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Gaseous emissions and nutrient dynamics during composting of swine solid fraction for pellet production

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Abstract

In this study, swine solid fraction was composted with the objective to obtain a composted manure with a moisture content between 20 and 40% - suitable to pelletize. Three identical SF windrows of approximately 4 m³ and 1800 kg were set up outside, on a concrete pad in an open-sided, roofed facility, and composted for a period of 72 days. An evaluation of the composting process and of the final product was made by monitoring process temperature, ammonia (NH₃) and GHG (carbon dioxide, CO₂; methane, CH₄; nitrous oxide, N₂O) emissions, moisture content, pH, volatile solids (VS), total organic carbon (TOC), total nitrogen (TN) and total ammoniacal nitrogen (TAN). In accordance with the results of the investigation it can be concluded that the composting of swine solid fraction in windrows could be a valuable process to concentrate the nutrients in manure and make it suitable to pelletize. However, appreciable amounts of CO₂, CH₄, N₂O and NH₃ emissions were detected. Total emission of the investigated gases recorded during the experimental period were 273 gCO₂ kgVS⁻¹, 3.50 gCH₄ kgVS⁻¹, 19.3 gN₂O kgTN⁻¹ and 87.4 gNH₃ kgTN⁻¹, respectively. These data can be used to carry out detailed life cycle assessments of GHG emissions from the Italian swine farming.

Keywords: ammonia, GHG, manure treatment, pelletization.

1 Introduction

According to estimates [Colonna and Alfano, 2010], pig farms in Italy produce approximately 17 million tons per year of liquid (slurry) manure. Slurry storage followed by land application is the predominate manure management practice due to its simplicity and low cost. However this practice could cause serious environmental problems [Rao et al., 2007] such as nitrate water pollution both in surface and in ground waters, especially in areas classified as vulnerable zones to nitrate in accordance with European Regulation (91/676/CEE).

Several techniques have been developed to manage livestock slurries as cheaply and conveniently as possible and to reduce potential risks of environmental pollution. Among these techniques, solid-liquid separation of slurry is a common practice in Italy. The liquid fraction (LF) is generally used in land applications in areas near the farm, while the solid fraction (SF) is exported to outside farmland areas.

However the low bulk density – less than 500 kg m⁻³ [Pampuro et al., 2012] makes costly to transport SF from production sites to areas where it could be effectively utilized for value-added

applications such as in soil fertilization. One possible solution to this problem is pelletization of SF [Pampuro et al., 2013]. Pelletization has been shown to increase the biomass bulk density from an initial bulk density of 40-200 kg m⁻³ to a final one more than 800 kg m⁻³ [McMullen et al., 2005]. Thus, pelletization of solid manure could reduce the costs for their transportation, handling and storage [Kaliyan and Vance Morey, 2009].

However the high moisture content (75-80%) of fresh SF makes it not suitable for pelletization. According to Alemi et al. [2010] the optimal moisture content of SF to be used for pelletization vary between 20% and 40%. One simple and cheap method to reduce the moisture content of SF is composting, a self-heating, aerobic degradation process of the organic matter. However the emission of harmful gases from composting of livestock manure has been the cause of serious environmental problems such as complaints from residents around farms about odor and destruction of the natural ecosystem by ammonia (NH₃) and greenhouse gases (GHG) namely methane (CH₄), carbon dioxide (CO₂) and nitrous oxide (N₂O) [Fukumoto et al., 2003; Dinuccio et al., 2008]. Some studies investigated gaseous emissions and nutrient dynamics during storage of pig solid manure heaps [e.g., Hassouna et al., 2008; Petersen and Sørensen, 2008]. However, to our knowledge, NH₃ and GHG (CO₂, CH₄, N₂O) losses during composting of swine slurry SF for pellet production have had limited investigation. In this study, swine solid fraction was composted in windrows, with the objective to obtain a composted SF with a moisture content between 20 and 40% - suitable to pelletize. The effect of composting process on i) manure characteristics and ii) NH₃ and GHG emissions was investigated.

