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Effect of C/N ratio, aeration rate and moisture content on ammonia and greenhouse gas emission during the composting

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Abstract

Gaseous emission (N_2O, CH_4 and NH_3) from composting can be an important source of anthropogenic greenhouse gas and air pollution. A laboratory scale orthogonal experiment was conducted to estimate the effects of C/N ratio, aeration rate and initial moisture content on gaseous emission during the composting of pig faeces from Chinese Ganqinfen system. The results showed that about 23.9% to 45.6% of total organic carbon (TOC) was lost in the form of CO_2 and 0.8% to 7.5% of TOC emitted as CH_4. Most of the nitrogen was lost in the form of NH_3, which account for 9.6% to 32.4% of initial nitrogen. N_2O was also an important way of nitrogen losses and 1.5% to 7.3% of initial total nitrogen was lost as it. Statistic analysis showed that the aeration rate is the most important factor which could affect the NH_3 ($p = 0.0189$), CH_4 ($p = 0.0113$) and N_2O ($p = 0.0493$) emissions significantly. Higher aeration rates reduce the CH_4 emission but increase the NH_3 and N_2O losses. C/N ratio could affect the NH_3 ($p = 0.0442$) and CH_4 ($p = 0.0246$) emissions significantly, but not the N_2O. Lower C/N ratio caused higher NH_3 and CH_4 emissions. The initial moisture content can not influence the gaseous emission significantly. Most treatments were matured after 37 days, except a trial with high moisture content and a low C/N ratio.

Key words: pig faeces; composting; methane; nitrous oxide; ammonia

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Introduction

Methane (CH_4) and nitrous oxide (N_2O) are both significant greenhouse gases (GHG). According to the report of International Panel on Climate Change (IPCC), the global warming potential of CH_4 and N_2O, on a 100-year frame, are 25 (CH_4) and 298 (N_2O) times higher than that of carbon dioxide (CO_2) respectively (IPCC, 2007). Until 2004, the CH_4 and N_2O account for the global anthropogenic GHG emissions 14.3% and 7.9% separately (IPCC, 2007). Agriculture has been identified as a main source of GHG emissions, about 13.5% of global anthropogenic GHG was emitted from agricultural production (IPCC, 2007). It was estimated that 80% of N_2O and 40% of CH_4 emitted from agriculture activities (Thompson et al., 2004). Manure management is one of the important sources, which is responsible for one third of agricultural N_2O emissions (Mosier et al., 1998), and 9% of total biogenic CH_4 emissions (Steed and Hashimoto, 1994).

Composting, one of the most suitable technologies for treating livestock manures can reduce the mass, destroy the weed seeds, provide sufficient sanitation effect and produce valuable end products. In terms of its inexpensive costs and rather simply technique, composting was used widely, especially in developing countries. For example, in China more than 17 million tons organic fertilizer was produced form composting per year; and in the municipal solid waste and swage sludge treatment field, the proportion of composting increased rapidly (Li et al., 2003). But the emission of harmful gases from composting caused serious environmental problems. As the results of nitrification and denitrification, about 0.02% to 9.9% of total nitrogen (TN) was emitted in the form of N_2O; and caused by the lack of oxygen, 0.1% to12.6% of total organic carbon (TOC) was lost as CH_4 (Beck-Friis et al., 2001; Osada et al., 2001; Zeman et al., 2002; Fukumoto et al., 2003; Hao et al., 2004; Wolter et al., 2004; Szanto et al., 2007).

There is a growing international focus on the GHG emissions from composting (Beck-Friis et al., 2000; Thompson et al., 2004; Brown et al., 2008), especially for windrow system. It was reported that the turning frequency, compact

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effect, the scale of the pile and the manure characters all could influence the GHG emissions (Beck-Friis et al., 2001; Fukumoto et al., 2003; Yamulki, 2006; El Kader et al., 2007). But for forced aeration system, which was used wildly in China, reports were scarcely. The purpose of this article was to investigate the effect of C/N ratio, aeration rate and moisture content on the emission of GHG from the composting of pig faeces and cornstalk in a forced aeration system.

