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The different effects of applying fresh, composted or charred manure on soil N_2O emissions

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ABSTRACT

New manure management strategies and technologies are currently being developed in order to reduce manure volume and odorous emissions, utilise energy potential and produce improved manure-derived fertilisers. This has accentuated the need to determine their effects on greenhouse gas emissions after soil application. A laboratory study was conducted over a period of 100 days to investigate the N_2O emissions from arable soil amended with different manure-derived fertilisers: fresh, composted and charred solid fraction of pig manure. The importance of several factors (fertiliser type, soil water potential, homogeneous or heterogeneous distribution of amendments in soil) was evaluated in this study. The mitigation potential of the combined application of charred manure with other amendments was also investigated. The application of fresh or composted manure solids was observed to have much higher N_2O emissions than that of charred manure solids, which contained low available C and N contents. Contrary to expectations, the immature compost with a high content of dissolved organic carbon did not have lower N_2O emissions than fresh manure solids. The homogeneous distribution of compost led to higher N_2O and CO_2 emissions than heterogeneous distribution. However, the effect of different distribution modes was not significant in treatments with charred manure, since N turnover in the immature compost was much more active than that in the charred manure. By combining charred manure with composted manure, N_2O emissions were significantly reduced by 41% at pF 2.0, but the mitigation effect of charred manure was not observed at lower soil water potentials.

1. Introduction

Animal slurry separation is an effective technique that enables improved slurry management and export of surplus nutrients in the form of a concentrated solid fraction to areas where the nutrients are needed (Burton, 2007; Hjorth et al., 2010). The solid fraction from separation can be used in different ways, *e.g.* applied as an organic fertiliser for cropland either directly or in a composted form (Nolan et al., 2011). Manure solids can also be used as feedstock for energy production, either in biogas digesters (Møller et al., 2007) or in incineration plants (Thygesen and Johnsen, 2012). Biochar produced by pyrolysis from pig manure solids is rich in nutrients, including nitrogen (N), phosphorus (P), calcium (Ca), magnesium (Mg) and potassium (K), and it has been suggested for use as a soil amendment (Tsai et al., 2012). The products from these kinds of treatments of the solid fraction affect the soil's biological activities (*e.g.* respiration rate and N turnover) differently, and are also expected to result in different emissions of greenhouse gases (GHG), especially nitrous oxide (N_2O), after soil application (Yoo and Kang, 2012). Previous studies (Amon et al., 2006; Fangueiro et al., 2008) have shown that manure composting or mechanical separation reduces N_2O, methane (CH_4) and carbon dioxide (CO_2) emissions after application to soil. However, information in this area is still limited. As far as it is known, the effect of combined manure treatment – separation followed by composting or pyrolysis – on gaseous emissions and N dynamics after soil application has not yet been studied.

When applied under natural conditions, manure will always, to some extent, be heterogeneously distributed in the soil. This may affect C and N turnover processes as well as emissions of GHG (Wulf et al., 2002). With heterogeneous distribution, oxygen depletion due to the mineralisation of organic matter in the manure can effectively create micro-sites of high denitrification activity (Parkin, 1987). In laboratory studies, Magid et al. (2006) observed that the heterogeneous distribution of organic manure may significantly affect organic matter decomposition and nutrient dynamics. In a field study, lower N_2O emissions were observed after surface

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application of manure than after direct injection (Thomsen et al., 2010). Consequently, it is important to understand the effects that the distribution of manure has on GHG emissions.

Soil water content controls soil oxygen concentration and for this reason greatly influences nitrification, denitrification and soil respiration (Grundmann et al., 1995). Drier soils, although highly conductive to gasses, could inhibit decomposition of organic matter due to lowered solute diffusion and water stress. Whereas moist conditions reduce gas diffusion in soil, higher water content also favours biological activity (Stark and Firestone, 1995; Manzoni et al., 2011). Impaired aeration in moist soils reduces O_2 availability and promotes the development of partially anaerobic conditions, which, coupled with low redox potential, are ideal conditions for N_2O production (Ciarlo et al., 2007). Therefore, interactions between soil water content and organic soil amendments will have a profound influence on N_2O emissions.

The aims of this study were: (i) to investigate N_2O emissions from arable soil that received different products derived from the solid fraction of manure, (ii) to evaluate the effects of the spatial distribution of products in the soil on N_2O emissions, and (iii) to study the effect of interactions between biochar and other manure amendments on N_2O emissions, all under the influence of different water potentials.

2. Materials and methods

2.1. The soil and organic amendments

The soil used in this experiment was collected at University of Copenhagen's experimental farm, Taastrup, Denmark (55° 40′ N, 12° 17′ E). The soil type is sandy clay loam (clay 15%, silt 18%, sand 65%) with 1.15% C, 0.13% total N, C/N of 9, soil pH (0.01 M $CaCl_2$) of 5.6 and CEC of 8.4 cmol kg^{-1} at pH 7. The top soil (0–0.1 m depth) was collected in March 2011 and while fresh, was passed through an 8-mm sieve in April 2011, covered by plastic and stored at ambient temperature in the farm's barn. Subsequently, the soil was mixed thoroughly and stored at room temperature (23 ± 3 °C) for two weeks prior to the start of the experiment in June 2011.

