Effect of aeration rates on the composting processes and Nitrogen loss during composting

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Abstract: Composting is a controlled biological process used to stabilize and transform waste into a soil treatment. Aeration rate is one factor that controls the process of composting, as it ensures the growth of adequate aerobic microbe populations. To investigate the effect of aeration rates on the physicochemical indexes of compost and the loss of nitrogen content during composting, aerobic composting processes with different aeration rates (A: 0.2 L/min/kg TS, B: 0.05 L/min/kg TS and C: 0 L/min/kg TS) were studied. Ammonium-nitrogen, nitrate nitrogen, total nitrogen and other factors in compost samples from different periods were measured. The results showed that aeration rate significantly affected O_2 content under different conditions. The aeration rate also significantly affected water content, nitrate nitrogen, and nitrogen loss. NH_3 emissions increased as aeration rates increased at high temperatures owing to nitrogen loss. These results showed that aeration rate had a significant effect on total nitrogen and ammonia emissions ($p < 0.05$). Thus, optimization of the ventilation method could significantly increase seed germination rate.

Keywords: manure composting, aeration rates, nitrogen loss, NH_3, oxygen gas

1. Introduction

The amount of cattle waste generated in China has increased dramatically with the rapid development of cattle farms. Manure is an important component of agricultural waste but is not properly treated: it is directly discharged into the environment and produces hygiene hazards, odor pollution, ground and surface water pollution due to the leaching of pollutants. Composting is considered an important process by which agricultural organic wastes can be stabilized through the degradation of biodegradable components by microbial communities (El-Nagerabi et al., 2012; Zeng et al., 2011). This process involves a significant loss of nitrogen (Gu et al., 2011).

During the aerobic composting of poultry waste/straw stalks, sludge/straw stalks and poultry waste/sawdust, the total N loss can be 16-76% (Gu et al., 2011). The emission of NH_3 will produce a compost product that has low nitrogen content, diminishing its value as a fertilizer. During composting, 9.6-46% of the initial TN loss of raw materials is in the form of NH_3 emissions (Jiang et al., 2011). Most previous studies have reported that NH_3 emission increases with increasing aeration rates (Jiang et al., 2011; Shen et al., 2011; Wu et al., 2011). This suggests that the aeration rate has a significant influence on the production and emission of NH_3 (Ahn et al., 2011; Shen et al., 2011).

The aeration rate may directly affect the quality of the compost product, loss of nitrogen, and energy consumption. 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 loss of heat, water, and ammonia, causing loss of nitrogen. The maintenance of appropriate oxygen content during composting would limit the formation of anaerobic zones and thereby avoid the generation of intermediate products of anaerobic metabolism (Scaglia et al., 2011). Therefore, it is not known whether the optimal values of aeration rate will lead to minimal loss of nitrogen.

The seed germination test is one common method used to evaluate compost maturity for further agricultural application (Bes et al., 2013). Several factors during the composting process could have an impact on compost maturity, such as aeration rate, pH, initial total ammonia nitrogen content and others (Grunditz and Dalhammar, 2001; Guo, et al., 2012). However, the effects of these factors of compost have not been examined systematically. In particular, the effect of aeration rate has not been examined.

Table 1. Property of raw materials for composting ($\overline{X}\pm$SD)

Material	pH	Water Content (%)	TOC (g/kg Dry sample)	TN (g/kg Dry sample)	C/N ratio
Cow	8.2	69.28±2.37	362.35±10.14	22.61±7.13	16.02
Turf grass	8.3	8.40±1.56	407.15±7.87	7.71±8.35	52.81
Mixture	8.2	64.28±2.73	382.35±11.04	19.61±7.13	19.5

This experiment, using cow dung and turf grass as the main raw materials, using 0.2 L/min/kg TS (treatment A), 0.05 L/min/kg TS (treatment B) and 0 L/min/kg TS (treatment C) as its three aeration rate treatment conditions, simulated the cow dung composting process. We sampled and measured the temperature, water content, pH, ammonium, nitrate, NH_3 and other physical and chemical parameters at different times during the composting process. Meanwhile, we also measured the content and the variation of O_2 in the compost pile. We explored how different aeration rates changed nitrogen content during manure composting. During the manure composting process, we set and regulated a reasonable aeration rate to reduce the loss of nitrogen and to lay the foundations for future study.

2. Materials and Methods

### 2.1. Composting Experimental Materials and Treatment

The experimental materials used were cow dung and turf grass (Table 1). Turf grass was used to adjust the initial C/N ratio of the composting material. Cow dung was collected from the surrounding countryside in Daqing, China. Turf grass was collected from a residential area of Heilongjiang Bayi Agricultural University.