1 Materials and methods

1.1 Raw materials and experiment installation

Pig faeces were collected from Zhouchunsheng pig farm (Shujiatuo Town, Beijing, China). In this farm Ganqingfen system (Schuchardt et al., 2009) was used for manure collection (separate collection of the faeces from the concrete floor before flushing the urine with water). All pig faeces were collected 3 days before the experiment was started. The chopped cornstalk as bulking agent and carbon source was obtained from Shangzhuang Station, China Agricultural University. The characteristics of the raw materials are shown in Table 1.

A series of 60-L composting vessels (Fig. 1) were used in this research to simulate the forced aeration system. The vessels were controlled by a program named C-LGX. Under this program the aeration can be controlled by time or temperature inside automatically, intermittent aeration (start 25 min, stop 5 min) was used in this study. The temperature in the vessel were recorded by this program.

Table 1 Characteristics of raw materials

	TOC (g/kg)[a]	TKN (g/kg)[a]	Ammonium (g/kg)[a]	Moisture content (%)	C/N ratio
Pig faces	362	27.4	1.1(0.01)	71.2	13.2
Cornstalk	419	10.1	–	8.9	41.5

TOC: total organic carbon; TKN: total Kjeldahl nitrogen.

[a] Based on dry matter (dm).

1.2 Experimental design

An orthogonal test L_9 (3^4) was designed to study the impacts of moisture content, aeration rate and C/N on GHG emission during composting (Table 2).

Pig faeces and cornstalks were mixed at different ratios to initial C/N ratios of 15, 18 and 21. This aims to estimate the composting at low C/N ratio, thus could save the demand of cornstalks. Different amounts of water were added to adjust the moisture content at 65%, 70% and 75%. According to the studies of de Guardia et al. (2010) and Gao et al. (2008) the aeration rate was decided at 0.24 to 0.72 L/(kg dm·min) to simulate the aeration at low, middle and high level.

The experiment was carried out from 12 June to 19 July in 2009, total 37 days. Piles were turned at day 3, 7, 15, and 24. Samples were taken at the start, during turning and at the end after 37 days. One part of sample was air-dried,

Table 2 Design of experiment

No.	Moisture content (%)	Aeration rate[a] (L/kg dm·min)	C/N ratio	For error
1	65	0.24	15	1
2	65	0.48	18	2
3	65	0.72	21	3
4	70	0.24	18	3
5	70	0.48	21	1
6	70	0.72	15	2
7	75	0.24	21	2
8	75	0.48	15	3
9	75	0.72	18	1

[a] Aeration for 25 min, stop for 5 min.

