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Effect of aeration rate, C/N ratio and moisture content on the stability and maturity of compost

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ABSTRACT

To estimate the order of importance of factors affecting the stability and maturation of compost, pig feces and corn stalks were co-composted at different aeration rates (AR: 0.24, 0.48, 0.72 L kg^{-1} dry matter (DM) min^{-1}), C/N ratios (15, 18, 21), and moisture contents (MC: 65%, 70%, 75%). The thermophilic phase with all treatments was long enough to meet sanitation requirements. The oxygen content and N losses increased with increasing AR, but no significant differences were observed between the moderate and high treatments. The compost with the lowest initial C/N ratio was significantly different from the other treatments and had the lowest germination index (53–66%). AR was the main factor influencing compost stability, while the C/N ratio mainly contributed to compost maturity, and the MC had an insignificant effect on the compost quality. The recommended parameters for composting are an AR of 0.48 L kg^{-1} DM min^{-1} and a C/N ratio of 18 with MCs of 65–75%.

1. Introduction

The amount of piggery waste generated in China has increased dramatically with the rapid development of pig farms. These wastes can cause hygiene hazards, odor pollution, and ground and surface water pollution from the leaching of pollutants, if not properly treated. The gan qing feng system is a special waste management system used in China, and used exclusively in Beijing. With this system urine and feces are collected separately and manually using a shovel. This system is able to separate considerably more N, P, K, Mg and dry matter with the solids when compared with the solids separated from liquid manure systems (a mixture of urine, feces and cleaning water) (Schuchardt et al., 2011).

As an agricultural country, China needs large amounts of organic fertilizers to improve crop yields and quality, and maintain or increase the nutrient status of soil and improve its structure. Fresh pig feces are a valuable resource for organic fertilizers because of their high organic matter and nutrient (N and P) content. However, fresh pig waste is unsuitable for direct land application because of the unstable organic matter, pathogens, weed seeds and the difficulties associated with preservation and transportation. Composting is an effective and economical method for the treatment of animal manure prior to land application, in which pathogens and weed seeds are destroyed and the highly heterogeneous solid state organic matter is transformed to more stable and mature humic substance by the activity of bacteria, epiphytes and actinomycetes.

Bulking agents are always required to modify the properties of animal manure during composting because of the high moisture contents, low C/N ratio and high density of animal manure. The National Bureau of Statistics in China has identified that the yield of maize in China is about 0.2 billion ton annually, leading to large amounts of corn straw waste. The corn straw is rich in carbon and has a low density and low moisture content, making it suitable for use as a bulking agent during composting.

The stability and maturity of compost are often referred to as the compost quality (Moral et al., 2009). The stability typically refers to microbial activity and can be defined by the respiration index or the conversion of various chemical species in compost organic matter (Gao et al., 2010a), while maturity refers to the amount of degradation of phytotoxic organic substances and is generally measured by the germination index or plant bioassays (Said-Pullicino et al., 2007; Gao et al., 2010a). Stable and mature compost can be applied to soil as an organic amendment to improve plant growth and soil fertility, as well as enhancing the function of soil for carbon sequestration (Piccolo et al., 2004). However, the application of unstable and immature compost would fix nitrogen in the soil and restrict plant growth by competing for oxygen in the rhizosphere and releasing toxic substances (Bernal et al., 2009).

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Table 1
Optimal aeration rates for different composting systems.

Optimal aeration rate	Raw materials	Ventilation method	Reference
0.4 L min^{-1} kg^{-1} OM[a]	Grass, tomato, pepper and eggplant wastes	Intermittent aeration of 15 min on/45 min off	Kulcu and Yaldiz, (2004)
0.25 L min^{-1} kg^{-1} VS[b]	Dairy manure with rice straw	Continuous aeration	Li et al. (2008)
0.6 L min^{-1} kg^{-1} in active phase, 0.4 L min^{-1} kg^{-1} in curing phase	Active municipal solid waste	Continuous aeration	Rasapoor et al. (2009)
0.5 L min^{-1} kg^{-1} OM[a]	Chicken manure with sawdust	Continuous and intermittent aeration	Gao et al. (2010b)
0.1 m^3 min^{-1} m^{-3}	Chicken manure with straw and dry grasses	Intermittent aeration of 30 min on/30 min off	Shen et al. (2011)

[a] OM: organic matter.
[b] VS: volatile solids.

Table 2
Successful composting systems with low initial C/N ratios.

C/N ratio	Raw materials	Reference
19.6	Green waste and food waste	Kumar et al. (2010)
20	Chicken manure with sawdust	Ogunwande et al. (2008)
20	Swine manure with rice straw	Zhu (2007)
15	Pig manure with sawdust	Huang et al. (2004)

Table 3
Optimum moisture contents of different composting systems.

Optimum moisture content	Raw materials	Reference
69%	Poultry manure with wheat straw	Petrica et al. (2009)
Less than 80%	Swine manure and corncob	Zhu (2006)
60–70%	Sewage sludge	Liang et al. (2003)
50–60%	Pig manure with sawdust	Tiquia et al. (1996a)
65–70%	The solid fraction of poultry manure with straw	Kalyuzhnyi et al. (1999)

The aeration rate (AR) is considered to be the most important factor influencing successful composting (Diaz et al., 2002). Insufficient aeration can lead to anaerobic conditions due to the lack of oxygen, while excessive aeration can increase costs and slow down the composting process via heat, water and ammonia losses. The optimal AR depends on the composition of the raw materials and ventilation methods (Table 1).

