MODELLING AMMONIA AND NITROUS OXIDE EMISSIONS FROM SLURRY-AMENDED SOILS – DEVELOPMENT OF AN INFILTRATION SUB-MODEL

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ABSTRACT

Application of manure to agricultural land is an important source of emission of both ammonia (NH_3) and nitrous oxide (N_2O). Much research has been conducted investigating the controlling factors but, to date, few studies have included concurrent measurements of both. However, this is important when considering mitigation strategies because of the phenomena of 'pollution swapping'. A key factor influencing the relative emissions of these two gases is the infiltration of slurry into soil. This paper focuses on the development of an infiltration sub-model as part of a larger model for the prediction of NH_3 and N_2O emissions from slurry-amended soils. A series of laboratory experiments were conducted in which slurry infiltration into soil columns was measured using time domain reflectometry. These data together with measurements of slurry and soil physical characteristics will be used for the parameterisation of the proposed infiltration sub-model.

INTRODUCTION

Land spreading of livestock manure is an important source of NH_3 and N_2O emissions to the atmosphere, both gases of environmental concern and for which there are international pressures to reduce emissions. Rapid infiltration of slurry into the soil after application will reduce the potential for NH_3 emissions (Sommer & Jacobsen, 1999; Thompson *et al.*, 1990) but will increase the potential for N_2O emissions (Chadwick *et al.*, 2000). The development of a mechanistic model describing the emission processes following slurry application to soils will allow for scenario testing and the identification of conditions and practices which may lead to reductions in NH_3 emissions without large increases in N_2O emissions. A key part of such a model is the description of slurry infiltration into the soil. Good characterization of the slurry infiltration process is lacking in existing mechanistic models for NH_3 volatilisation (Genermont & Cellier, 1997; Hutchings *et al.*, 1996). This paper describes a proposed process-based model for slurry infiltration, which will become a component of the larger NH_3/N_2O emissions model, together with data from laboratory studies using time domain reflectometery (TDR) to monitor infiltration into soil columns.

MATERIALS AND METHODS

Theoretical model for slurry infiltration

Infiltration of water through the soil profile (q, cm s^{-1}) can be described using Darcy's law:

$$q = \frac{-K\Delta h}{z}$$

where K (cm s^{-1}) is hydraulic conductivity of the transmission zone, Δh (cm) the difference in pressure head between the entry surface and the wetting front and z (cm) the distance between the surface and the wetting front. For a multi-layer model, the transmission of water from one layer (*i-1*) to the next (*i*) is given by

$$q_{i-1,i} = \frac{-\sqrt{K_{i-1}K_i}\,(h_i - h_{i-1})}{(z_1 - z_{i-1})}$$

Clapp & Hornberger (1978) give an empirical relationship relating the hydraulic conductivity at a given water content (θ, water filled pore space) to the saturated hydraulic conductivity (K_{sat}) for a given soil type. Thus

$$K_i = K_{sat}\theta_i^{(2\beta-3)}$$

with β as an empirical soil water parameter. For applications of slurry to soil, the hydraulic conductivity of the top soil layer rapidly declines. This is due to the combined effects of the increased viscosity of slurry compared with water, clogging of soil pores by slurry dry matter (DM) and water retention at the surface by the slurry DM. Following work by Swartzendruber & Uebler (1982), it is proposed that the hydraulic conductivity of the top soil layer following slurry applications is given by

$$K_1 = K_{sat}e^{Cv}$$

where C is an empirical parameter termed the 'clogging coefficient' and v the cumulative infiltration.

Laboratory experiments

Measurements to determine the resistance to infiltration of slurries were conducted using pressure plate extraction apparatus. Pig and cattle slurries of varying DM contents were placed in the chamber and liquid outflow at a pressure of 1 bar monitored for 16 h. Following theory by Ruth (1946) and work by Jacobsen and Sommer (DIAS, Denmark, pers. comm.), the resistance to liquid flow due to the slurry DM (R_s) was derived from the relationship

$$\frac{dt}{dv} = R_s v + R_m$$

with R_m as the resistance of the supporting media (the ceramic plate). It was hypothesised that the clogging coefficient described above could be derived as a function of the resistance parameter measured in this way.

Additionally, measurements of liquid infiltration following slurry application to soil columns were made using a system of TDR probes inserted horizontally at depths of 0.5, 1.5, 3, 5 and 7 cm. The soil columns were 14 cm diameter and 13 cm deep and repacked with sieved (5 mm) sandy loam soil to a bulk density of approximately 1.2. The soil columns were located on a porous ceramic plate and a constant soil water tension (40 cm) established. TDR probes were 14 cm long and were previously calibrated to give accurate soil moisture content readings specific to the soil type used. 100 ml of slurry was applied to the top of the soil columns, giving an initial depth of 0.6 cm. TDR readings of soil moisture content in each layer were taken every 10 minutes over a 24 h period. Experiments were conducted using pig and cattle slurries at a range of DM contents, with 3 replicate soil columns for each treatment.