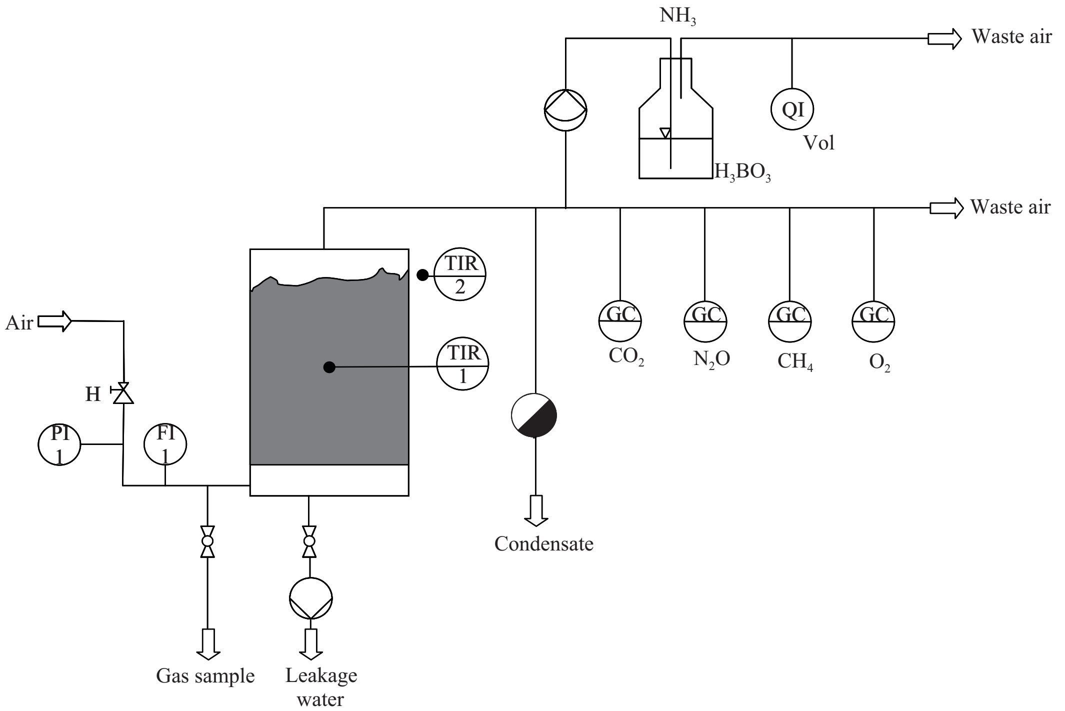

Fig. 1 Sketch map of the composting vessel.

chopped, passed through a 1 mm sieve; the other part was stored at 4°C.

1.3 Analysis method and statistic analysis

The TKN, TOC, pH were determined according to Chinese national standard (NY 525-2002). The moisture content was determined by drying the samples at 105°C until the weight was unvarying (Thompson et al., 2002). Inorganic nitrogen (NH_4^+-N, NO_3^--N, NO_2^--N) were extracted by 2 mol/L KCl (10:1, *V*/*m*), and then analyzed by auto analyzer (Auto Analyzer 3, Seal, Germany). The germination index (GI) was measured according to Tiquia and Tam (2000). CH_4 and N_2O were analyzed by gas chromatograph (3420A, Beifen, China). N_2O was examined by the electron capture detector (ECD), connected with a capillary column, and using He as carrier gas. The analysis temperatures: detector 280°C, injector 120°C, column 80°C. CH_4 was examined by flame ionization detector (FID) connected with packed column, the carrier gas was N_2, analysis temperature was detector 200°C, injector 120°C, and column 80°C. NH_3 was measured by washing bottle according to Ren et al. (2010). SAS (Statistical Analysis System) 8.2 for windows was used for the variance analysis.

2 Results and discussion

2.1 Temperature and oxygen content

The temperature of middle/high aeration treatments increased rapidly after the experiments were started (Fig. 2), the maximum temperatures (70 to 75°C) were observed at day 2, thus caused a short mesophilic phase. The thermophilic phase of all treatments were long enough to satisfy the requirement of Chinese national standard (GB 7989-87) for sanitation effect. The trials with low aeration rates had as result of slow degradation a longer thermophilic phase. Around day 21 an increase of temperature prior to the turning was observed in low aeration treatments. Hellmann et al. (1997) and Osada et al. (2001) found similar results in windrow systems, and they related it to the fungal growth. For the high/middle treatments the temperature rising were observed after turning. These risings were caused by the degradation of partially decomposed materials which were transferred from the anaerobic areas to the aerobic areas.

The oxygen content in the outlet were various by the aeration rate. For the low aeration series the oxygen content initially declined to 0 to 5.0%, and decrease to maintain at this level for about 2 weeks. After the 3rd week, the oxygen content of all treatments were higher than 16%. The oxygen content in the outlet of middle aeration treatments were between 10% and 12% in the first 5 days, and exceeded to 16% at the end of the first week, this seems that the oxygen content was satisfied with composting proceeds. The initial oxygen content in the outlet of high aeration treatments was higher than 16%, and maintained at this level for about 2 weeks, after that the oxygen content was closed to 20%. This indicated that the easily available carbon compounds were degraded in the first 2 weeks.