The initial carbon to nitrogen (C/N) ratio is one of the most important factors influencing compost quality (Michel et al., 1996). In general, initial C/N ratios of 25–30 are considered ideal for composting (Kumar et al., 2010). However, recently some researchers have successfully carried out composting at lower initial C/N ratios (Table 2). Composting at lower initial C/N ratios can increase the amount of manure treated, but can also increase the loss of nitrogen as ammonia gas.

During composting, the moisture content (MC) is important for transporting the dissolved nutrients required for the physiological and metabolic activities of microorganisms (Liang et al., 2003). The optimum MC depends on the specific physicochemical properties and biological features of the materials being composted (Table 3).

The interaction of these factors on composting has recently been studied by some researchers. The optimum MC was 60% during the composting of green waste and food waste at a low C/N ratio (19.6) (Kumar et al., 2010); while and the optimum conditions for the composting of poultry manure with wheat straw were an initial MC of 70% and an AR of 0.54 L min^{-1} kg^{-1} OM (Petric and Selimbašić, 2008).

Although several researchers have studied the effects of AR, C/N ratio and MC on the quality of compost, they have focused on one or two influential factors, with few studies designed to address the interaction and order of preference for different factors impacting the composting process. Therefore, an orthogonal test was used to investigate the main factors affecting the stability and maturity of composted pig manure and corn stalks; AR (0.24, 0.48 and 0.72 L kg^{-1} DM min^{-1}, DM: dry matter); C/N ratio (15, 18 and 21); and MC (65%, 70% and 75%).

2. Methods

2.1. Feedstocks

Pig feces were taken from a pig fattening farm that uses the gan qing feng system located in Beijing, China. The feces were collected on three consecutive days before the trial started. Corn stalks were obtained from a research station at China Agricultural University. The corn stalks were passed through a cutting mill to generate pieces ranging from 1 to 5 cm. The MC, C/N ratio, total organic carbon (TOC), total nitrogen (TN) and NH_4^+—N of the feedstocks were measured before mixing. The properties of the feedstocks are shown in Table 4.

2.2. Experimental set-up and design

The composting reactors were 60 L stainless steel cylinders (0.6 m high and 0.36 m inner diameter) (Fig. 1). The vessels were insulated with two layers stainless steel to minimize heat loss. A removable stainless steel lid was fitted to the top of each vessel to facilitate filling with feedstocks and removing compost. On the lid, there were holes for inserting a temperature sensor and sampling gas. The temperature sensor was connected to a computer to auto-record the data. At the bottom of the reactors, a 3 mm stainless steel grid was installed to support the composting bed and insure uniform gas distribution. There were two holes in the bottom of the reactor for aeration (using a controllable aquarium pump) and leachate drainage.

This study was established as an orthogonal test L_9 (3^4) lasting 37 d (Table 5). Pig feces and corn stalks were mixed manually in different amounts to adjust the C/N ratios to 15, 18 or 21, and the initial MC values to 65%, 70% or 75%. The ARs were 0.24, 0.48, and 0.72 L kg^{-1} DM min^{-1}. The aeration of all treatments was intermittent with 25 min of aeration followed by 5 min without aeration over the whole composting period. The compost piles were turned on days 3, 7, 15 and 24.

2.3. Sample collection and analytical methods

Solid samples (about 200 g) were taken at the beginning and end of composting and after each turning. The samples were divided, with one part stored at 4 °C, and the remainder air-dried and grounded to pass through a 1 mm sieve. The dried and ground samples were analyzed in triplicate for total nitrogen (TN) and

Table 4
Properties of the pig feces and corn stalks.

Materials	Moisture content (%)[a]	C/N (–)	TOC (g kg^{-1})[b]	TN (g kg^{-1})[b]	NH_4^+—N (g kg^{-1})[a]
Pig feces	71.2(1.55)[c]	13.2	362(5.82)	27.4(0.07)	1.1(0.01)
Corn stalk	8.9(0.01)	41.5	419(8.10)	10.1(0.12)	–

[a] Wet weight basis.
[b] Dry weight basis.
[c] Values in parentheses are standard errors ($n = 3$).

total organic carbon (TOC). Gas samples (600 μL) were taken daily from the gas sampling port and analyzed for CO_2 using a gas chromatograph (GC-9900, made in China) equipped with a thermal conductivity detector. Ammonia was trapped in a boric acid wash bottle and titrated against sulfuric acid (0.1 N, H_2SO_4), while O_2 was monitored using an oxygen sensor (DH6511A, made in China).

The TN, TOC were analyzed in accordance with the Chinese national standard (NY 525–2002). The NH_4^+—N, NO_3^-—N and NO_2^-—N were extracted with 2 M KCl (1:10 fresh solid sample to KCl, weight/volume) and analyzed in triplicate using a segmented flow analyzer (Technicon Autoanalyser system, Germany). The MC was determined in triplicate by drying 5 g fresh samples at 105 °C to a constant weight.

A water extract was prepared for the determination of the seed germination index (GI). Fresh solid samples were mixed with deionized water at a 1:10 ratio (mass ratio) and shaken for 1 h, then centrifuged at 4000 rpm for 20 min and filtered through 045 μm membrane filters. The GI was determined in triplicate using ten cucumber seeds and a water extract. Eight milliliter of the water extract was pipetted into petri dishes (10 cm in diameter) packed with a piece of filter paper. Ten seeds were evenly scattered on the filter paper and incubated at 20 ± 1 °C for 48 h in the dark. Deionized water was used as a control. The GI was calculated as follows:

GI (%) = [seed germination of treatment (%) × root length of treatment] × 100/[seed germination of control (%) × root length of control]

2.4. Statistical analysis

Data were analyzed by a one-way analysis of variance (ANOVA); the LSD-*t* test was used for significant difference testing. Pearson's correlation coefficient was used for the analysis of bivariate correlations. The SPSS 17 software for Windows was used for all statistical analyzes.

