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Pig slurry treatment modifies slurry composition, N_2O, and CO_2 emissions after soil incorporation

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ABSTRACT

The treatment of manures may improve their agricultural value and environmental quality, for instance with regards to greenhouse gases mitigation and enhancement of carbon (C) sequestration. The present study verified whether different pig slurry treatments (i.e. solid/liquid separation and anaerobic digestion) changed slurry composition. The effect of the slurry composition on N_2O and CO_2 emissions, denitrification and soil mineral nitrogen (N), after soil incorporation, was also examined during a 58-day mesocosm study. The treatments included a non-treated pig slurry (NT), the solid fraction (SF), and the liquid fraction (LF) of a pig slurry and the anaerobically digested liquid fraction (DG). Finally, a non-fertilized (N0) and a treatment with urea (UR) were also present.

The N_2O emissions measured represented 4.8%, 2.6%, 1.8%, 1.0% and 0.9% of N supplied with slurry/fertilizer for NT, LF, DG, SF and UR, respectively. Cumulative CO_2 emissions ranged from 0.40 g CO_2-C kg^{-1} soil (0.38 Mg CO_2-C ha^{-1}) to 0.80 g CO_2-C kg^{-1} soil (0.75 Mg CO_2-C ha^{-1}). They were highest for SF (56% of C applied), followed by NT (189% of C applied), LF (337% of C applied) and DG (321% of C applied). Ammonium was detected in the soil for all treatments only at day one, while nitrate concentration increased linearly from day 15 to day 58, at a rate independent of the type of slurry/fertilizer applied. The nitrate recovery at day 58 was 39% of the N applied for NT, 19% for SF, 52% for LF, 67% for DG, and 41% for UR. The solid fraction generally produced higher potential denitrification fluxes (75.3 for SF, 56.7 for NT, 53.6 for LF, 47.7 for DG and 39.7 mg $N_2O + N_2$-N kg^{-1} soil for UR). The high variability of actual denitrification results obfuscated any treatment effect.

We conclude that treatment strongly affects slurry composition (mainly its C, fibre and NH_4^+ content), and hence N_2O and CO_2 emission patterns as well as denitrification processes and nitrate availability. In particular, the solid fraction obtained after mechanical separation produced the most pronounced difference, while the liquid fraction and the anaerobically digested liquid fraction did not show significant difference with respect to the original slurry for any of the measured parameters. Combining data from the different fractions we showed that separation of slurry leads to reduced N_2O emissions, irrespective of whether the liquid fraction is digested or not. Furthermore, our results suggested that the default emission factor for N_2O emissions inventory is too low for both the non-treated pig slurry and its liquid fraction (digested or not), and too high for the separated solid fraction and urea.

1. Introduction

Intensification of animal husbandry results in an increasing production of manure that needs to be efficiently recycled. It is acknowledged that recovering nutrients is essential to prevent environment degradation. Excessive application of animal manure may lead to water pollution via runoff and nutrients leaching, to soil contamination by heavy metals and pathogens, and to gaseous emissions of odours, ammonia (NH_3), methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) (Dendooven et al., 1998; Edeogu et al., 2001; Mattila and Joki-Tokola, 2003; Dambreville et al., 2006; Sleutel et al., 2006).

The agricultural contribution to total greenhouse gas emissions is about 10%, with livestock playing a crucial role both through methane emission from enteric fermentation and through manure production (European Environment Agency, 2005). Manure emits CH_4 and CO_2 during storage, depending on aeration conditions, and

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contributes to N_2O and CO_2 emissions after soil application. The introduction of appropriate manure management techniques represents one opportunity for greenhouse gases mitigation and carbon (C) sequestration promotion (Duchateau and Vidal, 2003). Pig slurry from intensive livestock systems is generally inefficiently recycled and can potentially lead to atmosphere pollution, both during storage and after field spreading (Sherlock et al., 2002; Hansen et al., 2006). This pollution can be reduced by pig diet management to alter slurry composition (Misselbrook et al., 1998; Velthof et al., 2005) and by slurry processing techniques.

Several methods of slurry processing have been developed with various purposes, including ease in handling, energy production or soil amelioration. Among these methods, mechanical separation of slurry produces a large liquid fraction, and a minor solid fraction, that may be used as a soil amendment or for composting. This separation allows farmers to more efficiently transport the solid fraction (containing most of the nutrients) off-farm or to fields far from the farmstead, and thereby respecting the nitrogen (N) supply threshold set by the Nitrates Directive. Moreover, handling, transport, field spreading and soil infiltration of the liquid fraction are improved. Another treatment method is the anaerobic digestion of slurry that promotes anoxic processes and methane production, which can be used for electricity and heat production. The end-product of digestion is high in N, low in dry matter, very homogeneous and fast infiltrating, so as to reduce odours (Sommer et al., 2000; Hansen et al., 2006; Monteny et al., 2006). Although digestion of the non-treated slurry is the most common practice in Europe since it produces a high amount of biogas, in Italy the preliminary solid/liquid separation followed by digestion of the liquid fraction is a rather common technique (Piccinini, 2004). Although this method cuts the biogas yield by 30%, it presents the advantages of reducing the retention time and the digester capital cost (Wase and Thayanithy, 1994).