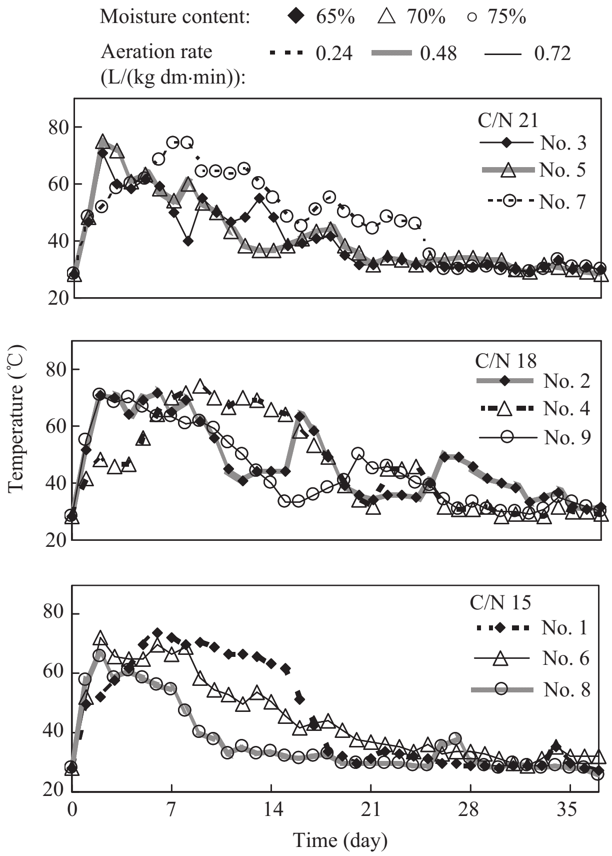

Fig. 2 Temperature profile. No. 1–9 refer to Table 2.

2.2 Chemical properties

Table 3 shows the initial and final compositions of the compost material. At the end of the experiment, the germination index (GI) of all treatments with a low C/N ratio of 15 was lower than 80%, consequently the mixtures are not mature. The final content of NH_4^+ in the compost is still high and may be toxic for the roots growing. Huang et al. (2004) found similar results after 63 days of composting at low C/N ratios. They attributed it to the high salinity of manure. On the other hand the treatments of C/N ratio 18 and C/N ratio 21 were all mature, except treatment 7 whose mature process was delayed by the low aeration rate and high moisture content.

The compost material at middle and high aeration rates lost the water quickly in the first week, due to the high temperature and high air ventilation rate. During this period, water was added into some treatments to maintain the moisture content at a suitable level for the microbe's activity. After the thermophilic period, the moisture content began to increase, because the amount of water created by the decomposition process was higher than the water in the outlet air.

During composting the comparative carbon losses were larger than that of nitrogen, consequently the nitrogen content in most treatments increased except trials No. 6 and 8, caused by high nitrogen losses and low degradation rate respectively.

Table 3 Chemical characters of the compost materials

Trial No.		1	2	3	4	5	6	7	8	9
TKN (g/kg dm)	Initial	23.6	20.8	19.0	20.6	19.0	23.5	19.3	23.7	20.9
	Final	28.1	25.5	23.9	24.7	27.9	20.6	26.2	19.6	23.8
TOC (g/kg dm)	Initial	348	380	394	380	401	352	409	353	376
	Final	302	319	351	343	369	284	371	324	338
NH_4^+ (g/kg dm)	Initial	1.83	1.25	0.90	1.48	1.25	2.02	0.90	2.25	1.64
	Final	2.16	0.50	0.33	0.83	0.36	0.76	0.76	2.38	0.45
NO_x (g/kg dm)	Initial	0.03	0.03	0.03	0.02	0.03	0.03	0.02	0.03	0.02
	Final	0.23	0.21	0.24	0.17	0.19	0.41	0.12	0.04	0.38
C/N ratio	Initial	14.7	18.3	20.7	18.4	21.1	15.0	21.2	14.9	18.0
	Final	10.7	12.5	14.7	13.9	13.2	13.7	14.1	16.5	14.2
pH	Initial	8.6	8.5	8.3	8.5	8.3	8.7	8.4	8.6	8.6
	Final	8.1	8.5	8.6	8.2	8.4	8.5	8.4	8.1	8.5
Moisture (%)	Initial	64.1	65.2	63.7	71.3	70.6	70.8	75.7	76.8	74.0
	Final	71.6	66.0	65.0	75.9	73.5	63.5	79.6	76.6	61.9
GI (%)	Initial	37.6	32.8	43.6	40.7	37.6	41.4	43.7	42.4	46.5
	Final	62.0	90.9	83.5	81.4	85.7	66.2	73.5	53.2	86.1