Table 5
Design of experiment.

Treatment	Moisture content (%)	Aeration rate[a] (L kg^{-1} DM min^{-1})	C/N
T1	65	0.24	15
T2	65	0.48	18
T3	65	0.72	21
T4	70	0.24	18
T5	70	0.48	21
T6	70	0.72	15
T7	75	0.24	21
T8	75	0.48	15
T9	75	0.72	18

[a] Aeration for 25 min, no aeration for 5 min

3. Results and discussion

3.1. Temperature and oxygen

Fig. 2 shows the changes in the ambient temperature and composting temperature. The ambient temperature ranged from 20 °C to 30 °C. The composting materials went through the three typical degradation phases: mesophilic, thermophilic and curing. Because of the metabolism of the psychrophilic and mesophilic microbes, the temperatures of treatments with moderate and high ARs reached the thermophilic phase (>50 °C) within the first 1–2 d. The temperatures of the treatments with the low AR rose more slowly but remained above 50 °C for the longest time. This difference is because the lowest AR leads to a lower organic degradation rate and lower losses of moisture and heat. The thermophilic phase (>50 °C) for all treatments lasted longer than 7 d and met the sanitation requirements specified in the Chinese national standard (GB 7989–87). After the easily degradable compounds were depleted, the composting entered the curing phase and the temperature slowly dropped. The statistic analysis showed that the AR had a significant influence on the change in temperature ($p = 0.023$), but the MC and the C/N ratio did not significantly affect the temperature ($p = 0.747$, $p = 0.134$).

The oxygen content in the outlet air during composting decreased sharply during the first day, from 21% to 2–6.3%, 10.9–11.3% and 12.2–16.3% for the low, moderate and high ARs, respectively, and a slowly fluctuating increasing trend was observed thereafter (Fig. 2). As the composting temperature became close to the ambient temperature, the oxygen content returned to 21%. During the whole composting period, the oxygen contents of all treatments were significantly negatively correlated to their temperatures ($R = -0.807$ to -0.944, $p = 0.000$). Magalhaes et al. (1993) identified that the oxygen content should be more than

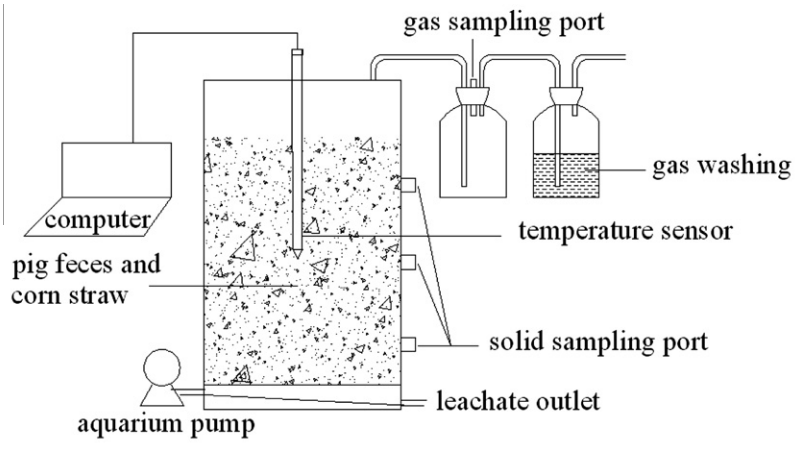

Fig. 1. Diagram of the composting vessel.

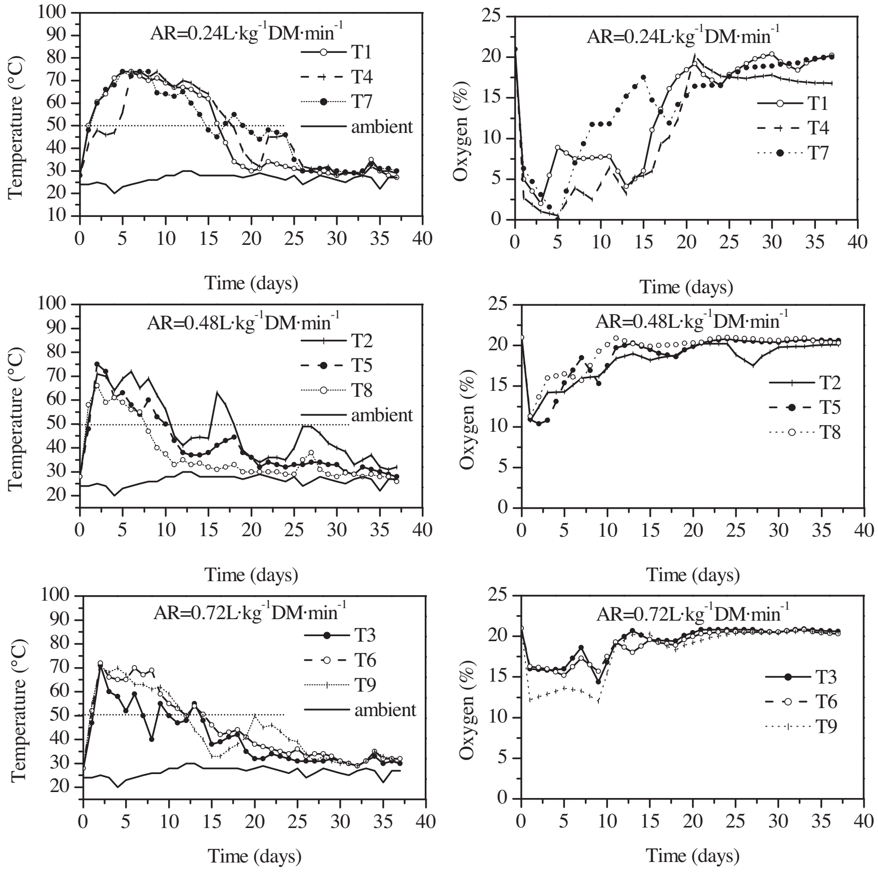

Fig. 2. Temperature of the compost in the vessel and oxygen content in the outlet air during composting (AR: aeration rate).