The cow dung was uniformly mixed with turf grass at a 1:1 volume ratio. The water content of the mixture was adjusted to approximately 65%, after which the mixture was put into three fermentation boxes (volume of 0.216 m³, 0.6 m long, 0.6 m wide and 0.6 m high). The starting weight of material was 60 kg in each box.

2.2. Device and Methods

Figure 1 is a schematic diagram of the experimental device. A fermentation room and a control system were included in this composting device. The fermentation room was made of steel and had ventilation screens at the bottom and an insulating layer in the wall. The ventilation control system contained a flowmeter and an air compressor. When the pressure fell below a set value, the ventilation control system could automatically control the air compressor, ensuring the stability of the ventilation rate. The air tester could test the properties of gases.

During the composting process, experiments were set up under three aeration rates (treatment A: 0.2 L/min/kg TS;
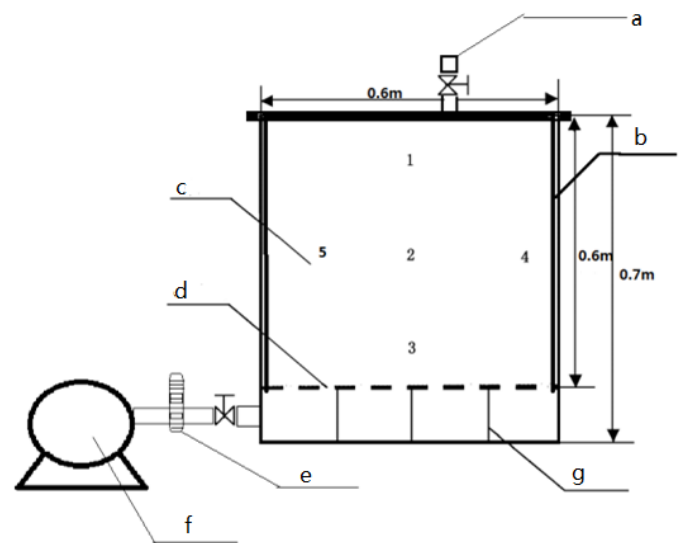
Note: (a) air tester and sealing cover; (b) insulating layer; (c) fermenting room; (d) wire grilling; (e) flowmeter; (f) air compressor; (g) separation wall. Numerical numbers (1, 2, 3, 4, and 5) for sampling points
Figure 1. The construction of manure composting

treatment B: 0.05 L/min/kg TS; and treatment C: 0 L/min/kg TS). After 6 days, the compost piles were plowed (the material in the center of the pile was thoroughly consumed, requiring that the material be fully re-blended). The material was not compacting completely and had air gap. The reactor was usually not sealed with the cover completely. Only when measuring gas, the reactor was sealed with the cover completely.

The composting process proceeded for 60 days. At 0, 1, 2, 3, 5, 7, 14, 21, 28, 35 and 60 d, the O_2 content and NH_3 emissions of the piles were measured. Samples which was about 200 g were collected using multi-point sampling; those not immediately analyzed were stored at 4°C until they were assessed for total carbon, total nitrogen, water, NH_4^+-N and NO_3^--N content and pH. Each treatment was replicated 3 times.

2.3. Determination of Indicators and Methods

The compost pile temperature was monitored by inserting a Digital Thermometer (UT325, China) into the center of the composting material at 13:00 every day.

O_2 content was monitored by inserting a gas detector (GT901-O_2, China) into five different locations (up, down, left, right and center) at 13:00 every day and then calculating the average of the five readings.

NH_3 emissions were measured using a washing bottle with boric acid titrated against H_2SO_4 at 13:00 every day. The fermentation box was sealed with a sealing cover that had an air outlet port. Released gas was absorbed by 0.05% boric acid liquid. After 1 hour, 2 to 3 drops of methyl red - methylene blue mixed indicator were added to the absorbing liquid and titrated with 0.025 mol H_2SO_4 standard liquid.

To determine pH value, a fresh sample of compost was mixed with deionized water (1:10), shaken at 200 rpm for 30 min, and then filtered by vacuum filter. The pH of the filtrate liquid was measured with a small pH detector B-212 (HORIBA, Japan).

Water content was determined by the constant weight method. First, a petri dish was weighed after drying to constant weight; fresh compost was then added to the dish and the dish containing compost was weighed. Then, the dish and compost were placed overnight in a drying box in an oven at 100°C, then removed to a desiccator to cool to room temperature and then weighed. The water content was calculated as follows: water content = (weight difference between the sample before and after being dried / weight of sample before drying) × 100%.

Ammonium-nitrogen (NH_4^+-N) and nitrate-nitrogen (NO_3^--N) content were determined by the KCl extraction-indophenol blue colorimetric method and the spectrophotometric method with phenol disulfonic acid (Sims et al., 1995), respectively.

