drained coarse loam over fine loam, classified as a Haplic Cambisol Brown Earth. Some characteristics of the topsoil are given in Table 1. Prior to the experiment, a 180 m^2 area was divided into 40 plots (2 m × 1.5 m, 0.5 m gap between each) (Fig. 1).

2.2. Soil measurements and analyses before experiment

In March 2009, before applying any treatment on the plots, soil samples ($n = 10$) were collected from the field (Fig. 1), at two different depths (0–10 and 10–20 cm).

Total C and N contents of soil were analysed using a LECO TruSpec CN analyser (LECO Corporation, St. Joseph, MI, USA). Prior to the analysis, the soil samples were wet sieved to 2 mm, frozen at −80 °C for 16 h, freeze dried for 48 h and finally ground into fine powder. Ammonium nitrogen ($NH_4{}^+$-N) and Total Oxidised

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