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# Emission factors for ammonia and nitrous oxide emissions following immediate manure incorporation on two contrasting soil types

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## HIGHLIGHTS

- Immediate incorporation of solid manures by plough reduced $NH_3$ emissions by *c.* 90%.
- Immediate incorporation by disc and by tine reduced $NH_3$ emissions by *c.* 60%.
- Immediate incorporation of solid manures does not necessarily increase $N_2O$ emissions.
- The impacts of immediate incorporation on $N_2O$ emissions may be related to soil type.

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## ABSTRACT

We carried out four replicated field experiments to measure the impacts of immediate incorporation of solid manures on emissions of ammonia ($NH_3$) and nitrous oxide ($N_2O$). Four manures: cattle farmyard manure (FYM); pig FYM; layer manure and broiler manure were applied to the soil surface or immediately incorporated by mouldboard plough, disc or tine. Two of the experiments were carried out on a clay soil and two on a sandy soil to find out whether soil type interacted with incorporation technique to influence emissions of $NH_3$ or $N_2O$. Ammonia emissions were measured for 1 or 2 weeks while $N_2O$ emissions were measured for 60 days in one experiment and for a complete year in the other three experiments.

Immediate incorporation by plough reduced $NH_3$ emissions by *c.* 90% and by *c.* 60% by disc and tine ($P < 0.001$). There was no effect of soil type on $NH_3$ abatement efficiency by plough or tine but the disc was less effective on the coarse sandy soil.

Cross-site analysis indicated no effect of incorporation by disc or tine on emissions of $N_2O$–N after 60 days but incorporation by plough increased direct emissions of $N_2O$–N compared with surface application of manure ($P < 0.001$). Direct emissions of $N_2O$–N, at *c.* 0.67% of total N applied, were substantially greater at the coarse-textured site than at the heavy clay site (0.04% of total N applied; $P < 0.001$). The impact of incorporation on total annual direct emissions of $N_2O$–N differed in the three experiments where emissions were measured for a full year. There was no effect of incorporation on $N_2O$–N emissions in the first experiment on the clay soil, and in the second experiment at this site incorporation by plough or disc, but not tine, reduced direct emissions of $N_2O$ ($P = 0.006$). However on the sandy soil direct emissions of $N_2O$–N were increased when manures were incorporated by plough ($P = 0.002$) but not when incorporated by disc or tine.

These results confirm that immediate incorporation of solid manures by plough is the most effective means of reducing $NH_3$ emissions following the application of solid manures. The results also indicate that immediate incorporation of solid manures to reduce $NH_3$ emissions does not necessarily increase emissions of $N_2O$. However, the impacts of immediate incorporation on emissions of $N_2O$ may be related to soil type with a greater possibility of emission increases on coarse sandy soils.

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## 1. Introduction

Following application of livestock manures to land, manure nitrogen (N) may be lost from the soil/plant system in forms that lead

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to pollution. Emissions of ammonia ($NH_3$), when deposited to terrestrial and aquatic ecosystems, increase N eutrophication and soil acidification (Butterbach-Bahl et al., 2011; Dise et al., 2011). Ammonia forms secondary particulates in the atmosphere by reacting with $SO_x$ and $NO_x$ (Renard et al., 2004). There is evidence that particles <2.5 μm diameter ($PM_{2.5}$) have a linear, no-threshold adverse effect on human health (Brunekreef and Holgate, 2002). Ammonium particulates are a major source of $PM_{2.5}$ with agriculture contributing *c.* 80% of the precursor $NH_3$. Although $NH_3$-derived aerosols are only one source of $PM_{2.5}$, Rohr and Wyzga (2012) reported that epidemiological studies have not fully exonerated any major component class of $PM_{2.5}$ mass from having an adverse impact on health. Nitrous oxide ($N_2O$) contributes to global warming (Bouwman, 1990) and to stratospheric ozone depletion (Crutzen, 1981). As well as contributing to global N enrichment and climate change such emissions also represent a loss of crop nutrients (e.g. Webb et al., 2013).

The Gothenburg Protocol to reduce atmospheric pollution (UNECE, 2000) limits national emissions of $NH_3$. To help meet this agreement, the EU has agreed on a National Emissions Ceilings Directive (NECD), under which the U.K. target for $NH_3$ emission is a maximum of $297 \times 10^3$ t $a^{-1}$ $NH_3$ (EC, 2010a). Under the Kyoto protocol on Climate Change, signatories committed themselves to greenhouse gas (GHG) emission reduction targets, including $N_2O$. For example, the UK has set a national target of an overall 80% reduction in GHG emissions by 2050 and the agriculture sector is committed to playing its part in contributing to this goal. The adoption of the Nitrates Directive 91/676 (EEC, 1991) and Water Framework (EC, 2010b) Directives has lead to member states preparing action plans to reduce $NO_3^-$ leaching, including that from livestock manure application.

