

# How does the timing and form of organic fertiliser application affect greenhouse gas emissions from arable soil?

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## **Abstract**

The application of organic waste to agricultural soil as a fertiliser is common practice due to its ability to provide nitrogen (N) to the crop. Considerable amounts of the N applied will never be utilised by the crop, but instead emitted to the environment in gaseous forms such as nitrous oxide (N<sub>2</sub>O) and ammonia (NH<sub>3</sub>). N<sub>2</sub>O is a powerful greenhouse gas (GHG) and causes ozone depletion. Deposition of NH<sub>3</sub> in terrestrial or aquatic environments may cause eutrophication and soil acidification. To reduce environmental pollution from the application of organic fertilisers, careful management of the timing and form of fertiliser application is required. This research has measured N<sub>2</sub>O and NH<sub>3</sub> emissions from organic fertiliser applications to an arable field experiment in Scotland, and compared the emissions from autumn and spring applications. The results will be used to improve the management of organic fertilisers, and to develop mitigation of N<sub>2</sub>O and NH<sub>3</sub> emissions.

## **Introduction**

Organic wastes such as manure and slurry are commonly used as fertilisers in arable agriculture due to their ability to provide large quantities of nitrogen (N) required for crop growth. However, considerable amounts of the N applied through organic fertiliser application will never be utilised by the crop, but instead emitted to the environment in gaseous forms such as nitrous oxide (N<sub>2</sub>O) and ammonia (NH<sub>3</sub>), and leached as nitrate (NO<sub>3</sub><sup>-</sup>) after undergoing transformations in the soil [1]. N<sub>2</sub>O is a powerful greenhouse gas (GHG) with a global warming potential 298 times greater than that of CO<sub>2</sub> and also depletes the stratospheric ozone layer [2]. At the global scale 65% of anthropogenic N<sub>2</sub>O emissions originate from soil [3]. NH<sub>3</sub> and NO<sub>3</sub><sup>-</sup> may be deposited in aquatic or terrestrial environments resulting in indirect N<sub>2</sub>O loss and environmental impacts such as eutrophication and soil acidification.

The potential for emission of N<sub>2</sub>O and NH<sub>3</sub> after application of organic fertilisers to agricultural soils is dependant on a combination of contributory factors. The N content of organic fertilisers, and the proportion of N in the form of readily available N (ammonium-N or uric-N) or organic N varies in relation to the type of organic fertiliser [4,5]. Large quantities of readily available N (35-70% of total N) are typically found in slurries and poultry manures in comparison to the relatively small quantity of readily available N (10-25% of total N) found in farmyard manure (FYM) [4]. The quantity of readily available N in organic fertilisers affects the potential for loss of N from the soil system through NH<sub>3</sub> volatilization, N<sub>2</sub>O emissions, or leaching of NO<sub>3</sub><sup>-</sup>, with greater probability of N loss from fertilisers containing large amounts of readily available N [4].

The timing of organic fertiliser application can also be critical if significant losses of N from the soil system are to be avoided. Ammonia volatilization from soils to which organic fertiliser containing large quantities of readily available N has been applied is generally increased when application occurs in warm conditions, and to dry soils [4]. Conversely, loss of N via NO<sub>3</sub><sup>-</sup> leaching and N<sub>2</sub>O emission is higher when organic fertiliser is applied in wet conditions as leaching of NO<sub>3</sub><sup>-</sup> and production of N<sub>2</sub>O via denitrification will occur before the crop is able to utilise the available N [4,5]. In order to reduce losses of N it is generally recommended that organic fertilisers should be applied in the late winter or early spring period when weather conditions are drier [4].

The method of organic fertiliser application is also crucial when considering N loss and subsequent environmental impacts. Application of slurry by band spreading or shallow injection has been found to reduce NH<sub>3</sub> losses by between 30-70% in comparison to broadcast application. The incorporation of slurries and manures into soil immediately following application is also effective in reducing NH<sub>3</sub>

losses. Application of organic manures using these techniques results in reduced loss of N from the soil which causes a resultant increase in the amount of N available for use by the growing crop [1, 4].

Due to the variety of conditions which affect N loss from soils amended with organic fertiliser, it is imperative that organic fertiliser is carefully managed through all stages from production to application, if significant environmental pollution is to be avoided. It is thus vital to understand how manipulation of the form, timing and application method of organic fertiliser applications may reduce potential environmental impacts. This research aims to quantify emissions of N<sub>2</sub>O and NH<sub>3</sub> from the application of a variety of organic fertilisers to an arable field trial in Eastern Scotland. Emissions from spring and autumn fertiliser applications will be compared, to assess what effect the timing of application has on gaseous emissions. The impact of fertiliser type and method of application will also be investigated. The results of this research will contribute to reducing uncertainty in the UK's agricultural GHG inventory, and will enhance the sustainability and GHG mitigation potential of farming systems.