The NH_4^+ content reached a maximum after the first week. Then, due to the NH_3 emission and nitrification, the NH_4^+ content began to decrease. Low aeration rates decreased the NH_3 losses and prolonged the ammonization period. At low aeration rates the NH_4^+ content were consistent high.

2.3 Ammonia emission

Caused by the high ammonia content and high temperature, the NH_3 emission at aeration rates of 0.48 and 0.72 L/(kg dm·min) increased sharply after the composting were started, and reached their maximum during the first two days, and then decreased to a lower level for 2 weeks (Fig. 3). The emission patterns were similar to the finding of Osada et al. (2001). After each turning the temperature and the NH_3 emission increased, this was caused by the degradation of partially decomposed material. Other researchers had also observed analogical emission patterns with higher NH_3 emissions after turning (Szanto et al., 2007; Ren et al., 2010). The NH_3 emission at a low aeration rate of 0.24 L/(kg dm·min) increased slowly, to such an extent that needed 7 to 10 days to reach their peak emission. After that, the emissions of NH_3 decreased to a low level.

For all treatments, the peaks of NH_3 emissions coincided with the maximum of temperature and oxygen uptake rate, which was confirmed by previous studies by Pagans et al. (2006) and de Guardia et al. (2008). High oxygen utilization rate means intensive microbiological degradation which produced large mount of NH_4^+ and heat at the same time. Statistic analysis showed that both the aeration rate (p = 0.0189) and C/N (p = 0.0442) could affect the NH_3 emission significantly, similar results were found in previous studies (Osada et al., 2001; Yamulki, 2006).

Moisture content could not affect the NH_3 emission significantly (p = 0.2483), this was contrary to the results of El Kader et al. (2007). Adding water to compost could reduce the free air space in a windrow system, thus reduce the NH_3 emission. But in an aeration system, the aeration rate dominates the O_2 supply, the influences of free air space is not significant.

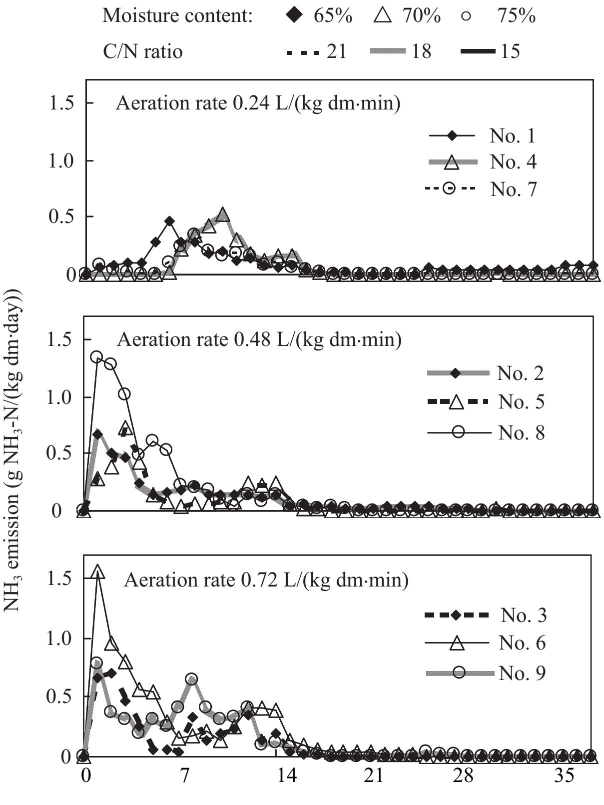

Fig. 3 Emission of NH_3. No. 1–9 refer to Table 2.

