



N and C transformations in stored cattle farmyard manure, including direct estimates of N₂ emission

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ABSTRACT

Nitrogen and carbon dynamics during the storage of cattle farmyard manure (FYM) throughout 52 days were evaluated in terms of mass balance, considering solid, liquid and gaseous components. The objectives were: (i) to quantify NH₃, N₂O, CO₂ and CH₄ emissions to supplement existing empirical evidence; (ii) to improve our understanding of the N and C transformations and the main factors that control these processes; and (iii) to provide the first measurement-based estimates of N₂ emissions from stored cattle FYM. Approximately 1.5% of the initial total N was emitted as NH₃ and 1.0% as N₂O. Losses of N₂ via denitrification were estimated to be greater than N losses via NH₃ and N₂O, at 5.2% of initial total N. The main C loss was as CO₂, accounting for ca. 10% of the initial total C content, with CH₄ emissions accounting for <1%. Heap temperature and rainfall strongly influenced gaseous emissions from this type of storage.

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1. Introduction

Significant numbers of cattle and pigs in the UK and across Europe are housed on straw-bedded systems, and such housing systems may be increasing in response to welfare considerations and market demands. These systems result in the generation of large volumes of farmyard manure (FYM), a mixture of the bedding material and animal urine and faeces, which are typically stored in heaps for approximately 2–12 months prior to application to the land. Potential environmental impacts arising from the storage of FYM include the following aspects: diffuse pollution of water via leachate from storage heaps (Dewes et al., 1993); ammonia (NH₃) emissions to the atmosphere (Sommer et al., 2006), with associated risks to sensitive ecosystems (Erisman et al., 2007); and emissions of nitrous oxide (N₂O) and methane (CH₄) to the atmosphere (Chadwick et al., 2011), both potent greenhouse gases with global warming potentials of 297 and 25 times that of carbon dioxide (CO₂), respectively (Forster et al., 2007). Environmental and management factors influence the extent of these losses and also, more importantly, the nutrient content and availability of the FYM subsequently being applied to land. Quantification of the losses and transformations of N and C during FYM storage are therefore important in order to provide robust parameters for national emission

inventories (e.g. Reidy et al., 2009), to enable scenario analyses for management options and to provide recommendations on nutrient content and availability at spreading (e.g. AFM, 2010).

Stored FYM contains organic and inorganic forms of N, with the inorganic being predominantly as NH₄⁺-N, but some NO₃⁻-N may also be present (Chadwick, 2005). The ratio of organic to inorganic N in stored FYM at the beginning of the storage will depend on a number of factors, including the composition of the excreta of the housed livestock (which in turn will be influenced by livestock diet), the nature and amount of bedding material used, and the effect of ammonia and denitrification losses and immobilisation and/or mineralisation processes that occur within the manure whilst in the house. In general, immobilisation processes are assumed to occur during the housing phase (Webb and Misselbrook, 2004; Reidy et al., 2009) while net immobilisation or mineralisation may occur during the storage phase, depending on conditions (Webb et al., 2011; Chadwick, 2005; Thomsen, 2000). Ammonium-N in stored FYM will be subject to losses via volatilisation, the magnitude of which will depend on factors such as heap porosity, moisture content and temperature, typically in the range 2–30% of initial heap total N (Sommer et al., 2006). Emissions of N₂O occur from the processes of nitrification and denitrification, are typically in the range <1–4.3% of the total N content of the stored FYM and will be influenced by factors including heap aerobicity, temperature and C/N ratio (Chadwick et al., 2011).

Emissions of N₂ from FYM storage heaps via denitrification have not been directly measured before, but total N losses through denitrification estimated by mass balance studies, may account for

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between 1 and 30% of the total N content of the FYM (Chadwick, 2005; Petersen et al., 1998; Sommer, 2001). Emissions of N₂ are environmentally benign, but such emissions represent a loss of N from the agricultural system which may require supplementation by inorganic fertilizer N thereby indirectly contributing to the environmental effects associated with fertilizer N use. While total N loss through denitrification is of interest in this respect, so is the ratio of the products of denitrification i.e. N₂O:N₂ and factors which influence this ratio. If some denitrification losses are inevitable, then understanding conditions which may result in a low N₂O:N₂ ratio, and therefore a lower environmental impact, would be of benefit.

Carbon is lost from stored FYM heaps as CO₂ and CH₄ through either aerobic or anaerobic decomposition of the organic material. Previous measurements from stored FYM have shown CH₄ emissions to be in the range 0.5–10% of initial manure C content, being dependant on factors including heap anaerobicity and temperature (Chadwick et al., 2011).

The aims of the current study were (i) to quantify emissions of NH₃, N₂O, CO₂ and CH₄ from stored cattle FYM to supplement existing empirical evidence; (ii) to improve our understanding of the N and C transformations during the storage of cattle FYM and the main factors that control these processes; and (iii) to provide the first measurement-based estimates of N₂ emissions from stored cattle FYM.

