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PREDICTING AMMONIA LOSS FOLLOWING THE APPLICATION OF LIVESTOCK MANURE TO LAND

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INTRODUCTION

Applications of livestock manure to agricultural land are a significant source of ammonia (NH_3) emission to the atmosphere, with potentially detrimental impacts to the environment. The most recent estimate of annual NH_3 emission from land applications of manure is 80 kt NH_3-N, accounting for 33 % of the total emission from UK agriculture. A better understanding of the variables affecting both the rate and extent of emission following land application would improve predictions of NH_3 loss in nutrient management models and give indications of application strategies with mitigation potential. The aim of this study was to quantify the effects of selected environmental and management variables on NH_3 emissions from the main types of manure produced by housed livestock, through field experimentation, and to develop a simple predictive model for estimating NH_3 loss following application of manure to both grassland and arable land.

MATERIALS AND METHODS

Ammonia emission measurements
A series of experiments was conducted using a system of small wind tunnels to investigate the influence of a wide range of variables on NH_3 loss. Measurements were made following applications of cattle and pig slurry and cattle farm yard manure (FYM) to grassland and pig slurry, pig FYM and poultry manure to arable land (both to stubble and growing cereal crops). In addition to NH_3 emissions, measurements were also made of manure dry matter (DM) content, total N content, total ammoniacal N (TAN) content and pH, soil moisture content (top 10 cm), soil pH, crop height (and growth stage for cereals), wind speed (at a height of 25 cm), air and soil temperature (at 5 cm height and 5 cm depth, respectively) for each experiment.
Most emphasis was placed on emissions following slurry applications, where variables investigated included temperature, wind speed, rainfall, slurry dry matter (DM) content, slurry pH, application rate, soil type, soil pH, soil moisture content and crop cover. For applications of solid manure, rainfall and temperature were the only variables assessed.

Modelling
For each of the individual wind tunnel observations for every experiment, a Michaelis-Menten type curve was fitted to NH_3 emission rate with time, as described by Sogaard *et al.*, (2001):

$$\overline{N}_{rate}(t, \Delta t) = N_{\max} \frac{K_m}{(t + K_m)(t + \Delta t + K_m)} \quad (1)$$

where N_{rate} is the mean emission rate (kg N ha^{-1} h^{-1}) between times t and t+Δt. For each individual manure application, the parameters N_{max} and K_m were derived using the model fitting procedure in GENSTAT. Data for which there was a poor curve fit ($r^2 < 0.90$) were excluded from further analyses. Data were divided into manure type/land use groups (cattle slurry to grassland, cattle slurry to arable, pig slurry to grassland, *etc*.) and multiple linear regression was then used to relate *Nmax* and *Km* to measured variables, enabling cumulative NH_3 loss to be predicted from Eq. 1. Independent data sets, derived from micrometeorological mass-balance measurements following manure applications to land were used for model validation.

RESULTS AND DISCUSSION

For the solid manure (cattle and pig FYM, poultry manure), of the variables studied, persistent rainfall following application was the most important controlling NH_3 loss. The addition of 3 mm rainfall per day to cattle FYM on grassland resulted in a 20 % reduction in NH_3 emission. However, further work is required to assess the effects of a wider range of variables on emission from solid manure than was included in this study.

For the slurries, the most important variables influencing emission were wind speed and slurry DM content. Rainfall immediately following application reduced emissions from cattle slurry applied to grassland (by approximately 50%) but not from pig slurry applied to cereal stubble. Other variables (crop height, soil moisture content, soil pH) were less important in controlling NH_3 loss.

A linear relationship was established between wind speed and NH_3 loss (as %TAN applied) between wind speeds through the tunnel of 0.5 and 4 m s^{-1}. The slopes of the derived relationships were similar for cattle and pig slurry, with an increase in total NH_3 loss of 15 %TAN and 10 %TAN applied per 1 m s^{-1} increase in wind speed for cattle and pig slurry, respectively. Wind speed has previously been identified as an important controlling variable for NH_3 loss from surface applied slurry (Sommer *et al.*, 1991; Thompson *et al.*, 1990). Sommer *et al.* (1991) reported increasing NH_3 loss with increasing wind speed up to 2.5 m s^{-1} during the first 12 h after application, but no further increase in emission was observed up to wind speeds of 4 m s^{-1}. They proposed that at low wind speeds the volatilisation rate would be small and gas phase resistance to transport within the laminar boundary layer above the soil surface would dominate. At higher wind speeds, resistance to transport within the liquid phase would become the dominant controlling factor. In this study, the relationship was linear, in agreement with that found by Thompson *et al.* (1990).

Slurry DM content had an important influence on NH_3 loss from cattle slurry, but there was less evidence of a significant effect with pig slurry. For applications of cattle slurry to grassland, total NH_3 loss increased with increasing DM content at the rate of 3.9 %TAN applied per 1 % increase in DM content. This is very similar to relationships derived by Sommer and Christensen (1990), Smith and Chambers (1995), and Smith *et al* (2000), with slopes of 5.3, 5.4 and 6.2, respectively. However, these relationships were derived from experiments involving primarily cattle slurries (Smith and Chambers (1995) included 5 data points for pig slurry from a total of 27). The lack of a relationship for pig slurry may be due to the different nature of the solid material in cattle and pig slurries. Cattle slurry typically contains more fibrous material, which increases the viscosity and gives a greater water holding capacity and may impede soil infiltration to a greater extent than the more 'gravelly'-natured solid material in pig slurry. This area warrants further investigation.

