Influence of aeration rate on transformations of separated pig manure and gaseous emissions during composting

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Introduction

In Brittany (France), the quantities of nitrogen and phosphorous in livestock manures are in excess of the absorption capacity of the local environment. Treatment is being used to remove excess nitrogen but for the phosphorous, surpluses need to be exported from the region most conveniently as separated pig solids (SPS). However, such materials must first be treated by composting and they need to meet organic fertilizers quality standards: for example, the nitrogen content must be superior to 1.5% fresh material. Moreover SPS dry matter content should be over 65% to reduce transportation costs. Finally, specific the EU regulations on animal by-products (1774/2002) require that the SPS treatment has an equivalent hygienic effect to that of 70°C maintained for one hour (and it is free of *Salmonella* in 25 g wet weight). Forced aeration was seen to be the most promising way to control SPS compost quality. However forced aeration may also encourage gaseous emissions which can contribute to acid rain or eutrophication (ammonia), add to the greenhouse effect (methane and nitrous oxide) or be a cause of offensive odours. This study sought to characterize the influence of aeration rate on material transformations (moisture, stability, nitrogen content and sanitary quality) and on gaseous emissions (methane, ammonia, nitrous oxide) during composting.

Materials and methods

Two samples of SPS were used. These were taken from the same piggery on 23/04/07 (Batch A) and on 25/06/07 (Batch B). 24 h after sampling, the SPS was loaded in the reactor. Each of six trials used a constant aeration rate ranging between 3.5 to 44.8 L/h/kg DM_0.

The composting reactor

The reactor described by de Guardia et al. (2008 a) consisted of an airtight stainless-steel cylindrical chamber (300 L, Height = 80 cm, Depth = 70 cm). Heat losses were reduced by insulation. SPS was placed on top of a grid under which air was blown. A tap was placed at the bottom of the reactor to collect leachate. The upper-part of the reactor was a cone-shaped lid equipped with a gutter allowing condensate collection. The out-going gas passed through a pipe towards a bottle condenser to trap water vapor before reaching gas analysers and chemical traps. To turn material required emptying the reactor, and mixing then to refilling.

Mass variations were followed by a set of three load cells under the reactor. The temperatures of the composting material and in the gaseous phase under the lid were measured by four Pt100 temperature probes. The in-coming airflow was controlled thanks to a flow-meter and the volume of air was measured daily with a volumetric gas meter. The concentrations of oxygen, carbon dioxide, methane, nitrous oxide and ammonia were measured in both the in-coming and out-going airflows. O_2 was measured by a paramagnetic analyser and CO_2, CH_4 and N_2O with an IR spectrometric analyser. NH_3 was trapped in sulphuric acid (1N). Traps were changed every day. Condensates and

leachates were collected daily. Their contents in total carbon (TC), chemical oxygen demand (COD), total ammoniacal nitrogen (NH_4^+/NH_3) and Kjedahl nitrogen (N-NK) were quantified according to the methods described below.

Chemical analyses

Dry matter (DM) in SPS and in composts was measured by drying fresh samples (3 replicates each 3 kg) at 80 °C until the weight became constant. Organic matter (OM) was measured by calcination at 550 °C of three dried and ground (500 µm particle size) samples using the method described in the standard, NF U 44-160 (AFNOR, 1985). SPS and composts were characterized by analyzing their content for TC (NF-EN-13137, AFNOR, 2001), COD (NF T 90-101, AFNOR, 1971), NH_4^+/NH_3 and N-NK (NF ISO 11261, AFNOR, 1995). Noting that drying was responsible for some losses in carbon and nitrogen, these measurements were applied on fresh samples. Although the samples were mixed, variability for fresh sub-samples was greater than for the dried and ground samples. Consequently, 5 to 15 measurements were necessary to get a coefficient of variation (CV) inferior to 5%.