2. Materials and methods

2.1. Experimental procedure

Three storage bunkers were constructed at North Wyke, Okehampton (Devon, UK) with concrete bases and concrete block walls to hold FYM from beef cattle (*Bos taurus*). The FYM stores were 3.5 m × 5 m × 1.1 m with a storage capacity of ca. 19 m³. The front wall was constructed from a steel frame and exterior-grade plywood that could be removed at times of filling and emptying. The floor of each bunker sloped to a central drain, from which effluent was collected and the volume measured. Cattle FYM was obtained from beef cattle housing at IGER North Wyke. Cattle were provided with straw bedding at the conventional straw rate of 4 kg head⁻¹ day⁻¹ and were fed with a grass silage based diet plus concentrates. Cattle FYM heaps were established in early July, with around 4 t of manure (fresh weight) put into each of three replicate storage bunkers. Average initial bulk densities of the FYM heaps were calculated as 0.3 and 0.4 t m³. A mass balance of total and inorganic N and C was made through analysis of the manure at the start and end of the storage period.

Representative samples of FYM (ca. 10 kg in total) from each storage bunker were taken as the FYM was placed into them, maintaining the initial replication. A 2 kg subsample from each FYM heap was collected and then used to analyse for total N, C and P, dry matter content and total ammonium N (TAN) using conventional analytical techniques (MAFF, 1986). At the end of the storage period, the FYM was weighed out of each storage bunker and representative samples taken from each heap and the analyses repeated. Temperature sensors were placed in the middle of each FYM heap and average hourly temperature was recorded. Leachates were collected periodically from the individual collection tanks from each manure heap and the total volume measured. Sub-samples were taken for total N, TAN, total P and total C.

2.2. Gaseous measurements from the stores

Measurements of NH₃ emissions were obtained using a movable 'windtunnel style' emission hood, attached to a steel trolley that could be rolled back and forth along a steel runner system across

the top of the 3 bunkers and lowered onto each bunker in turn. The base of the frame supporting the emission hood was fitted with an expanded neoprene seal. The emission hood had a semi-circular cross section with a maximum height of 1.15 m. The volume of the emission hood was 7 m³. An adjustable speed fan was attached to the outlet end of the emission hood, with a maximum air flow of 0.32 m³ s⁻¹. The air flow used in the study (0.13 m³ s⁻¹) resulted in approximately 1 air change per minute (Chadwick, 2005). A 40 cm long honeycomb section on the outside of the fan resulted in laminar airflow to a multipoint cross-sectional air sampler. This allowed hood exhaust air to be sampled from the entire cross section of the fan ducting. A plastic flap was rolled down to within 30 cm of the base of the emission hood at the inlet end and allowed clean air to be drawn through the emission hood by the fan. Air samples from the inlet and outlet of the hood were passed through separate absorption flasks containing 100 ml of orthophosphoric acid (0.02 M) at a rate of 4 l min⁻¹ to trap NH₃. In the air lines, filters were not used prior to the bubblers so, in theory, particulate material could pass through to the acid traps. The NH₄⁺-N content of the acid solution was analysed by automated flow-injection (Searle, 1984). Measurements were made from each heap over a 2-h period on days 0, 1, 2, 3, 4, 7, 8, 9, 10, 11, 15, 17, 22, 25, 32 and 52 after heap establishment. The concentration of NH₃ in the air at the inlet and outlet of the emission hood was calculated according to the following expressions (Chadwick, 2005):

$$C = \frac{X}{V} \quad (1)$$

where C is the concentration in air (g NH₃-N m⁻³), X the NH₃-N collected in the flask (g) and V the volume of air sampled (m³).

Flux at any measurement occasion was then calculated according to:

$$F = \frac{(C_{\text{outlet}} - C_{\text{inlet}})Y}{Mt} \quad (2)$$

where F is the flux (g NH₃-N t⁻¹ FYM h⁻¹), C_{outlet} the concentration in outlet air flow (g m⁻³), C_{inlet} the concentration in inlet air flow (g m⁻³), Y the total air flow through the emission hood (m³), M the initial fresh weight of the FYM heap (tonnes) and t the duration of measurement (h).

Nitrous oxide, CH₄ and CO₂ measurements from the FYM stores were taken on the same days as NH₃ emissions were quantified by taking gas samples from the inlet and outlet of the emission hood at 0, 60 and 120 min. Samples were stored in evacuated 20 ml vials prior to analysis by gas chromatograph (GC) (Hewlett Packard, 5890). Fluxes of these gases were calculated from the mean inlet and mean outlet concentrations of the gases over each 2-h measurement period according to Eq. (2). The system was previously validated by Chadwick (2005). The flow rate with the optimal recovery of gases was chosen for the experimental measurements and a correction factor, derived from the calibration, was applied to the measured fluxes from the FYM heaps.

2.3. Potential production of nitrous oxide and dinitrogen

FYM samples from the heaps were taken to establish the potential production of gaseous N₂O-N and N₂-N. Kilner jars (1 l) were used to quantify potential N₂ emissions using the acetylene inhibition technique (Müller et al., 1998). About 500 g of FYM (fresh weight) were taken on days 0, 2, 4, 7, 9, 11, 15, 17, 22, 24, 31 and 51 from three different areas of the heap, associated with different zones of aerobicity: the surface 0–25 cm depth (which we assumed to be aerobic); the middle zone of the heap, approximately 25–60 cm below the surface (which we classified as facultative aerobic); and the bottom of the heap (which we classified as predominantly an anaerobic zone). On each sampling occasion, one

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