Total nitrogen (TN) was measured by the Kjeldahl method according to the Chinese national standard for organic fertilizer (NY 525-2012). The sample was completely dissolved in a mixed acid, diluted, filtered and distilled, and finally titrated with boric acid solution. The total nitrogen loss rate during composting = ($m_{starting} \cdot \rho_{start}$-$m_{end} \cdot \rho_{end}$) × 100% / ($m_{starting} \cdot \rho_{start}$), wherein $m_{starting}$ and m_{end} are the total mass of raw materials and the total mass of the compost sample at the end, respectively, and ρ_{start} and ρ_{end} are the corresponding total nitrogen contents.

The TOC of the dried samples was measured using a TOC/TN analyzer (multi N/C ®2100, Jena, Germany), we analyzed the TOC of the dried samples.

To test seed germination, two qualitative filter papers were put into petri dishes that were 9 cm in diameter, 10 test seeds (which were the same size and had a similarly plump shape) were evenly spaced on the filter paper, and 5 mL leaching liquor was pipetted into the petri dishes (deionized water as CK). After culturing the seeds in the dark at 30°C for 48 h, we recorded the seed germination rate and measured the root length. Each treatment was replicated 3 times. The test seeds were cucumber seeds, the germination rate of the test seeds was above 90%, and root morphological characteristics and length were easily measured. According to the following formula, we calculated the relative germination rate (RGP) of seeds, relative root elongation (RRE) and germination index (GI).

RGP (%) = average germination rate of treatment × 100/average germination rate of CK

RRE (%) = average root length of treatment × 100/average root length of CK

GI(%) = RGP×RRE

Significance was tested using SPSS 19.0 software to express the impact of different aeration rates on the nitrogen content of the compost. Figures were created using Origin 9.1 (OriginLab, USA).

3. Results and Discussion

3.1. Temperature and O_2 Content

The temperature during the composting process is an important indicator of whether the compost is decomposed well. The temperatures of the compost under the three treatments were above 50°C on the second day (Figure 2). The maximum temperature of the compost under treatment B was 60°C. Compost under treatment A lost a large amount of heat because it had the highest aeration rate; the high-temperature phase for treatment A lasted four days, but for treatments B and C this phase lasted five days. Accordingly, all three compost piles achieved compost hygiene indicators (GB 7959-1987) (Yu et al., 2007). The compost produced under treatment A lost significantly more heat than did the composts produced under treatments B or C. In the mature stage, the temperature difference among treatments was not significant.
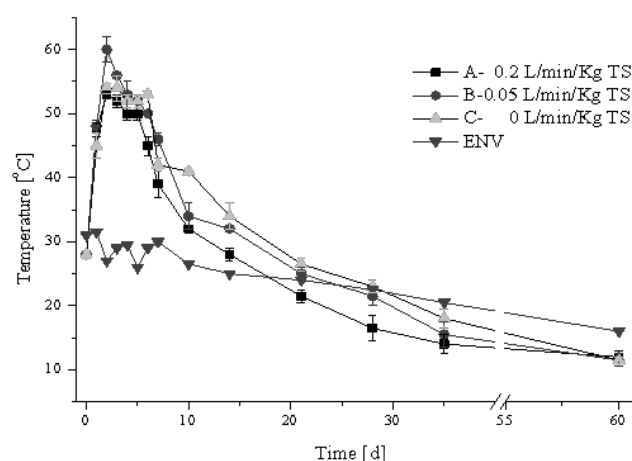
Note: ENV, environment; A, treatment A (0.2 L/min/kg TS); B, treatment B (0.05 L/min/kg TS); C, treatment C (0 L/min/kg TS).
Figure 2. Changes of temperature during composting

But the statistical analysis showed that the aeration rate had a significant influence on the change in temperature in the high-temperature period. Guo et al. (2012) also found this rule.

The change in the O_2 content of the composts essentially followed the same trend for each treatment (Figure 3). The lowest O_2 content was observed on the third day for all treatments. The minimum O_2 contents for treatments A, B and C were 14.10%, 11.26% and 5.19%, respectively. On