RESULTS AND DISCUSSION

The resistance to infiltration, as measured in the pressure plate extraction experiments, increased with increasing slurry DM content (Fig. 1). Although the DM range for pig slurries is limited, the data suggest that different relationships exist for cattle and pig slurries. Fitted relationships were forced through the origin (a zero resistance would be expected for zero DM) and a power curve gave the best fit to the data. The clogging coefficient, *C*, was derived from the resistance for a given slurry type and dry matter simply as R_s x 1000. Figure 2 shows how the modelled conductivity of the top soil layer changes with cumulative infiltration for pig and cattle slurries of different DM contents. For cattle slurries at higher DM contents infiltration is rapidly impeded.

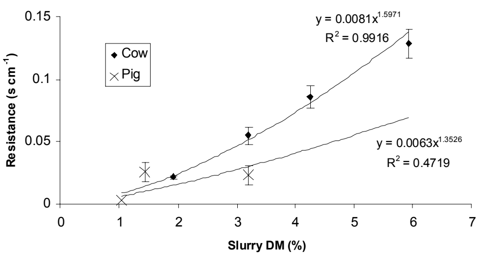

***Figure 1**. Resistance parameter for cattle and pig slurries.*

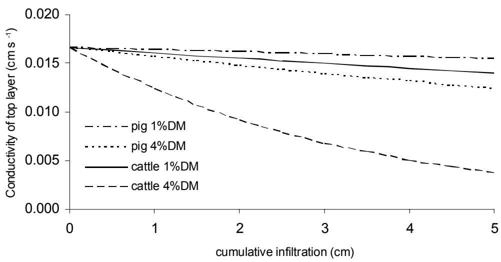

***Figure 2**. Influence of resistance parameter on top layer hydraulic conductivity.*

From TDR measurements the change in water content of each soil layer with time, as the slurry infiltrated, was derived. Figure 3 shows a typical trace for the 24 h measurement, with successive increases in water content in each soil layer as the slurry liquid moved down through the profile, followed by a slower decline. The slurry type and DM content influenced both the magnitude of increase in water content of each layer and the time between increases in water content of successive layers. The 10 min resolution on moisture measurements at each depth proved to be insufficient to fully characterise infiltration of water and very dilute pig slurries, with the initial peaks being missed entirely.

Data from the TDR measurements were used to calculate the volume of slurry infiltrating into the soil within 1 h of application (for a 6 mm application) and this was compared with the model output (Fig. 4). For cattle slurry the model fits the empirical data reasonably well, although the data point for the 5 % DM would appear to be an outlier. For the pig slurry, model output was a very poor prediction of measured values. The data point at 1.5 % DM (labelled A on Fig. 4) is an underestimate of volume infiltrated as a significant volume was missed due to the coarse time resolution of the TDR measurements. It can be assumed that infiltration at this DM content was also approximately 100% within 1h.

Although based on relatively few data, the results presented here do suggest there to be significant differences in the infiltration of pig and cattle slurries, as previously hypothesised by Misselbrook *et al.* (in press), due to differences in the nature of the DM content of the slurry types. Further development and parameterisation of the model presented here requires more empirical measurements (particularly for pig slurry) and more attention should be given to the derivation of the clogging coefficient from the resistance parameter for the slurry types. Slurry DM content is known to be a major factor influencing infiltration, and thereby NH_3 volatilisation (Sommer & Jacobsen, 1999; Thompson *et al.*, 1990). This model provides the mechanism by which slurry DM impedes infiltration i.e. the resistance parameter, which is greater for the more fibrous cattle slurries than for pig slurries. Combining this model with those for NH_3 volatilisation (e.g. Hutchings *et al.*, 1996) and a soil process model for decomposition and denitrification (e.g. Li *et al.*, 1992) will enable better prediction of the relative emissions of NH_3 and N_2O for a range of scenarios.

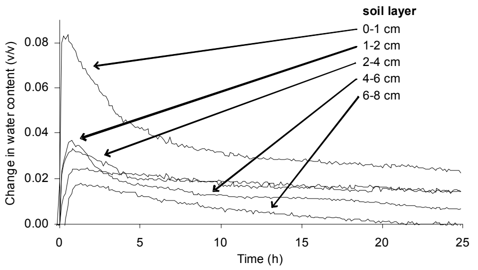

Figure 3. *TDR trace for cattle slurry (4.8 % DM) infiltration into sandy loam soil.*

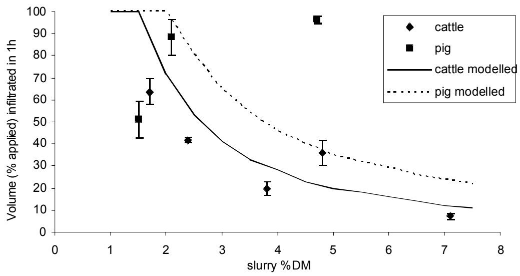

Figure 4. *Modelled and measured cumulative infiltration over 1h for cattle and pig slurries.*

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