Fresh, composted and charred solid fractions of pig manure were used as soil organic amendments. Manure solids were produced from pig slurry which had been chemically pre-treated (flocculation with polyacrylamide), and then separated by a belt and screw press (mobile separator, Kemira Water A/S, Denmark). The pig slurry was obtained from a sow farm in Toftlund, Denmark. Composted manure solids were the product of a 30-day actively aerated composting process (temperature reaching approximately 60 °C during the first 5–7 days) on the freshly separated manure solids without the addition of any bulking agents (Chowdhury et al., 2013). The compost was freshly composted and must be considered as an immature product given its short composting period. Charred manure solids (referred to as biochar below) were produced by the slow pyrolysis of air-dried manure solids at a peak temperature of 550 °C for three hours at laboratory scale. The manure solids were tightly wrapped in aluminium foil, which allowed pyrolysis gases to escape but ensured a very limited oxygen supply during the pyrolysis process. The properties of the organic soil amendments are given in Table 1.

Table 1
Properties of manure solids, compost and biochar (dry matter is referred to as DM).

Amendments	Manure solids	Compost	Biochar
Dry matter (wt/wt %)	21.48	23.12	100.00
Ash (% of DM)	22.10	26.70	56.60
Total C (g kg^{-1} DM)	400.40	360.70	522.60
Total N (g kg^{-1} DM)	21.96	30.10	15.48
NH_4^+–N (g kg^{-1} DM)	1.36	0.89	<0.01
NO_3^-–N (g kg^{-1} DM)	0.06	0.04	<0.01
C:N ratio	18.20	12.00	33.76
Total P (g kg^{-1} DM)	28.57	34.59	71.12

2.2. Incubation under controlled conditions

There were eight treatments of different organic soil amendments with three replicates for each (Table 2). All treatments were applied at an equivalent phosphorus (P) rate (56 mg P kg^{-1} soil, equivalent to 100 kg P ha^{-1} assuming a 12 cm soil incorporation layer), since the P load will usually be the limiting factor for the sound agronomic practice of applying manure solids to arable land. In the combined treatments, 50% of the applied P was contained in the biochar and the other 50% of P was in the fresh manure solids or compost respectively. Therefore, different rates of carbon (C) and nitrogen (N) were supplied from the soil amendments. The total C supplied to the soil was 7.9, 5.9 and 3.1 g kg^{-1} soil for manure solids, compost and biochar respectively. Total N was 0.43, 0.49 and 0.16 g kg^{-1} soil for manure solids, compost and biochar respectively. In all these treatments, ammonium nitrate (NH_4NO_3) solution was applied superficially at the rate of 56 mg N kg^{-1} soil (equivalent to 100 kg N ha^{-1}) to simulate N fertiliser application and ensure a more or less equal initial level of available inorganic N in all treatments.

Water retention curves for the soil with different amendments were determined using sand suction tables (Smith and Mullins, 2000). No significant differences regarding water retention were observed between different treatments. High N_2O emissions have been reported from soils at water potentials between pF 0.7 and pF 1.7 (van der Weerden et al., 2012). Therefore, three levels of soil water potential were selected in this study: pF 1.0 (−1 kPa) and pF 1.7 (−5 kPa), and in addition pF 2.0 (−10 kPa) to include conditions at field capacity. The corresponding gravimetric water contents were 30.0%, 27.4% and 24.2% respectively, equivalent to water filled pore space of 98%, 91% and 80% respectively.

Moist, sieved (<8 mm) soil corresponding to a dry weight of 100 g was added to incubation cups (polypropylene containers, 120 mL capacity) and compacted to 67 mL, corresponding to a dry bulk density of 1.5 g cm^{-3}. To ensure a well-mixed distribution, organic solid amendments were mixed thoroughly with the soil before compacting. Treatments with layered distribution were made by compacting half of the soil, placing the organic solids in a layer, and compacting the remaining half of the soil on top (placing the organic amendment in the middle of the incubation cup, with 1.7 cm of soil below and above). After adding different soil amendments, the soil samples were adjusted to the designated water contents by adding deionised water and incubated for 100 days in the dark at 20 °C. All cups were covered by a moist cloth to reduce water evaporation loss, but facilitating air exchange during

Table 2
Treatments with different organic soil amendments.

Abbreviation	Amendments	Amendment distribution	Application rates (dry matter, g kg^{-1} soil)
CON	None (control)	No amendments	None
SOL	Manure solids	Layer	2.0
COM	Compost	Layer	1.6
COM_{mix}	Compost	Well-mixed	1.6
BC	Biochar	Layer	0.8
BC_{mix}	Biochar	Well-mixed	0.8
BC + SOL	Biochar and manure solids	Layer	0.4 (BC) and 1.0 (SOL)
BC + COM	Biochar and compost	Layer	0.4 (BC) and 0.8 (COM)