10% for optimum microorganism activity. The oxygen contents of the moderate and high AR treatments were continually above 10%, and reached 21% at day 13. The oxygen content was below 10% during the thermophilic phase with the low AR, indicating that 0.24 L kg^{-1} DM min^{-1} does not provide sufficient oxygen for the microorganism's requirements. The statistic analysis showed the AR can significantly influence the oxygen content ($p = 0.000$). There were no significant differences between the 0.48 and 0.72 L kg^{-1} DM min^{-1} AR treatments ($p = 0.849$), but both of those treatments were significantly different from the low AR treatment ($p = 0.000$, $p = 0.000$).

3.2. Carbon dioxide and Total organic carbon

The CO_2–C concentrations in the outlet air during composting (Fig. 3) were significantly correlated to their temperatures ($R = 0.360–0.936$, $p = 0.000–0.026$). Carbon dioxide was mainly emitted during the thermophilic period because of the degradation of easily degradable carbon under vigorous bacterial and fungal activity. During the curing period, CO_2 emissions are related to the degradation of complex organic molecules such as lignin and lignocelluloses by some fungi and actinomycetes. After composting, the CO_2 emissions from T1 to T9 were 239–464 g CO_2–C kg^{-1} of initial total carbon. Treatment T8 had the lowest CO_2 emissions indicating that a high MC and a low C/N ratio restricted organic degradation even at a high AR. This low degradation rate occurred because the large pieces of waste material (diameter 3 cm) combined with a low C/N ratio and high MC reduced the oxygen diffusion rate into the interior of the waste particles, reducing microbial activity. The statistic analysis showed that neither the AR, C/N ratio nor the MC had a significant influence on CO_2 emissions.

Wang et al. (2004) suggested that the composts from cattle and pig manure were more stable when the respiration rates were below 1 mg CO_2–C g^{-1} DM d^{-1}. Higher CO_2 emissions indicate unstable compost that needs further decomposition. On day 37, the CO_2 emissions from treatments T1, T3, T5, T8 and T9 were 0.30–0.90 mg CO_2–C g^{-1} DM d^{-1}, but the emissions for the other treatments were 1.04–1.99 mg CO_2–C g^{-1} DM d^{-1}. The low CO_2 emission rate for treatment T8 was related to its low activity.

The total organic carbon (TOC) contents of all treatments decreased during composting (Fig. 3). As with the CO_2 emissions, the rates of decrease were greater during the thermophilic phase (67–92% of the total carbon loss) and less during the curing phase. A total of 34–55% of the initial TOC (348–409 g kg^{-1} DM) was lost at the end of composting (Table 6). Higher TOC losses occurred with the higher AR except for treatment T8, which had low activity. At the end of composting, CO_2 was the main source of carbon loss, accounting for 70–85% of the total carbon losses. The remaining carbon losses were caused by the emission of CH_4 and other volatile organic compounds (such as methyl mercaptan and dimethyl sulfide) (Hanajima et al., 2010).

3.3. Nitrogen variations

As shown in Fig. 4, the initial NH_4^+—N contents of the treatments with C/N ratios of 15, 18 and 21 were 1.83–2.25, 1.25–1.64 and 0.90–1.25 g kg^{-1} DM, respectively. The NH_4^+—N contents of all treatments, except T8, increased during the first day and reached the maximum values (1.70–8.22 g kg^{-1} DM) on day 7. This increase is related to the conversion of organic nitrogen into ammonia by ammonification. The statistic analysis showed that the AR significantly influenced the increase in NH_4^+—N content ($p = 0.004$), but