The rapid incorporation of solid manures into tillage land has been identified as an effective means of reducing $NH_3$ emissions. Published data indicate that rapid incorporation of FYM may reduce $NH_3$ emission by 40%–90%, with the greatest reduction coming from ploughing (Mulder and Huijsmans, 1994; Webb et al., 2010).

Concerns have, however, been expressed that rapid incorporation of manure into soil, in order to reduce $NH_3$ emissions, will increase the pool of mineral N in soil and lead to increased emissions of $N_2O$ (Bouwman, 1996). Few papers have been published which report the impact of solid manure application using $NH_3$ abatement techniques on emissions of $N_2O$ and some of those published were incubation studies and hence extrapolation of their results to field-scale application needs caution. In a review of field studies which measured emissions of both $NH_3$ and $N_2O$ following rapid incorporation of solid manures, Webb et al. (2010) reported that incorporation may reduce emissions of $NH_3$ while not increasing, or even reducing, those of $N_2O$.

The objectives of the work reported here were, first, to make a balanced comparison of the impact of two contrasting soils types on the efficiency of a range of incorporation techniques in reducing $NH_3$ emissions following the application of solid manures. Second, to measure the effects of these incorporation techniques on subsequent emissions of $N_2O$ over the following 12 months. Third, to assess whether there was any interaction between soil type and incorporation method on emissions of $NH_3$ or $N_2O$ or on any trade-offs between emissions of those two gases following immediate incorporation.

## 2. Materials and methods

Between February 2003 and October 2005, 4 experiments were carried out at two sites of contrasting soil type to measure the impact of immediate incorporation of solid manures on emissions of $NH_3$ and $N_2O$. Incorporation began as soon as manure spreading had been completed. We tested four types of solid manure, cattle farmyard manure (FYM), pig FYM, layer manure and broiler litter. The four application treatments were as follows:

1. Manure left on surface.
2. Immediate incorporation by plough.
3. Immediate incorporation by disc.
4. Immediate incorporation by spring tine.

Each incorporation treatment was applied as a single pass, as is the standard practice in the UK to rapidly incorporate manures. When non-inversion tillage is used to incorporate manures it is usual to carry out further cultivation to establish a seedbed. However, this would normally be done some time later, and not have any measurable effect on $NH_3$ emissions. The dimensions of incorporation machinery used are given in Table 1. Manures were applied by hand at rates intended to apply 150 kg $ha^{-1}$ $N^{-1}$ based on standard analysis of livestock manures used in the UK (Webb et al., 2013). Due to the variability in the N content among the manures sourced in the different years of the project the actual amounts of N in the manures applied varied considerably. The amounts of manures applied in t $ha^{-1}$ are given in Table 1.

There was an additional control plot (no manure applied and no incorporation) in each block to provide estimates of background emissions of $N_2O$, giving a total of 17 plots per block. Each of the 17 treatments was replicated four times in a randomised block design with treatments applied to each block in successive weeks in order to allow efficient use of resources, e.g. wind tunnels to measure $NH_3$.

((4 manure types * 4 application treatments) + control) * 4 replicates = 68 plots.

Each plot was $6 \times 10$ $m^2$ with a 3 m race and 15 m gaps between blocks. Samples of manure were taken from each plot and analysed for % dry matter (DM), total-C, total-N and total ammoniacal-N (TAN).

### 2.1. Sites

The two sites were at ADAS Gleadthorpe (GL) in north Nottinghamshire, UK, and ADAS Drayton (DT) in Warwickshire, UK. The soil at GL is a free draining loamy sand of the Cuckney Soil Series, described by Ragg et al. (1984) as slightly stony loamy sand to a depth of *c.* 70 cm with sand below and pH generally >6.5. These soils are mainly under arable rotations often including crops of potatoes and sugarbeet. The soil at GL comprises 77% sand and 6% clay. The soil at DT is of the Evesham Soil Series described (Clayden

**Table 1**
Dimensions of incorporation machinery used in field experiments.

| Implement | Site | |
|---|---|---|
| | Gleadthorpe | Drayton |
| Plough | | |
| Furrow width (mm) | 360 | 350 |
| Number of shares | 4 | 3 |
| Depth of operation (mm) | 230 | 230 |
| Discs[a] | | |
| Disc diameters (mm) | 510 front, 460 rear | 700 |
| Disc spacing (mm) | 200 | 230 |
| Depth of operation (mm) | 120 | 150 |
| Tines | | |
| Type | Spring | Spring |
| Width of points (mm) | 40 | 30 |
| Leg spacing (mm) | 160 | 250 |
| Depth of operation (mm) | 100 | 100 |

[a] Pressing not used in these experiments.

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