Microbiological analyses

10 g samples of SPS (or SPS composts) were transferred to 90 mL of peptone water and then serially 10-fold diluted. *E. coli* was enumerated using 3M™ Petrifilm E. coli (incubated 24 h at 44°C). Glucuronidase positive colonies were then transferred into peptone water (24 h at 44°C) to confirm indole-reaction by addition of Kovacs' reagent. Enterococci were enumerated on selective Slanetz–Bartley agar (Biokar, France), incubated 48 h at 37°C, and subsequent confirmation on Bile Esculin Agar (Biokar, France), 4 h at 44°C. *Salmonella* was detected in 10 g of SPS according to method described by AFNOR (Anonymous, 2004). Enumerations of bacterial indicators and detection of *Salmonella* were performed in triplicate.

Results and discussion

SPS - Batch A was used for the experiments at the three lowest aeration rates. In these experiments, the material was turned at day 14th and the treatment last 27 days. SPS – Batch B was used for the experiments at the three highest aeration rates. Here the material was turned at day 13th and composting last 22 days. Aeration rates, masses and chemical and microbiological characteristics of SPS and SPS composts are given in Tables 1 and 2.

Concentration of oxygen in the exhaust gas and composting material temperature

Fig. 1: Composting material temperature as a function of aeration rate
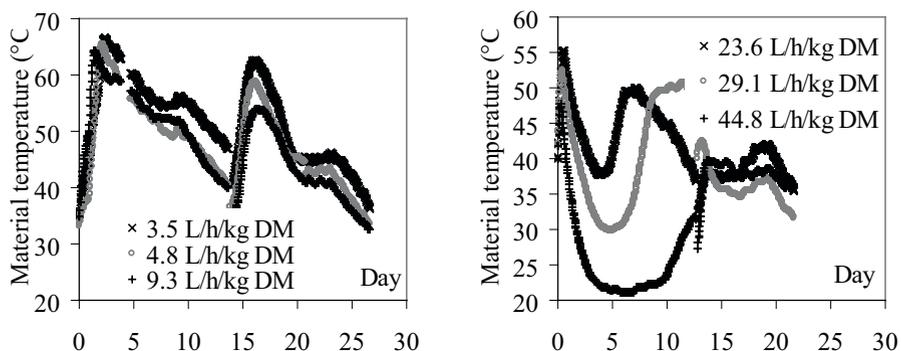
At the three higher aeration rates, compost temperature increased less than for the low aeration rates (Fig. 1). Moreover, at these high aeration rates, temperature initially decreased quickly meaning that an excessive aeration cooled the material. After a few days the temperature recovered although more slowly with the highest air flow rates which confirms the cooling effect of high aeration. In contrast, at low aeration rates, the temperature increased reaching a peak of # 65°C before decreasing slowly. The temperature recovered after turning corresponding to the biodegradation of material poorly aerated previously.

Chemical characteristics of SPS and composted SPS

Except for COD, the two fresh samples of SPS were very similar (Table 1). The COD of Batch A was more than Batch B implying a higher content in biodegradable organic matter.

Table 1: Chemical characteristics of SPS and composted SPS (per % or per g fresh material)

Aeration rate	Initial mass	Final mass	DM	Water	OM	TC	COD	Norg	NH$_4$+ /NH$_3$	N-NK
L/h/kg DM$_0$	kg	kg	%	%	%	g/kg	g/kg		g N/kg	
Fresh SPS Batch A			32.51	67.49	23.48	123.6	318.2	6.7	3.4	10.1
3.5	144.03	111.79	30.86	69.14	19.20	99.9	285.7	9.0	3.2	12.2
4.8	144.74	116.50	29.17	70.83	18.20	92.1	263.3	8.9	2.9	11.8
9.3	146.39	117.10	29.63	70.37	18.65	93.2	255.2	8.4	3.2	11.6
Fresh SPS Batch B			34.48	65.52	25.18	125.1	368.6	7.2	3.4	10.6
23.5	117.11	78.05	39.34	60.66	25.27	122.5	344.2	10.8	4.1	14.9
29.1	119.66	82.62	37.05	62.95	24.05	112.5	333.8	9.8	3.9	13.7
44.8	123.53	89.59	40.95	59.05	27.50	132.1	393.0	9.9	4.1	14.1

In SPS composts, dry matter and N-NK must exceed 40% and 0.015 g N/g to comply with organic fertilizers standards. The composting led to a slight decrease of DM content at low aeration rates whereas DM content increased at high aeration rates. N-NK was between 0.011 and 0.015 g N/g compost and the highest concentrations were obtained at the three highest aeration rates. Thus the low aeration rates especially don't meet organic fertilizers standards.