2.4 Methane emission

In most treatments the CH_4 emissions had a maximum in the first 5 days, and about 63% to 93% of total CH_4 emissions were in the first 2 weeks (Fig. 4). This pattern was similar to the research of Fukumoto et al. (2003) and Szanto et al. (2007). Production of CH_4 by methanogens is limited to strict anaerobic condition, but high CH_4 emission coupled with high O_2 concentration in the outlet gas was observed at beginning periods. The inconsistency should be explained by the characteristics of the materials. The pig faeces used in this experiment contain particles with diameters of some centimetres, in which oxygen cannot infiltrate into the centre. This results in aerobic

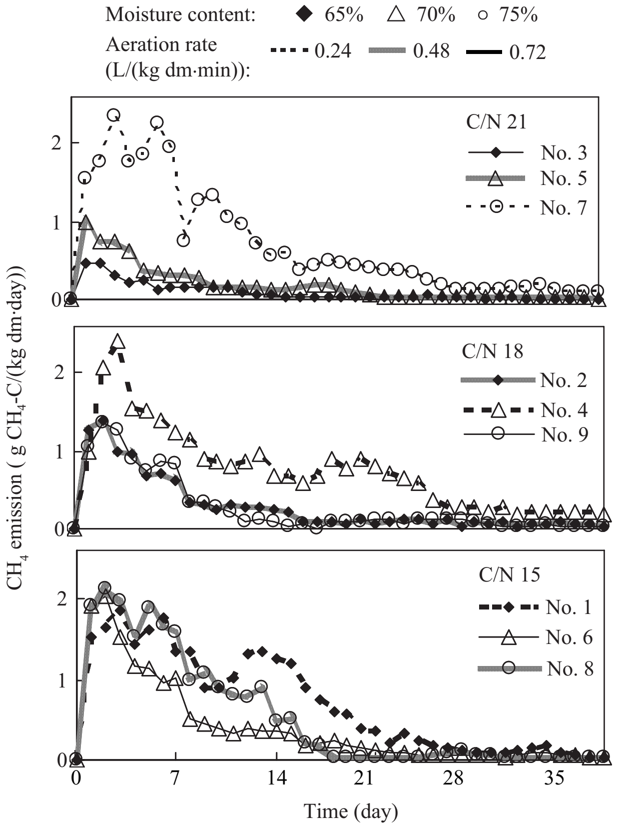

Fig. 4 Emission of CH_4.

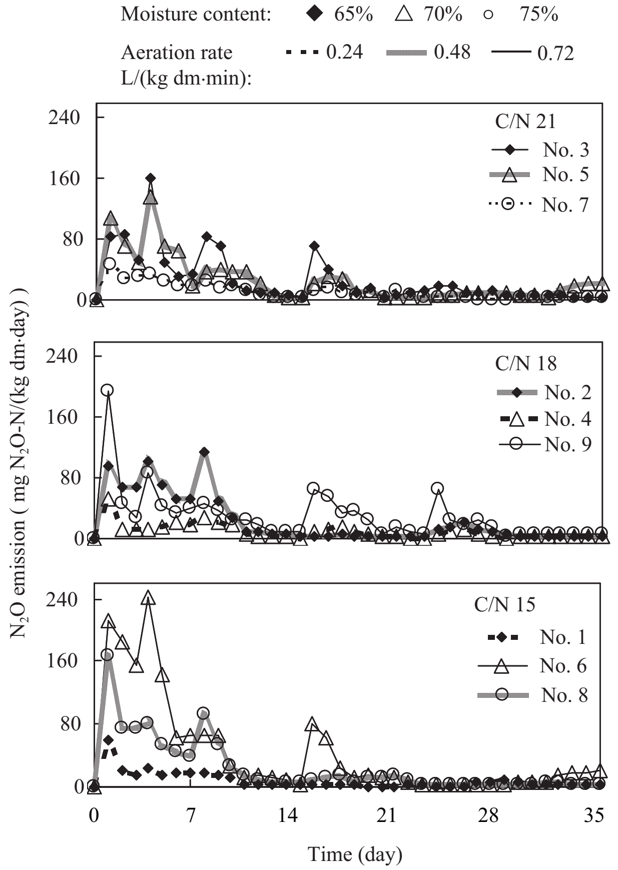

Fig. 5 Emission of N_2O.

conditions at the surface of the particles and anaerobic conditions in the centre (Zausig et al., 1993).