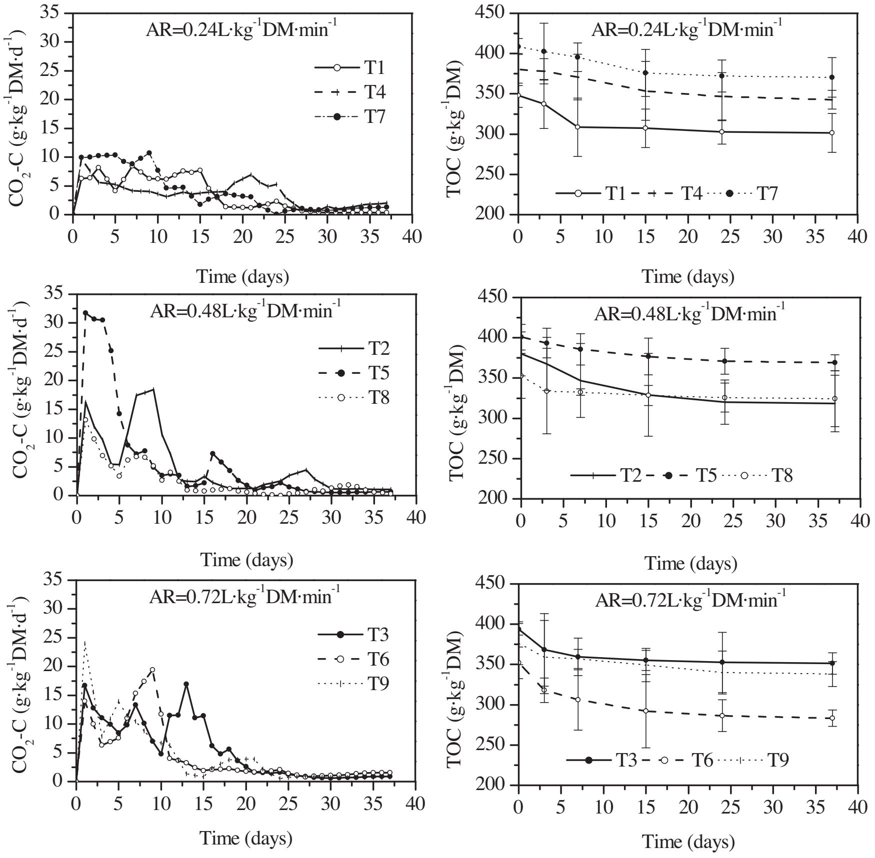

Fig. 3. CO_2–C in the outlet air and TOC during composting (AR: aeration rate).

no significant changes were attributed to the MC ($p = 0.931$) and C/N ratio ($p = 0.828$). There was no significant difference between the moderate and high AR treatments ($p = 0.698$), but the low AR treatments were significant different from the moderate and high ARs ($p = 0.003$, $p = 0.002$). The low AR treatments had the highest increase in NH_4^+—N and the lowest N losses as NH_3. The higher ARs enhanced the emission of NH_3 and the transformation of aqueous NH_3 to gaseous NH_3. After day 7, the NH_4^+—N content decreased because of NH_3 volatilization at high temperature and high pH (data not shown), immobilization as nitrogenous compounds such as amino acids, nucleic acids and proteins (Sánchez-Mondero et al., 1999) by microbes, and the conversion of NH_4^+—N to NO_3^-—N. The NH_4^+—N content in treatment T8 remained at a higher level (2.25–2.92 g kg^{-1} DM) during the whole composting period, as the lowest C/N ratio (15) and the lowest amount of bulking agent in this treatment led to the compaction of the materials, while the high MC allowed the absorption of some of the NH_3, which impeded microbial activity and NH_3 volatilization. The low microbial activity was also reflected by the low temperature (<40 °C) after day 9, low CO_2 emissions and only slight changes in the TOC and NO_3^-—N contents. Previous studies have shown that compaction and rainfall or adding water to the compost pile can significantly reduce NH_3 emissions by 30% to 90% (Chadwick, 2005; El Kader et al., 2007).

High NH_4^+—N concentrations in compost indicate instability (Sánchez-Mondero et al., 2001). The maximum NH_4^+—N content in mature compost should be less than 0.4 g kg^{-1} (Zucconi and de Bertoldi, 1987). At the end of composting, the NH_4^+—N contents were below the limit value of 0.4 g kg^{-1} for all treatments except T1 and T8. The statistical analysis showed that there was

Table 6
Total carbon and nitrogen mass balance at the end of composting.

Treatment	Total organic carbon (TOC)			Total nitrogen (TN)		
	Initial (g kg^{-1} DM)	Final (g kg^{-1} DM)	ΔTOC[a] (%)	Initial (g kg^{-1} DM)	Final (g kg^{-1} DM)	ΔTN[b] (%)
T1	348	302	43	24	28	21
T2	380	319	50	21	26	27
T3	394	351	53	19	24	31
T4	380	343	41	21	25	22
T5	401	369	55	19	28	28
T6	352	284	50	24	21	46
T7	409	371	46	19	26	18
T8	353	324	34	24	20	40
T9	376	338	49	21	24	35

[a] Based on initial carbon content.

[b] Based on initial nitrogen content.