Microbiological quality of SPS composts

The concentrations of indicator bacteria were similar in the two SPS batches and no *Salmonella* were detected (Table 2).

Table 2: Average concentrations of indicators bacteria (per g of fresh material) in SPS and composts

	SPS - Batch A			SPS - Batch B		
E. coli in initial mass	2.5x10^5			1.3x10^4		
Enterococci in initial mass	7.1x10^4			3x10^4		
Presence of Salmonella in initial mass	nd (not detected)nd					
Aeration rate (L/h/kg DM$_0$)	3.5	4.8	9.3	23.5	29.1	44.8
maximum temperature measured (°C)	68	65	64	55	52	40
E. coli in final mass	<10	<10	<10	<10	13	17
Enterococci in final mass	<50	<50	<50	<50	120	50
Presence of Salmonella in final mass	nd	nd	nd	nd	nd	nd

At low aeration rates, the peak temperature ranged between 64 and 68°C and the corresponding concentrations of *E coli* and enterococci were below detectable levels after 27 days composting. At the two highest aeration rates, the temperatures did not exceed 52°C and both indicator bacteria were still detected after 22 days composting. Nonetheless, for these two trials, the decrease was still between 2.4 and 3 logarithmic units. These results, which confirmed that the temperature was a key factor of hygienisation during composting, are in agreement with data reported by Turner (2002) who showed that mesophilic composting process did not inactivate faecal coliforms.

Sanitising versus drying

The rate of water loss as function of temperature and aeration rate is shown in Fig. 2. This confirms that the higher temperatures were reached at lower aeration rates. Thus, applying low aeration rates is a way to control sanitisation since the increase of temperature in these conditions was sufficient to inactivate indicator bacteria (Table 2). In contrast, in spite of the higher temperature, the water evaporation depended more on aeration rate than on temperature. Thus, at 44,8 L/h/kg DM_0, for a material temperature around 45°C, water exportation was four times greater to that at 65°C for an aeration rate around 4 L/h/kg DM_0.

Fig. 2: Influence of aeration rate on temperature and on water loss

□ 3.5 L/h/kg DM   ◇ 4.8 L/h/kg DM   △ 9.3 L/h/kg DM
× 23.5 L/h/kg DM   + 44.8 L/h/kg DM   ✳ 29,1 L/h/kg DM
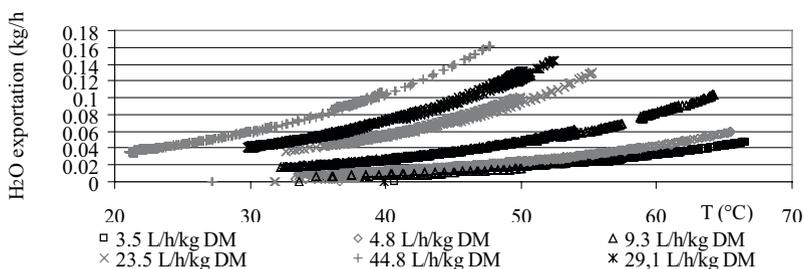
Carbon balance

Fig. 3a, 3b: DM, OM, TC and COD removal rates and O_2 consumption and CO_2 production