Compared with high/middle aeration series, the low aeration treatments had a higher emission rate and a longer emission period. Low O_2 content in the vessels should be responsible for the higher CH_4 emission at the beginning stage. High moisture and long thermophilic phases should be responsible for the CH_4 emission in the later period. Similar to the study of Yamulki (2006), a good correlation between temperature and CH_4 emission was found in this study, indicated that the production of CH_4 was temperature sensitive. This was also proved by Steed and Hashimoto (1994) and Yamulki (2006).

The decrease of CH_4 emission after the 2nd week should be the results combined action of two aspects. First, the turning activities break the big particles, destroying the anaerobic regions. Second, as the composting process went on, the carbon sources especially the easily available carbon compounds were exhausted, these decreased the activity of microbes in the composting materials.

Statistic analysis showed that both aeration rate (p = 0.0113) and C/N ratio (p = 0.0246) could affect the CH_4 emission significantly, but not the moisture content. The main reason is that the moisture content in the vessels changed sharply by the aeration and biodegradation and was not maintained at the initial level during turning.

2.5 Nitrous oxide emission

Most treatments immediately had a relative high emission after the composting started, and the highest N_2O emissions of all treatments were observed in the first week (Fig. 5). This emission patterns were similar to previous studies (Sommer and Møller, 2000; Yamulki, 2006; El Kader et al., 2007). On the contrary, the results of Fukumoto et al. (2003) and Thompson et al. (2004) showed that there was a low N_2O emission in the first week. The authors attributed it to the inhibition by high temperature, because the activity of nitrifiers ceased above 40°C. Otherwise Szanto et al. (2007) concluded that methanotrophs were capable of ammonium oxidation under thermophilic conditions. Hao et al. (2001) believed that the chemodenitrification of NO_2^- to N_2O plays an important role in the early N_2O emission. El Kader et al. (2007) consisted that the high N_2O at the beginning could be produced before the pile was made.

In this study, the N_2O emissions at the beginning could be created by the nitrification of ammonia, because the NO_2^-/NO_3^- content in the raw materials was not high enough to sustain such a high emission rate at the beginning of the composting. For most treatments especially the high aeration series, a significant increase of N_2O emission were observed after turning. The same tendency was found also in previous publications (Fukumoto et al., 2003; El Kader et al., 2007). The turning activities make the transportation of NO_2^-/NO_3^- from aerobic portion to anoxic portion feasible. The denitrification of NO_2^-/NO_3^- should be responsible for the N_2O emission in this period. Statistic analysis show that the aeration rate could significantly affect the N_2O emission (p = 0.0493), but not the C/N ratio and moisture content.

Table 4 Mass balance and total GHG emission

No.	Carbon balance (%)				Nitrogen balance (%)				GHG (kg CO_2-eq/ton dm)	
	CO_2-C	CH_4-C	Other N losses	Total C losses	NH_3-N	N_2O-N	Other N losses	Total N losses	Power GHG emission	Total GHG emission
1	31.4	7.5	3.8	42.7	13.9	1.6	5.8	21.3	38	740
2	42.9	3.7	4.4	51.0	18.7	4.2	3.7	26.6	75	541
3	44.8	0.8	5.0	50.7	20.6	5.3	4.7	30.6	113	324
4	32.1	7.2	2.3	41.6	12.7	1.5	7.9	22.0	38	758
5	45.6	1.7	6.8	54.0	16.9	5.0	6.5	28.4	75	364
6	42.4	4.2	3.8	50.3	32.4	7.3	6.2	45.9	113	704
7	33.3	6.4	6.0	45.6	9.6	2.1	6.8	18.4	38	743
8	23.9	5.7	4.2	33.8	27.7	3.8	8.9	40.3	75	695
9	37.2	3.8	7.8	48.9	24.9	5.2	5.2	35.3	113	610