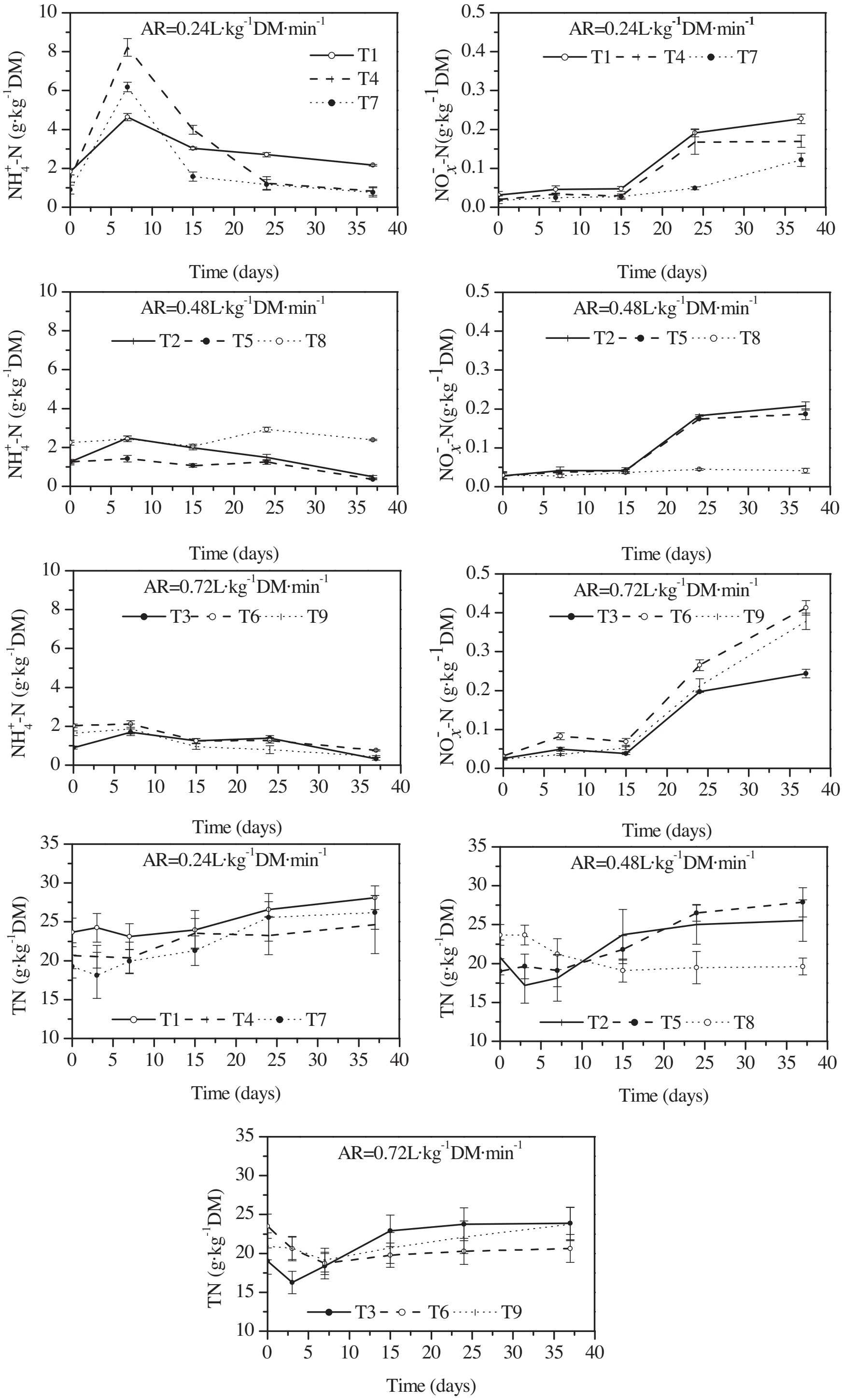

Fig. 4. NH_4^+—N, NO_x^-—N and TN in the compost (AR: aeration rate).

significant negative correlation between the NH_4^+—N content and the GI ($R = -0.556$, $p = 0.037$).

The initial NO_x^-—N concentrations were very low for all treatments (0.02–0.03 g kg^{-1} DM) (Fig. 4). The NO_x^-—N concentrations did not change significantly until day 15 (0.03–0.07 g kg^{-1} DM) because of the inhibition of the growth and activity of nitrite bacteria and nitrobacteria from excessive NH_3 accumulation and high temperatures (more than 40 °C) (Sánchez-Mondero et al., 2001). After day 15, the NO_x^-—N content of all treatments except T8 increased rapidly due to the fast conversion of NH_4^+—N to NO_x^-—N, and the final NO_x^-—N concentrations were 0.12–0.38 g kg^{-1} DM. However, in treatment T8, the NO_x^-—N concentration changed only slightly and the final value was 0.04 g kg^{-1} DM.

An NH_4^+—N/NO_3^-—N ratio of less than 0.16 has been established as a maturity index for composts of various origins including pig slurry, poultry manure, municipal refuse and sewage sludge (Bernal et al., 1998). In this study, the NH_4^+—N contents were clearly higher than the NO_x^-—N contents and the NH_4^+—N/NO_3^-—N ratios ranged from 1 to 60. After 56 d of composting swine manure with corncobs, Zhu (2006) measured final NH_4^+—N/NO_3^-—N ratios of 9.13 to 48.33, while after 63 d of composting swine manure with rice straw the ratios were about 5.47–6.93 (Zhu, 2007), although

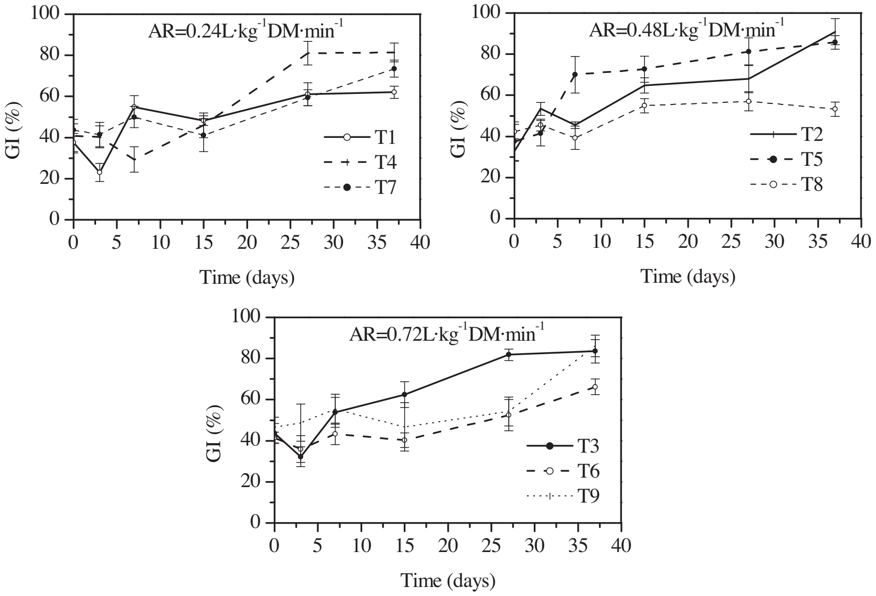

Fig. 5. Germination index (GI) during composting (AR: aeration rate).

both composts were mature. Therefore, the NH_4^+—N /NO_x^-—N ratio may not be suitable as a maturity index for pig manure composts, and this should be further studied.