• OM   ▲ TC   ■ COD   ◇ DM   ■ O2   ▲ CO2
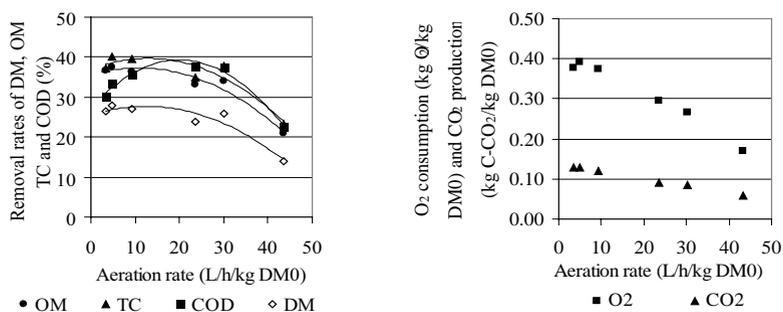
Biodegradation was estimated by calculating removal rates of DM, OM, TC and COD (Fig. 3a) and O_2 consumption and CO_2 production per kg initial dry matter (Fig. 3b). From 3.5 to 43L/h/kg DM_0, stability level differed by a factor of 2 between the highest lowest aeration rates. At high aeration rates, the low temperatures resulted with the lower stability of composts. Carbon removed from material as CO_2, CH_4 and in leachates and condensates are given in Table 3. The combined losses in condensates, leachates and as CH_4 accounted for less than respectively 0.4, 0.7 and 0.25% of carbon removed; most of it was converted

as CO_2. The difference between losses and removal was especially at the higher aeration rates which could traduce an increase of the emissions of volatile organic compounds (VOC). In a previous work (de Guardia et al., 2008 a), losses of COD in leachates and in condensates were negligible; these were not quantified here. At low aeration rates, O_2 consumption was found to be higher than the COD removed from the material (Table 4). In contrast, at the three highest aeration rates, O_2 consumption accounted for only 60.6 to 73.1% of COD removed. The representation of O_2 consumption and CO_2 production as function of carbon removed (Fig. 4) shows that both fell as the aeration rate increased. This fall suggests that at high aeration rates carbon metabolites were emitted with a lower oxidation level than at low aeration rates meaning higher emissions of VOC.

Table 3: Carbon mass balance

Aeration rate	C removed from material	C emitted as CO_2	C emitted as CH_4	C in leach	C in condensate	Loss accounted for
L/h/kgDM$_0$	Kg C					%
3.5	6.6325	5.9673	0.0099	0.0029	0.0225	90.5
4.8	7.1533	6.1127	0.0094	0.0009	0.0182	85.9
9.3	7.1722	5.7523	0.0126	0.0009	0.0215	80.7
23.5	5.0932	3.6978	0.0107	0.0000	0.0130	73.1
29.1	5.3747	3.5252	0.0109	0.0035	0.0064	66.0
44.8	4.0504	2.4404	0.0093	0.0000	0.0038	60.6

Table 4: COD mass balance

Aeration rate	COD removed from material	Total O_2 Consumed	Loss accounted for
L/h/kg DM$_0$	Kg O_2		%
3.5	13.8943	17.6477	127.0
4.8	15.3788	18.4999	120.3
9.3	16.6985	17.8759	107.1
23.5	16.3006	11.9489	73.3
29.1	15.6331	10.9406	61.8
44.8	11.6423	7.1922	70.0

Fig. 4: O_2 consumption and CO_2 production per mole of carbon removed
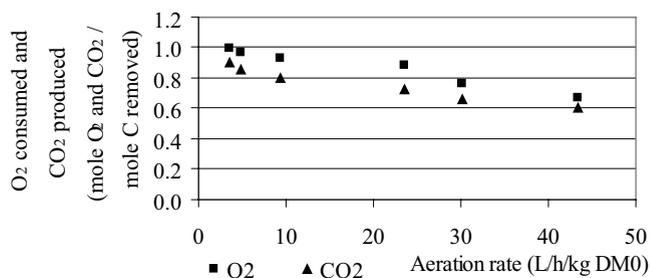
Nitrogen dynamic

Removal rates of Kjeldahl nitrogen were between 3 and 10% of the original amounts in the fresh SPS (Fig. 5a). Noting these low removal rates, at high air flows, the higher N-NK concentrations in SPS composts were mainly the result of drying. Changes in the organic nitrogen were between -7.5 and 6% meaning that biodegradation of SPS was responsible

for a low release of organic nitrogen. The slight accumulation of organic nitrogen at low aeration rate may result from error analysis and should be interpreted carefully.