## Materials and Methods

### *Site description and experimental design*

An 18 month field trial was established at an arable farm in Eastern Scotland in autumn 2012 on a sandy loam soil with a pH of 6 and organic matter content of 6%. Prior to this experiment, the field had been sown with a spring barley crop for the previous four years. The site is located at an elevation of 195m a.s.l and has a 40 year (1955-1995) mean annual precipitation of 849 mm and mean daily temperatures in July and January of 13.3 and 3.8°C respectively. The experiment was split into two areas within the same field. One area received autumn applications of organic fertiliser in October 2012, and the other spring applications in April 2013. Both areas were sown with winter wheat (v. Grafton) which is a typical crop for the area on 25<sup>th</sup> October 2012 at a seed rate of 400 m<sup>-2</sup>. Treatments were established on plots (12m x 6m) and replicated in triplicate, in a randomized block design which included a control. A range of organic fertiliser treatments were applied, including FYM, poultry litter, layer manure, and cattle slurry, all of which are livestock wastes commonly applied to Scottish farmland. Details of treatments can be found in Table 1. All of the organic fertiliser treatments were applied at 180 kg N/ha using methods which are usually practiced in the locality. Throughout the experiment, pesticides and herbicides were applied following the farmer's recommendations.

**Table 1. Treatments and application timings**

<i>Treatments</i>	<i>Total N applied (kg N/ha)</i>	<i>Autumn (A) or Spring (S) application</i>
Control	0	A +S
Farmyard manure (FYM)	180	A
Poultry litter	180	A +S
Layer manure	180	A +S
Cattle slurry (broadcast)	180	A +S
Cattle slurry (trailing hose)	180	A +S

### *Measurements and analysis*

15 measurements of N<sub>2</sub>O were taken from each treatment on each sampling occasion using the static closed chamber technique [6]. Five opaque plastic chambers each covering a soil area of approximately 0.16m<sup>2</sup> were inserted to a soil depth of 5cm on each plot, resulting in the use of 15 chambers per treatment. The chambers remained in situ for the entire experiment with the exception of removal when agricultural operations were taking place. An intensive sampling strategy was initially adopted to capture N<sub>2</sub>O fluxes from the period of high emissions, with the frequency of sampling decreasing with time. In total, N<sub>2</sub>O fluxes will be measured on 64 occasions during the 18 month experimental period. On each sampling occasion the chambers were closed for 40 minutes and gas samples were taken using a syringe through a sampling port in the chamber lids. Sampling was conducted between 10:00 and 12:00h to ensure consistency. The N<sub>2</sub>O concentration of the gas samples was analysed using gas chromatography (Agilent 7890A Gas Chromatograph) and N<sub>2</sub>O flux

was calculated using linear regression. The use of a large number of chambers per treatment, combined with the intensive N<sub>2</sub>O sampling strategy was designed to take into account the high spatial and temporal variability of N<sub>2</sub>O emissions from soils, allowing more reliable estimates of N<sub>2</sub>O fluxes from each treatment than has been obtained in similar experiments [7, 8].

Ammonia emissions were measured using small scale wind tunnels through absorption of NH<sub>3</sub> in orthophosphoric acid. The wind tunnels consisted of a canopy (2m x 0.5m) which was placed over part of the plot area, with air drawn through the canopy at 1ms<sup>-1</sup> by a fan in a stainless steel duct. Subsamples of the air from the canopy inlet and outlet were passed through absorption flasks containing 0.02M orthophosphoric acid. On each sampling occasion the flasks of orthophosphoric acid were replaced and samples of the orthophosphoric acid were analysed for NH<sub>3</sub> content [9]. One wind tunnel was placed on each plot and NH<sub>3</sub> emissions were measured daily for 7 days from the slurry and FYM treatments, and for 14 days from the poultry treatments. Soil samples were collected frequently for measurement of mineral N content using KCl extraction and soil moisture content. A weather station was used to record climatic conditions and soil temperature was also measured frequently.

## Results and Discussion

N<sub>2</sub>O losses from autumn and spring applied manure treatments will be compared in order to assess the effects of fertiliser type and timing and method of application on the magnitude of gaseous losses from the soil. NH<sub>3</sub> losses from the autumn experiment will be analysed to assess the effects of fertiliser type and method of application on these fluxes. Comparison between NH<sub>3</sub> losses from the autumn and spring experiments will also be made when results become available (but not presented here). The effect of temperature and rainfall on overall losses of N<sub>2</sub>O and NH<sub>3</sub> during the measurement period to date will also be discussed. Results from the intensive period of high emissions from the spring application will be available in April 2013, allowing a full discussion and comparison of results to take place.