Fig. 4 shows the variation in the TN content. The TN contents of treatments with moderate and high ARs decreased during the thermophilic phase because of intensive NH_3 volatilization, but only minor changes in TN were observed for treatments at the low AR. The TN increased after the thermophilic phase for all treatments except T8, because the rate of N loss as NH_3 was slower than the rate of dry matter loss as CO_2 and water evaporation (Huang et al., 2004). The TN in treatment T8 decreased slightly, but had little variation after day 15, which is related to the minor losses of NH_3 by aeration coupled with the low carbon and vapor emissions due to the inactive state of the material. At the end of composting, the TN losses were 18% to 46% (Table 6). The statistical analysis showed that AR ($p = 0.045$) had the most significant influence on the nitrogen losses compared with the MC ($p = 0.747$) and C/N ratio ($p = 0.426$). There was a significant difference between the treatments with low and high ARs ($p = 0.018$), but no significant differences between those two treatments and the moderate AR ($p = 0.0740$, $p = 0.329$). Thus, we conclude that higher ARs can cause higher nitrogen losses.

3.4. Germination index

The GI is a sensitive indicator of maturity and phytotoxicity (Tiquia et al., 1996b). Fig. 5 shows the changes in GI for all treatments. The GIs of all treatments except T5 decreased slowly during the early phase. Fang et al. (1999) attributed this drop to the production of low molecular weight short chain volatile fatty acids (mainly acetic acid) and ammonia. The GIs increased with the decomposition of these toxic materials. The statistical analysis showed that the C/N ratio had a significant influence on GI ($p = 0.004$), but MC ($p = 0.771$) and AR ($p = 0.864$) were not important influential factors. No significant differences were found between the treatments with C/N ratios of 18 and 21 ($p = 0.328$), but both of those were significantly different from the treatments with a C/N ratio of 15 ($p = 0.002$, $p = 0.006$).

A GI of more than 80% indicates phytotoxic-free and mature compost (Tiquia and Tam, 1998). At the end of composting, the GIs for treatments with a C/N ratio of 18 were higher than treatments with a C/N ratio of 21 at the same AR, and both were much higher than treatments with a C/N ratio of 15. The GIs of the treatments at the lowest C/N ratio were 53–66%, suggesting that a longer time was required to form mature compost when a low C/N ratio was used. This result is similar to that found by Huang et al. (2004), who used two static aerobic piles (initial C/N ratios of 15 and 30) to compost pig manure, and found that at day 63, the GIs were 46% and 85% for C/N ratios of 15 and 30, respectively. The GIs of all treatments with moderate and high C/N ratios except T7 exceeded 80%. The high MC (75%) and low AR ($0.24\ L\ kg^{-1}\ DM\ min^{-1}$) in treatment T7 restricted the decomposition of toxic compounds.

4. Conclusions

The AR was the major factor influencing the stability of compost, while the initial C/N ratio mainly influenced the maturity of the final compost. The MC can affect the quality of compost but not significantly. To economically treat the increasing quantities of pig manure, composting with an AR of $0.48\ L\ kg^{-1}\ DM\ min^{-1}$ and a C/N ratio of 18 is recommended with a MC ranging from 65% to 75%.

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References

Bernal, M.P., Alburquerque, J.A., Moral, R., 2009. Composting of animal manures and chemical criteria for compost maturity assessment. a review.. Bioresour. Technol. 100, 5444–5453.

Bernal, M.P., Paredes, C., Sánchez-Monedero, M.A., Cegarra, J., 1998. Maturity and stability parameters of composts prepared with a wide range of organic wastes. Bioresour. Technol. 63, 91–99.

Chadwick, D.R., 2005. Emission of ammonia, nitrous oxide and methane from cattle manure heaps: effect of compaction and covering. Atmos. Environ. 39, 787–799.

Diaz, M.J., Madejon, E., Lopez, F., Lopez, R., Cabrera, F., 2002. Optimization of the rate vinasse/grape marc for co-composting process. Process Biochem. 37, 1143–1150.

El Kader, N.A., Robin, P., Paillat, J.M., Leterme, P., 2007. Turning, compacting and the addition of water as factors affecting gaseous emissions in farm manure composting. Bioresour. Technol. 98, 2619–2628.

Fang, M., Wong, J.W.C., Ma, K.K., Wong, M.H., 1999. Co-composting of sewage sludge and coal fly ash: nutrient transformations. Bioresour. Technol. 67, 19–24.

Gao, M., Li, B., Yu, A., Liang, F., Yang, L., Sun, Y., 2010a. The effect of aeration rate on forced-aeration composting of chicken manure and sawdust. Bioresour. Technol. 101, 1899–1903.

Gao, M., Liang, F., Yu, A., Yang, L., 2010b. Evaluation of stability and maturity during forced-aeration composting of chicken manure and sawdust at different C/N ratios. Chemosphere 78, 614–619.

Hanajima, D., Kuroda, K., Morishita, K., Fujita, J., Maeda, K., Morioka, R., 2010. Key odor components responsible for the impact on olfactory sense during swine feces composting. Bioresour. Technol. 101, 2306–2310.

Huang, G.F., Wong, J.W.C., We, Q.T., Nagar, B.B., 2004. Effect of C/N on composting of pig manure with sawdust. Waste Manage. 24, 805–813.