Ammonia emissions were calculated by adding NH_4^+/NH_3 contained in condensates and NH_3 trapped in acid solutions. As observed by de Guardia et al. (2008 b), the peak of emission was greater and occurred sooner when the aeration rate was high. However, the increase of NH_3 emissions was observed only from 3.5 to 23.5 L/h/kg DM_0 (Fig. 5b). At the two highest aeration rates, the slowdown of biodegradation and the low temperatures were responsible for lower emissions. N_2O emissions increased when the aeration rate applied was increased (Fig. 5b). From 3.5 to 44.8 L/h/kg DM0, NH_3 and N_2O emissions were comprised respectively between 0.73 and 2.05 g N/kg DM_0 and 0.30 and 0.34 g N/kg DM_0.

Fig. 5a, 5b: N-NK and organic nitrogen removal rates and, NH_3 and N_2O emissions as function of aeration rate
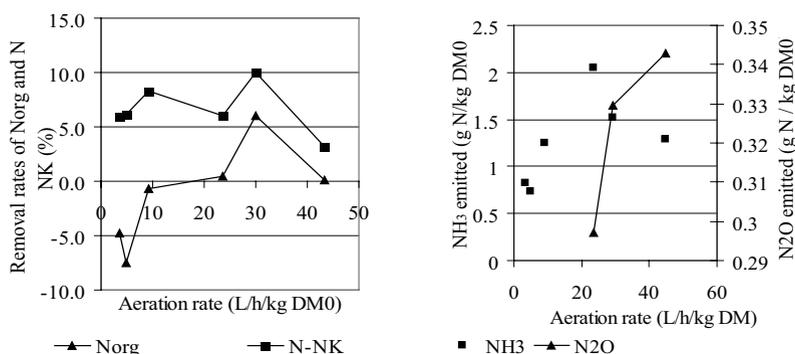
Nitrogen losses in leachates accounted for less than 1.2% of nitrogen removed from material (Table 5). At low aeration rates N_2O emissions were not quantified. At high aeration rates, these accounted for 13.3 to 19.6% of nitrogen removed. The difference between nitrogen removed from substrate and nitrogen losses as NH_3 and N_2O emissions were the highest, 52 to 60%, at the three lowest aeration rates. At high aeration rates, losses accounted for 74.7 to 100% of nitrogen removed. In literature, unexplained losses of nitrogen are interpreted as corresponding to conversion of NH_4^+/NH_3 to N_2 through nitrification and denitrification. As postulated by de Guardia et al. (2008 b), the lower aeration rates correspond with longer retention of ammonia in the composting material which favours nitrification.

Table 5: Nitrogen mass balance (nd: not determined)

Aeration rate	N removed from material	N in leach	N in condensates	N emitted as NH_3	N emitted as N_2O	Loss accounted for
L/h/kgDM$_0$	g N					%
3.5	83.9	1.0	29.5	9.2	nd	47.3
4.8	86.4	0.4	23.3	11.2	nd	40.5
9.3	122.6	0.2	30.7	28.7	nd	48.5
23.5	76.6	0.0	19.6	63.2	12.0	123.7
29.1	102.1	0.0	6.6	56.1	13.6	74.7
44.8	74.7	0.8	10.3	44.7	14.6	94.3

Conclusion

These results showed that applying high aeration rates resulted with higher dry matter and total nitrogen in composts products as required by organic fertilizers standards. However, high aeration rates were also responsible for lower composting temperature leading to lower levels of stabilisation and hygienisation. Moreover, emissions of ammonia, nitrous oxide and volatile organic compounds were higher at high aeration rates. A compromise strategy might be to apply a low aeration rate initially for a few days to achieve hygienisation and biodegradation and favour nitrification. Then the aeration rate could be increased to pursue material drying and concentration.

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