2 Materials and methods

2.1 Composting experiment

The trial was carried out in summer season at the experimental station of the Institute for Agricultural and Earth Moving Machines (IMAMOTER) – Italian National Research Council (CNR) - of Turin (northern Italy).

The solid fraction (SF) used for the study was obtained by mechanical solid-liquid separation of fresh swine slurry from a fattening swine farm. Slurry separation was performed using a screw press separator (Chior, mod. COM300/600). Three identical SF windrows of approximately 4 m³ and 1800 kg were set up outside, on a concrete pad in an open-sided, roofed facility, and composted for a period of 72 days. Each windrow was trapezoidal in shape, about 6 m in base-width and 1 m in height. During the experimental period the windrows were turned six times: at days 7, 16, 28, 35, 50 and 57. The environmental temperature and temperatures inside the heaps at a depth of 0.2 m (T1) and 0.6 m (T2) were continuously recorded using thermocouple sensors (Type K) connected to a multichannel acquisition system (Grant, mod. SQ 1600).

2.2 Physicochemical parameters

Representative samples of the tested manure were taken from each windrow at day 0 (beginning of the trial), 7, 16, 28, 35, 50, 57 and 72 (end of the trial). All collected samples were analyzed for moisture content, pH, volatile solids (VS), total organic carbon (TOC), total nitrogen (TN) and total ammoniacal nitrogen (TAN) according to procedures described by Heiermann et al. [2009] and Plochl et al. [2009].

2.3 Gas sampling and analysis

During the experimental period, CO₂, CH₄, N₂O and NH₃ emissions were measured simultaneously, from each investigated SF windrow, at least two times a week. Emissions of CO₂, CH₄ and N₂O were measured using static closed chamber technique [Livingston and Hutchinson, 1995]. At each sampling time, three polyvinyl chloride chambers (volume 0.021 m³, surface area 0.138 m²) were evenly placed over surface of each investigated windrow. Thirty mL of air was drawn with a plastic syringe from the chamber headspace at 0, 10, and 20 min after chamber placement. All samples were stored in airtight glass vials and analyzed for CO₂, CH₄ and N₂O within 24 h by gas chromatography (Agilent 7890). NH₃ emissions were measured by wind tunnels and the flux measurement procedure described by Dinuccio et al. [2012]. In correspondence of the turning operations, gas [CO₂, CH₄, N₂O and NH₃] emissions rates were evaluated two times: before turning and immediately after turning.

3 Results and discussion

3.1 Temperature development

The environmental temperature and the temperature profile in the three SF windrows as a function of time is shown in Figure 1. The average recorded environmental temperature was 23.5°C (range 18.8°C – 27.8°C).

The average temperature of SF windrows rapidly increased to approximately 65°C during the first 7 days from their establishment. These high temperatures were maintained during 40 days (Fig. 1) and then slightly decreased to 40°C, indicating the end of the thermophilic phase [Bernal et al., 2009]. The temperatures increases observed after each turning operation (Fig. 1) were due to the increased levels of oxygen that stimulate microbial activity [Getahun et al., 2012]. During maturation, the temperatures gradually decreased to final values close to ambient air (about 25°C) after 62 days of composting.

<<Figure 1, Here>>

3.2 Physicochemical properties of composted SF

Table 1 shows the characteristics of SF during the composting process. As a consequence of the production of heat during the process, the moisture content of the SF decreased from 73.4 g kg⁻¹ at the beginning of composting to a value of 34.6 g kg⁻¹ found 72 days after composting was initiated. Likewise, TOC content gradually decreased over time due to degradation of organic material [Getahun et al., 2012]. Relative to the fresh SF (day 0), the concentration of TN in the composted manure at the end of the trial (day 72), was 3.61 times higher, while in contrast the TAN content was as much as 18 times lower. Specifically, the concentration of TAN at the end of the process reached a value below 400 mg kg⁻¹ of dry matter (Tab. 1), a fact that indicates that the material has stabilized sufficiently [Zucconi and De Bertoldi, 1987].