Kalyuzhnyi, S., Sklyar, V., Fedorovich, V., Kovalev, A., Nozhevnikova, A., Klapwijk, A., 1999. The development of biological methods for utilization and treatment of diluted manure streams. Water Sci. Technol. 40, 223–229.

Kulcu, R., Yaldiz, O., 2004. Determination of aeration rate and kinetics of composting some agricultural wastes. Bioresour. Technol. 93, 49–57.

Kumar, M., Ou Yan L., Lin J.G., 2010. Co-composting of green waste and food waste at low C/N ratio. Waste Manage. 30, 602-609

Li, X.J., Zhang, R.H., Pang, Y.Z., 2008. Characteristics of dairy manure composting with rice straw. Bioresour. Technol. 99, 359–367.

Liang, C., Das, K.C., McClendon, R.W., 2003. The influence of temperature and moisture contents regimes on the aerobic microbial activity of a biosolids composting blend. Bioresour. Technol. 86, 131–137.

Magalhaes, A.M.T., Shea, P.J., Jawson, M.D., Wicklund, E.A., Nelson, D.W., 1993. Practical simulation of composting in the laboratory. Waste Manage. & Res. 11, 143–154.

Michel, F.C., Forney, L.J., Huang, A.J.F., Drew, S., Czuprendski, M., Lindeberg, J.D., Reddy, C.A., 1996. Effects of turning frequency, leaves to grass mix ratio and windrow vs. pile configuration on the composting of yard trimmings. Compost Sci. Util. 4, 126–143.

Moral, R., Paredes, C., Bustamante, M.A., Marhuenda-Egea, F., Bernal, M.P., 2009. Utilization of manure composts by high-value crops: safety and environmental challenges. Bioresour. Technol. 100, 5454–5460.

Ogunwande, G.A., Osunade, K.O., Adekalu, K.O., Ogunjimi, L.A.O., 2008. Nitrogen loss in chicken litter compost as affected by carbon to nitrogen ratio and turning frequency. Bioresour. Technol. 99, 7495–7503.

Petric, I., Selimbašić, V., 2008. Development and validation of mathematical model for aerobic composting process. Chem. Eng. J. 139, 304–317.

Petrica, I., Šestan, A., Šestan, I., 2009. Influence of initial moisture content on the composting of poultry manure with wheat straw. Biosyst. Eng. 10, 125–134.

Piccolo, A., Spaccini, R., Nieder, R., Richrer, J., 2004. Sequestration of a biologically labile organic carbon in soils by humified organic matter. Clim. Chang. 67, 329–343.

Rasapoor, M., Nasrabadi, T., Kamali, M., Hoveidi, H., 2009. The effects of aeration rates on generated compost quality, using aerated static pile method. Waste Manage. 29, 570–573.

Said-Pullicino, D., Erriquens, F.G., Gigliotti, G., 2007. Changes in the chemical characteristics of water-extractable organic matter during composting and their influence on compost stability and maturity. Bioresour. Technol. 98, 1822–1831.

Sánchez-Mondero, M.A., Roig, A., Cegarra, J., Bernal, M.P., 1999. Relationships between water-soluble carbohydrate and phenol fractions and the humification indices of different organic wastes during composting. Bioresour. Technol. 70, 193–201.

Sánchez-Mondero, M.A., Roig, A., Paredes, C., Bernal, M.P., 2001. Nitrogen transformation during organic waste composting by the Rutgers system and its effects on pH, EC and maturity of the composting mixtures. Bioresour. Technol. 78, 301–308.

Schuchardt, F., Jiang, T., Li, G.X., Mendoza Huaitalla, R., 2011. Pig manure systems in Germany and China and the impact on nutrient flow.. J. Agric. Sci. Technol. 1, 858–865.

Shen, Y., Ren, L., Li, G., Chen, T., Guo, R., 2011. Influence of aeration on CH_4, N_2O and NH_3 emissions during aerobic composting of a chicken manure and high C/N waste mixture. Waste Manage. 31, 33–38.

Tiquia, S.M., Tam, N.F.Y., 1998. Elimination of phytotoxicity during co-composting of spent pig-manure sawdust litter and pig sludge. Bioresour. Technol. 65, 43–49.

Tiquia, S.M., Tam, N.F.Y., Hodgkiss, I.J., 1996a. Microbial activities during composting of spent pig-manure sawdust litter at different moisture contents. Bioresour. Technol. 55, 201–206.

Tiquia, S.M., Tam, N.F.Y., Hodgkiss, I.J., 1996b. Effects of composting on phytotoxicity of spent pig-manure sawdust litter. Environ. Pollut. 93, 249–256.

Wang, P., Changa, C.M., Watson, M.E., Dick, W.A., Chen, Y., Hoitink, H.A.J., 2004. Maturity indices for composted dairy and pig manures. Soil Biol. Biochem. 36, 767–776.

Zhu, N., 2006. Composting of high moisture content swine manure with corncob in a pilot-scale aerated static bin system. Bioresour. Technol. 97, 1870–1875.

Zhu, N., 2007. Effect of low initial C/N ratio on aerobic composting of swine manure with rice straw. Bioresour. Technol. 98, 9–13.

Zucconi, F., de Bertoldi, M., 1987. Compost specifications for the production and characterization of compost from municipal solid waste. In: de Bertoldi, M., Ferranti, M.P., L'Hermite, P., Zucconi, F. (Eds.), Compost: Production, Quality and Use. Elsevier, Barking, pp. 30–50.