Surprisingly, no relationship was found between total NH_3 loss and temperature for the slurry applications. Theory would indicate that, for an ammonium solution, losses increase with temperature as both the dissociation constant (determining the NH_4+/NH_3 ratio in solution) and the Henrys law constant (determining the NH_3 in solution/NH_3 gas ratio) are temperature dependent. However, manure applied to land represents quite a different situation than a vessel containing a pure solution. Crusting of the surface layer of manure at higher temperatures may have reduced emission of NH_3 from beneath the crust. Also, achieving temperature differences by applying manure at different times of year may have resulted in interactions with other variables, such as soil moisture content (and infiltration rate for slurries), relative humidity, solar radiation input and possibly sward density for grassland sites, which were not necessarily the same on all measurement occasions.

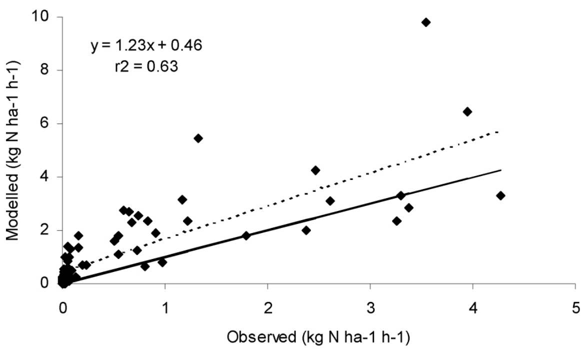
Modelling results

Most validation data are available for cattle slurry applications to grassland, therefore the results of modelling for that data set are presented here. The following expressions were derived for N_{max} and K_m by multiple linear regression analysis:

$$N_{max} = -11.8+13.24(ST)-6.80(SpH)+7.13(WS)+2.98(DM)+0.86(SH)+0.37(TANA)$$
$$K_m = 62.5-3.38(ST)-1.81(SpH)-0.39(T)-0.42(WS)+1.72(DM)-5.78(MpH)+0.25(SH)$$

where ST is soil temperature (°C), SpH is soil pH, WS is wind speed (m s^{-1}), DM is slurry DM content (%), SH is sward height (cm), TANA is TAN applied (kg ha^{-1}), T is air temperature (°C) and MpH is manure pH. This model accounted for 88 % of the variation in the data set for cattle slurry applications to grassland.

Figure 1 Validation of model for NH_3 emission from cattle slurry applications to grassland, showing fitted (dashed) and 1:1 (solid) lines.

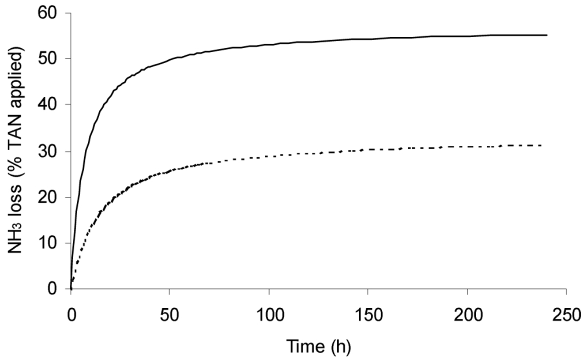


The model overestimated emission rates for the validation data set (Fig 1) to a small extent, and this led to a larger overestimation of cumulative losses over 5 days. Model fit and validation was similar for the pig slurry applied to arable data set. There are several reasons for the over-estimations in emission given by these two models. Firstly, there were differences in the height at which wind speeds were measured. Whilst this was corrected during the validation procedure, the correction was subject to some uncertainty. Secondly, the turbulence of the air drawn through a wind tunnel is quite different from that at the same height in an ambient situation, leading to differences in resistance to NH_3 emission at the manure surface. Thirdly, wind tunnels measure emission from a 2 m long plot of land, which, in effect, might be considered to be the edge of a manure-applied field. Emissions towards the upwind edge of a field will be greater than at points further downwind over the treated area due to the clean air entering the upwind edge offering less resistance to emission. Finally, there may be other variables important in determining emission rate that were not measured in these experiments (such as slurry infiltration rate and crop density). Calibration of the models against the existing validation data may take account of these errors, but further validation data would be needed to test this.

Development of useful predictive tools

The above models require input parameters which would not be readily available to a farmer or consultant and therefore require some simplification. No useful relationships were derived for solid manure within this project, so it is suggested that 'standard' curves, derived from fitting Michaelis-Menten fuctions to the validation data set (*i.e.* observations derived from non-intrusive measurements) are used for the prediction of NH_3 emission following application of cattle and pig FYM and poultry manure (Fig 2). Curves for emissions from cattle and pig slurries would be derived from relationships between N_{max} and the main influencing variables, which, from above, are likely to be wind speed and slurry DM content. As already discussed, the models derived by the procedure above led to overestimation of losses, therefore further calibration/validation work is required to develop more accurate and robust relationships requiring few, simply obtained input parameters.

Figure 2 ' Standard' NH_3 loss curves for FYM (solid line) and poultry manure (dashed line) applied to land



Two management practices which will have a large influence on NH_3 emission, and which therefore need to be included in the model, are slurry application method and timing and method of manure incorporation. For slurry application methods, reduction coefficients could be included in the calculation of the cumulative emission curve. For slurry applications to grassland, coefficients of 0.75, 0.40 and 0.25 for trailing hose, trailing shoe and shallow injection might be applicable (Misselbrook *et al*, in press). For manure incorporation, experimental results (unpublished) show that ploughing effectively stops any further NH_3 emission, whereas incorporation by discing reduces subsequent emission by c. 50%. Inclusion of the time and method of incorporation in the model will therefore allow for calculation of effective reduction in emission following incorporation.

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