The pH of SF was generally alkaline (range 7.51–7.96) during composting, because of the accumulation of hydroxyl groups resulting from proteolysis and ammonification [Cáceres et al., 2006]. Mass balance calculations indicated that through the composting process around 1100 liters of water evaporated from each windrow. A total mass reduction of 70 percent was observed.

<<Table 1, Here>>

3.3 Gas emissions

In agreement with other published data [e.g., Sommer and Moller, 2000; Dinuccio et al., 2012], the emissions of CO₂, CH₄, N₂O and NH₃ took place primarily during the thermophilic phase (Fig. 2), when bacterial activity reached its maximum.

<<Figure 2, Here>>

As can be seen in Figure 2A, NH₃ emissions peaked at the beginning of the trial and then decreased sharply to a negligible value at day 5. After the first turning operation, NH₃ emissions began to increase again and persisted for around 4 days (Fig. 2A). After this time, with the exhaustion of easily degradable materials, the degradation rate decreased and consequently the NH₃ emission declined [Jiang et al., 2013]. The cumulative N losses as NH₃ (Tab. 2) recorded over the experimental period were on average about 25% higher than the overall losses (6.5-7.3%) from the initial TN content recorded by Hassouna et al. [2008] during uncovered storage of turned swine solid manure heaps. The highest NH₃ losses observed in this study might be explained by the greater TAN content (Tab. 1) of fresh SF and greater surface area-to-volume ratio (3.6) of the windrows, both of which may increase NH₃ emissions [Bernal et al. 2009].

<<Table 2, Here>>

The production of N₂O (Fig. 2B) indicated that during composting, incomplete nitrification/denitrification processes - that normally convert NH₄ into N₂, a non-polluting gas - occurred. Turning the material produced a significant effect on N₂O emission, because NO₂⁻/NO₃⁻ produced in O₂ sufficient region was transferred to O₂ deficient region, thereby promoting N₂O production by denitrification process [Fukumoto et al., 2003 and Yang et al., 2013]. Cumulative losses of initial total N content as N₂O were close to 2% (Tab. 2), up to 40% lower than those (3.2-2.5% of initial N content in manure) reported in the study of Hassouna et al. [2008]. As expected, the CH₄ emission rate decreased immediately after turning operations as a result of the adequate aeration of the pile (Fig. 2C). However, in the interval between turnings, the intense aerobic activity determined a decrease of oxygen concentration that promoted anaerobic conditions and hence the production of methane [Chiumenti et al., 2007]. The CO₂ emissions were also influenced by turning (Fig. 2C). The average daily CO₂ emissions reached a maximum value of 13.2 g m⁻² h at the 11th day. After 20 days from the beginning of the test the production of CO₂ decreased sharply due to the lower availability of easily fermentable organic matter [Chiumenti et

al., 2007]. Total CO₂ and CH₄ emissions represented, respectively, a loss of 27.3% and 0.35% of the initial VS content of the manure (Tab. 2), values that agreed well with those reported by Hansen et al. [2006] from storage of uncovered swine SF piles.

4 Conclusions

In accordance with the results of the investigation it can be concluded that the composting of swine solid fraction in windrows could be a valuable process to concentrate the nutrients in manure and make it suitable to pelletize. However, appreciable amounts of CO₂, CH₄, N₂O and NH₃ emissions were detected. Total emission of the investigated gases recorded during the experimental period were 273 gCO₂ kgVS⁻¹, 3.50 gCH₄ kgVS⁻¹, 19.3 gN₂O kgTN⁻¹ and 87.4 gNH₃ kgTN⁻¹, respectively. These data can be used to carry out detailed life cycle assessments of GHG emissions from the Italian swine sector.