The effect of these processing techniques on gaseous emissions during slurry storage have been investigated (Sommer et al., 2000; Hansen et al., 2006; Balsari et al., 2007), so as their effect on ammonia volatilisation during and after field spreading, but there is little information about greenhouse gases emissions and N dynamics following soil incorporation.

The liquid fraction and the end-product of the digestion are more likely to loose ammonia than untreated slurry during storage (Sommer and Husted, 1995) and from soil surface application (Bernal and Kirchmann, 1992; Hansen et al., 2006; Sommer et al., 2006), due to their higher pH and NH_4^+ content. The anaerobically digested slurry produces more N_2O than the untreated slurry during storage (Sommer et al., 2000) while CH_4 production is more pronounced from the storage of solid fraction and less from the liquid fraction or from the digested slurry (Husted, 1994; Martinez et al., 2003).

In this study, we assessed N_2O and CO_2 emissions, denitrification, and soil mineral N content in a soil amended with a non-treated pig slurry (NT), and from pig slurries obtained after solid fraction (SF)/liquid fraction (LF) separation, and anaerobic digestion of the liquid fraction for biogas production (DG), during a 58-day mesocosm study under controlled conditions. We tested the hypotheses that: (i) treatment of slurry changes N_2O and CO_2 emission patterns as well as net N mineral availability; (ii) these differences are related to the different chemical composition after treatment.

2. Materials and methods

2.1. Experimental set-up

We assessed the effect of different processing methods on pig slurry composition and we quantified N_2O and CO_2 emissions, N release, and denitrification activity following the application of different treated slurries to the soil, in a mesocosm study. The treatments included in the experiment are: a non-treated pig slurry, the solid and the liquid fraction obtained from the separation of the original non-treated slurry, and the anaerobically digested liquid fraction. A non-fertilized soil (N0) and a soil receiving urea (UR) were also present, for a total of six treatments. The experiment was set up as a randomised block design. The number of replicates was nine for the gas measurements. Twenty-four extra replicates were present for the destructive analyses (mineral N, pH and denitrification), which were performed at eight different dates across the incubation period for three replicates. The total number of mesocosms at the start of the experiment was therefore 198, disposed in three different blocks, corresponding to as many different vertical levels in the climate room.

The soil used in the experiment comes from a field cropped with silage maize and fertilized with urea since 1992 and is classified as Typic Udifluvent (Grignani et al., 2007). The texture of the tilled horizon (0–40 cm) is loam, with a dry bulk density of 1.43 g cm^{-3}, alkaline pH (7.9), 11.6 g kg^{-1} of total C and 1.7 g kg^{-1} of total N. The exchangeable K is low (0.22 meq) while the Olsen P is high (29.4 mg kg^{-1}). The soil was collected in autumn 2006, air dried at 20 °C for 10 days, then sieved at 5 mm.

The slurries chosen for this study originated from gestating sow housing on a pig livestock farm. The solid/liquid mechanical separation was performed in a screw press plant on the farm. The liquid fraction was then anaerobically digested in a laboratory batch reactor at 38 °C. The digestion was achieved in approximately 3 weeks and we included in our experiment the end product resulting from the digestion. Different slurries were analysed for dry matter content, N Kjeldhal, ammonium (NH_4^+) by distillation, organic matter (OM) using the Spingler–Klee method, ash and fibre fractions (Robertson and Van Soest, 1981). Based on the dry matter content of the original slurry, and of the solid and liquid fractions, it was then possible to estimate the quantitative proportion of the two fractions following separation.

All the mesocosms (2.5 l cylindrical glass jars) were filled with 2 kg of dry soil homogeneously mixed with 486 g of demineralized water resulting in a soil water retention of −33 kPa (Grignani et al., 2007), conventionally considered as field capacity condition (Janik et al., 2007). The soil was then brought back to field density (1.43 g cm^{-3}) at which the soil moisture equalled approximately 63% WFPS and the headspace volume equalled 1.14 l. The mesocosms were then pre-incubated until the initial CO_2 flux, due to soil rewetting, had subsided (14 d). Subsequently, the soil from each mesocosm was homogeneously mixed with the amount of slurry (or urea) appropriate to each treatment. The amount of fertilizer was calculated so as to supply 0.079 g N kg^{-1} dry soil, corresponding to 170 kg N ha^{-1} incorporated at 15 cm depth, to simulate common farm practices. The amount of C supplied to the soil with the different slurries was 0.106 g kg^{-1} soil for NT, 0.862 g kg^{-1} soil for SF, 0.067 g kg^{-1} soil for LF and 0.057 g kg^{-1} soil for DG, corresponding to 0.48, 0.82, 0.06 and 0.05 Mg C ha^{-1}, respectively.

Mesocosms were protected laterally and on the upper side by a woven black polyethylene cover, to allow gaseous exchange with the outside air, to retard evaporation, and to prevent exposure to light. The mesocosms were maintained inside a climatic room, with a constant temperature (25 °C) and air humidity (about 55%). The soil moisture content in the mesocosms was kept constant for 58 days, gravimetrically adjusted every 2–3 d for each individual mesocosm, at least 12 h before a gas measurement. The average evaporation from the mesocosms was 12 g kg^{-1} soil d^{-1}.

At the end of the 58-day incubation period, we stopped adjusting the soil moisture for 14 d, reaching a soil water retention value of approximately −1500 kPa (permanent wilting point) which corresponds to about 20% WFPS. After that, at day 72, we