### *Autumn application*

N<sub>2</sub>O emissions from the autumn applied treatments show high temporal variation with the majority of emissions occurring during a single flux episode in October. This peak in emissions occurred nine days after application, during which time the fluxes from all treatments remained below 25 g N<sub>2</sub>O-N ha<sup>-1</sup> d<sup>-1</sup>. The single large peak in emissions was characterized by a sudden increase from all treatments, with a maximum flux of 147.58 g N<sub>2</sub>O-N ha<sup>-1</sup> d<sup>-1</sup> from the surface broadcast slurry treatment, and the lowest flux (excluding the control) from the FYM (41.68 g N<sub>2</sub>O-N ha<sup>-1</sup> d<sup>-1</sup>). The peak in emissions was followed by two smaller peaks later in October and in November, with the maximum flux of 44 g N<sub>2</sub>O-N ha<sup>-1</sup> d<sup>-1</sup> observed from the layer manure treatment. The large peak in emissions, nine days after fertiliser application coincided with a large quantity of rainfall (49mm in 24 hours) and a slight increase in temperature. Prior to this large rainfall event, there had been only 2.6 mm since the treatments were applied. The rainfall event resulted in an increase in soil water filled pore space (WFPS) to 54%; the maximum value obtained since the start of the experiment. Soil WFPS is often regarded as the primary variable controlling the production of N<sub>2</sub>O by nitrification and denitrification within soil, with maximum N<sub>2</sub>O production and emission occurring at 50-70% WFPS [3]. An increase in temperature is also suggested to increase denitrification rates due to an increase in the number of anaerobic microsites within the soil [10].

Cumulative emissions of N<sub>2</sub>O demonstrate the effect of the type of organic fertiliser and the quantity of readily available N on the magnitude of N<sub>2</sub>O fluxes, with the lowest emissions occurring from the FYM treatment (812 g N<sub>2</sub>O-N ha<sup>-1</sup> d<sup>-1</sup>), in which there are lower amounts of readily available N [5]. The maximum cumulative flux occurred from the layer manure treatment (1891 g N<sub>2</sub>O-N ha<sup>-1</sup> d<sup>-1</sup>), which was 16% higher than the cumulative flux from the poultry litter (p>0.05). This could be due to the difference in dry matter (DM) content between the two treatments, with the poultry litter having a DM content of 70% and layer manure having a DM content of 24%. Lower dry matter content is likely to result in lower losses of N by NH<sub>3</sub> volatilization due to faster infiltration of the organic fertiliser into the soil, resulting in enhanced N availability for production of N<sub>2</sub>O [4]. The difference between

cumulative N<sub>2</sub>O fluxes from the cattle slurry treatments were negligible at 2% (p>0.05), suggesting that in terms of magnitude of N<sub>2</sub>O emissions, the choice of method of application is insignificant.

NH<sub>3</sub> emissions from the autumn treatments are expected to be large from the slurry and layer manure treatments due to their high NH<sub>4</sub><sup>+</sup>-N content resulting in greater potential for NH<sub>3</sub> volatilization [4]. It is likely that NH<sub>3</sub> emissions from the slurry treatments which are incorporated into the soil will be lower than from those which are not incorporated as demonstrated by previous work which found that NH<sub>3</sub> emissions from incorporated slurry treatments were negligible [1]. Comparison of gaseous N losses from the autumn and spring applied treatments is expected to demonstrate higher losses of N from the autumn applications due to generally wetter soil conditions which promote the production of N<sub>2</sub>O and leaching of NO<sub>3</sub><sup>-</sup> and lower uptake of N by the crop in comparison to the spring period when the plants are actively growing and require more nutrients [11].

### Conclusion and perspectives

Our study demonstrates the very large emissions of N<sub>2</sub>O that can be associated with the use of organic manures. Results obtained thus far also demonstrate the importance of when to apply organic fertilisers with regard to the potential for rainfall in the days immediately following application, as shown by the large peak in N<sub>2</sub>O emissions occurring as a consequence of a high rainfall event. The type of organic fertiliser applied is also critical, with lower emissions evident from the FYM treatment which has lower readily available N. However, as mineralisation converts the organic N in this treatment to mineral N, emissions of N<sub>2</sub>O may then increase unless this is taken up by the growing crop. However, the method of fertiliser application, when the surface broadcast and bandspread slurry treatments are compared seems to have little effect on N<sub>2</sub>O emissions. The overall results from this study will be used to highlight the importance of effective management of organic nutrient sources in contributing to improved environmental outcomes from the overall management system.

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