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FIGURES AND TABLES

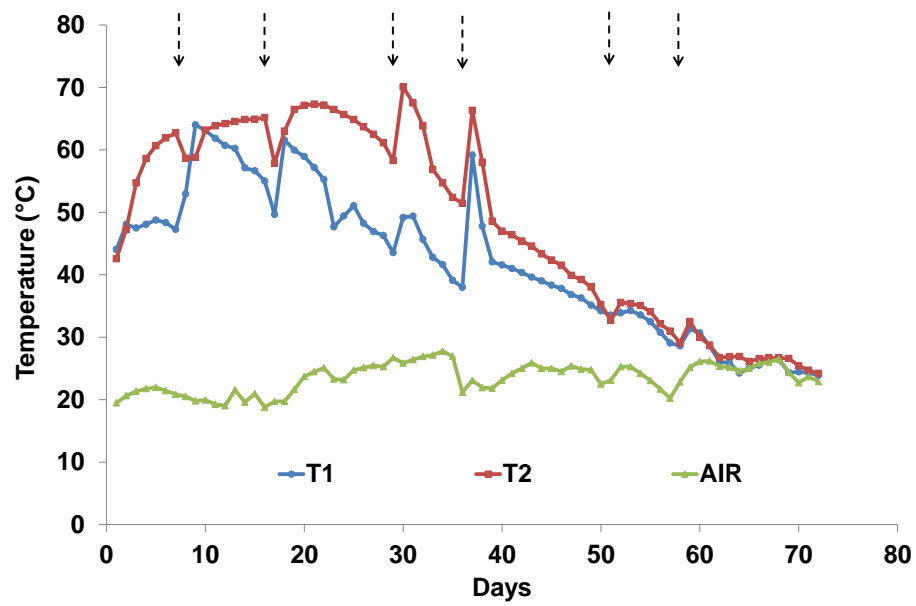
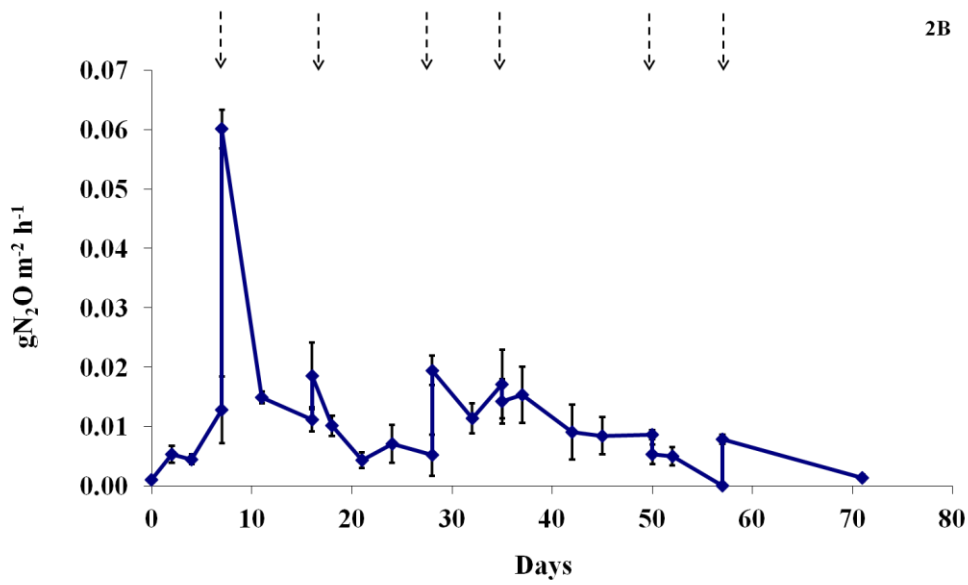
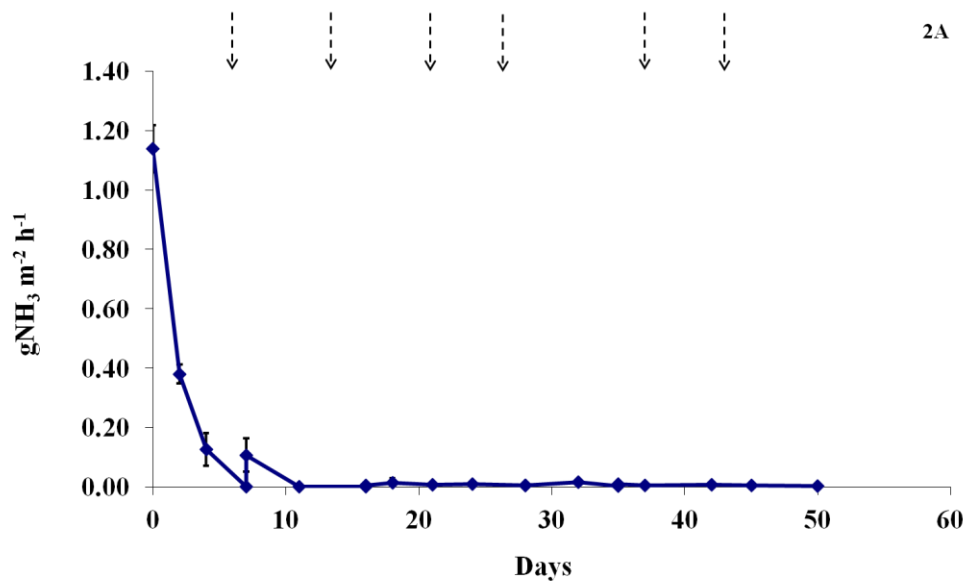