Total GHG emission = CH_4 (kg CO_2-eq/ ton dm) + N_2O (kg CO_2-eq/ ton dm) + aeration power (kg CO_2-eq/ ton dm); where, global warming potential calculation: 1 mol CH_4 = 25 mol CO_2-eq, 1 mol N_2O =298 mol CO_2-eq; aeration power calculation based on: 1 m^3 = 0.004 kWhr, 1 kWhr = 0.997 kg CO_2-eq.

2.6 Mass balance and total greenhouse gas emission

Most nitrogen was lost in the form of NH_3, but also a considerable part was lost in the form of N_2O (Table 4). In this study the N_2O emissions were various from 1.5% to 7.3% of initial total nitrogen. These results were similar to the research of Szanto et al. (2007) and Fukumoto et al. (2003), but comparatively higher than the results of Wolter et al. (2004) and Sommer (2001), where only 0.1% to 1.9% of TN were emitted in the form of N_2O. Aeration condition was one of the reasons responsible for the difference, in the research of Szanto et al. (2007) an effective aeration facility was constructed in the bottom of the composting reactors to enlarge the chimney effect and in the study of Fukumoto et al. (2003) a ventilation blower was used to draw out the air in the composting chamber. All these actions accelerated the gaseous emission from the compost piles. Without these aeration actions, even the gaseous concentration in the pile was considerable high, the surface emission was limited (Hao et al., 2001).

In forced aeration systems the emission rates depends largely on the air flow. It was reported that the size of composting piles could influence the N_2O emissions significantly, small piles had higher emission rate than bigger ones (Fukumoto et al., 2003). The previous studies showed that low emission rates are always coupled with large pile size (Osada et al., 2001; Morand et al., 2005; Sommer, 2001), and vice versa (Fukumoto et al., 2003; Tamura and Osada, 2006; Szanto et al., 2007).

Almost all treatments lost more than 40% of carbon except the trial No. 8 which ended it's degradation after the second week. The main reason for the termination could be the interaction of high moisture content and high ammonia concentration. On the contrary, the trials No. 7 and No. 9 with the same moisture content finally reached a higher germination index.

In windrow system without forced aeration in the top layer parts aerobic conditions predominate. In these regions a microbial oxidation of CH_4 may be possible. In forced aeration systems fresh air passes through the piles from the bottom to the top, caused the a lower O_2 supply in the top parts. When the CH_4 pass through these regions there were no suitable conditions to oxidation. Coupled with the aeration and small size which were discussed above the methane emission from the aeration system was high.

The total GHG ranged from 324 to 743 kg CO_2-eq/ton dm. Orthogonal analysis showed that both aeration rate and C/N ratio could affect the total GHG emission. The treatment with a moisture content of 65% and an aeration rate of 0.48 L/(kg dm·min), and a C/N ratio of 21 should acquire the lowest total GHG emission.

3 Conclusions

The effects of C/N ratio, aeration rate and moisture content on the emissions of GHG and ammonia during composting of mixtures of pig faeces and chopped cornstalks were investigated in this study. Lower C/N ratio (higher proportion of faeces) caused higher methane emission by reducing the air spaces and increasing the easily available carbon sources. Lower C/N ratio is preferable to increase the NH_3 emission. High aeration rate can reduce the emission of CH_4, whereas the emissions of N_2O and NH_3 increase. Low aeration rates can reduce the NH_3 emission and delay and prolong the ammonification phases. The moisture content can affect the methane and ammonia emission during the composting period, but not significantly. The orthogonal analysis showed that mixtures with a moisture content of 65%, aeration rate 0.48 L/(kg dm·min) and C/N ratio 21 should acquire the lowest total GHG emission.

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