Fig 1: Average environmental temperature and temperatures development at a depth of 0.2 m (T1) and 0.6 m (T2) inside the windrows (n=3).

Arrows mark time of turning.



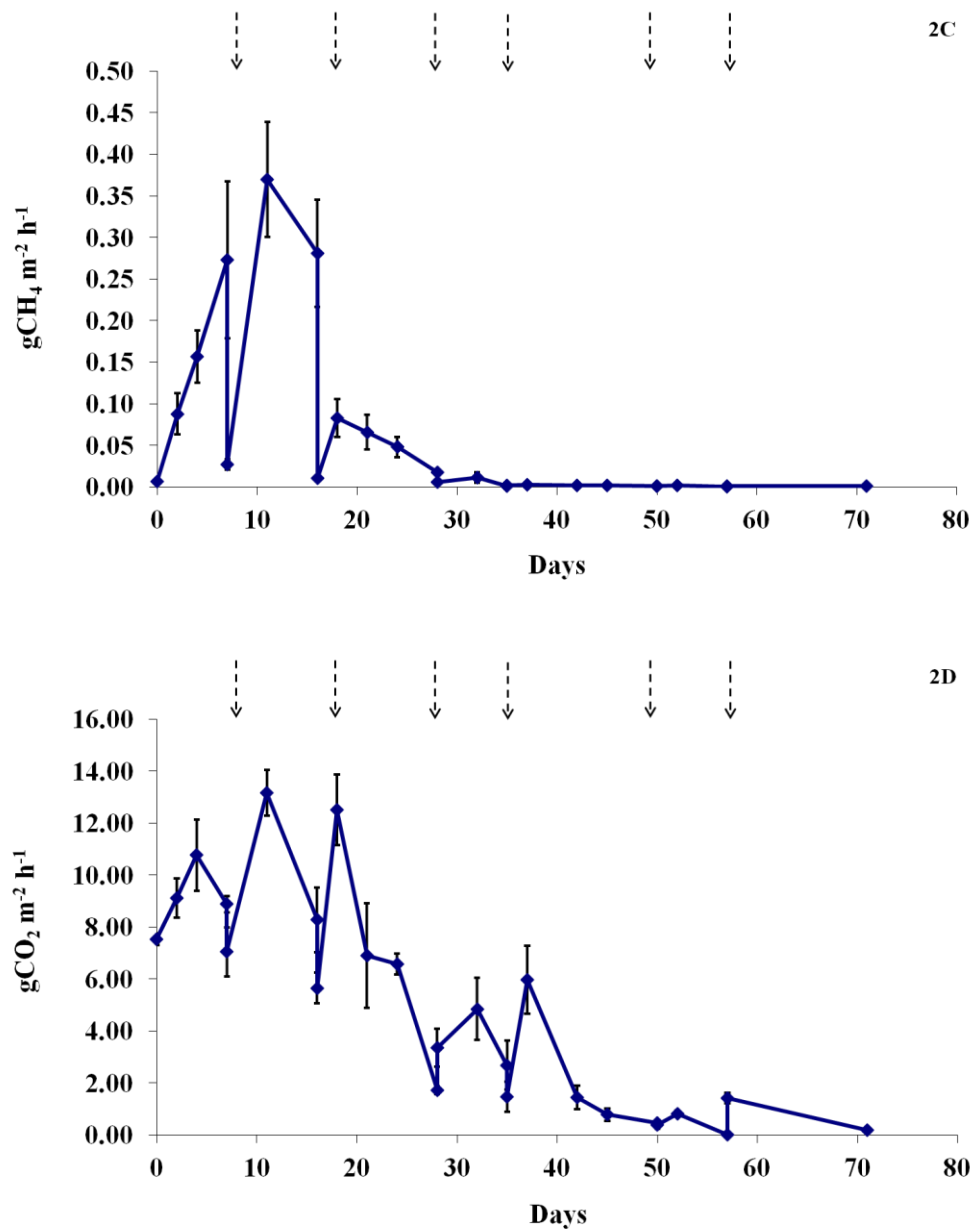


Fig 2: NH₃ (A), N₂O (B), CH₄ (C) and CO₂ (D) emission fluxes (n=3) during the composting of swine solid fraction.

Error bars indicate standard error (n=3).

Arrows mark time of turning.

Tab 1: Physical-chemical characteristics of SF during the composting process. Mean value and standard error (in parentheses) of 3 replicates.

Parameter	Days							
	0	8	17	29	36	51	58	72
Moisture (%)	73.4	67.9	65.7	46.9	44.8	37.5	35.8	34.6
	(0.65)	(2.29)	(2.86)	(1.79)	(2.88)	(1.33)	(0.49)	(0.26)
VS (%)	22.4	26.6	27.2	27.7	29.8	34.3	35.0	36.2
	(0.69)	(1.79)	(2.21)	(0.94)	(2.21)	(1.43)	(0.82)	(1.72)
pH	8.36	7.96	7.68	7.51	7.81	7.59	7.70	7.56
	(0.25)	(0.35)	(0.34)	(0.09)	(0.08)	(0.04)	(0.08)	(0.16)
TOC (%)	42.3	41.1	39.3	36.7	36.2	35.3	34.7	34.5
	(0.84)	(0.47)	(0.69)	(0.48)	(0.09)	(0.49)	(0.73)	(0.30)
TN (%)	0.61	0.74	0.87	1.54	1.74	1.95	2.11	2.20
	(0.07)	(0.19)	(0.25)	(0.02)	(0.16)	(0.05)	(0.02)	(0.09)
TAN (mg kg ⁻¹)	2643	1877	903	427	1095	967	947	150
	(115.66)	(95.27)	(149.12)	(164.55)	(171.98)	(321.44)	(31.80)	(6.98)

Tab 2: Cumulative emissions of NH₃, CH₄, CO₂ and N₂O. Mean value and standard error (in parentheses) of 3 replicates.

NH ₃	CH ₄	CO ₂	N ₂ O
(%TN)	(%VS)	(%VS)	(%TN)
8.74	0.35	27.3	1.93
(0.55)	(0.01)	(2.32)	(0.17)

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