the ninth day, when the high-temperature period was completely over, the O_2 content for each treatment increased to 19.90%, 18.44% and 9.21%, respectively. Then, the O_2 content of each pile increased to approximately 20.0% and remained stable until the end of the study. Jiang et al. (2011) and Guo et al. (2012) also found that as the composting temperature became close to the ambient temperature, the oxygen content returned to 20-21%. The reason was that along with composting, the pile became more loosened to let more O_2 gas into the compost pile. In a study of the aerobic composting of manure (Gao et al., 2007), high levels of microbial activity were detected when the air was constantly replenished from the cross-sectional distribution during the heating period and the high-temperature period; meanwhile, O_2 was continuously consumed, so the O_2 content of each pile decreased. The O_2 content of the compost produced under treatments A and B could be adapted to the requirements of aerobic composting because the ventilation was sufficient. At the beginning of the 30 days, the impact of the three different aeration rates on O_2 content was remarkable ($p < 0.05$).
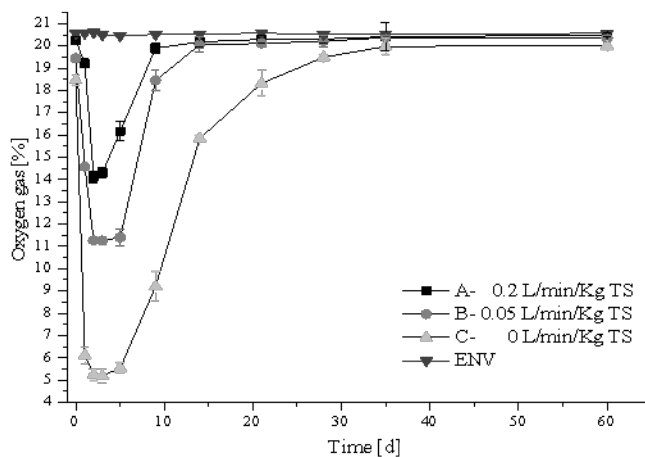

Figure 3. Changes of O_2 content during composting

3.2. pH and Water Content

During the entire composting process, the pH of each treatment was above 7.4 (Figure 4), which was in the range of 6.0-9.0 that is recommended for rapid composting. Figure 4 shows that during the warming period, the pH of the compost produced under treatments A, B, and C decreased to 8.03, 8.03, and 7.5, respectively; the pH for each treatment increased to approximately 8.5 during the high-temperature phase. The pH of the compost produced under treatment C was maintained at 8.0 at the end of the experiment, and the pH for treatments A and B decreased to approximately 7.7. In the early phase of composting, mesophilic microorganisms can rapidly decompose organic matter; nitrification bacteria can turn ammonia and ammonia compounds into nitrate as a result of a decline in pH. Owing to the lack of O_2, treatment C produced more acidic substances during the decomposition of organic matter. Therefore, the pH of

compost produced under treatment C decreased significantly during the high-temperature period. But from the seventh day to the sixty-third day, the pH of treatment C was higher than A and B, the result was not the same as the result of the Michel Jr and Reddy's (1998) research. At low oxygenation rates (0 and 0.1 ml O_2/min) composts had a low pH (< 5.0), and high levels of soluble salts (>7 mS), phosphorus, and ammonia. In contrast, at the highest rate of oxygenation (10 ml O_2/min), the final compost had an alkaline pH (8.6). The reason might be more NH_3 emission from treatment B and A. Statistical analysis shows that the impact of aeration rate on pH is significant ($p < 0.05$).
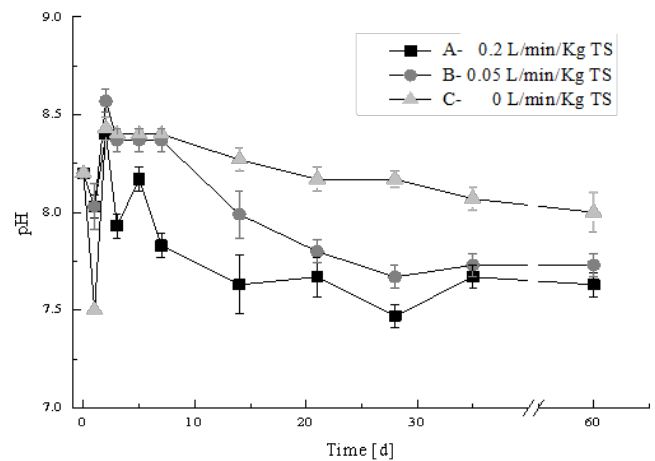

Figure 4. Changes of pH during composting

As treatment A was the highest aeration rate, more water was removed from the compost and the water content decreased rapidly. At the end of composting, the water content for treatments A, B and C decreased to 39.47%, 44.25% and 49.50%, respectively (Figure 5). Statistical analysis showed that, at the end of composting, the impact of the three treatments on water content was significant ($p < 0.05$). The results were in contrast with the research carried out by Zhou et al.(2014). Zhou et al.(2014) found that after the aeration rate increased to a certain extant, the water removal rate would not increase significantly. But this result showed that the aeration rate was negatively correlated with water content in the compost pile.

3.3. NH_4^+-N, NO_3^--N and NH_3

Figure 6 shows that in the early phase of composting, the NH_4^+-N content of each compost pile decreased. Subsequently, the NH_4^+-N content of each compost rose rapidly. On day 5, the NH_4^+-N content of compost produced under treatments A, B and C reached maximum values of 659 mg/kg, 771 mg/kg and 623 mg/kg, respectively. The NH_4^+-N content in the late high-temperature period showed a significant decreasing trend with each treatment. At the end of 60 days of composting, the NH_4^+-N content for each treatment was above 25 mg/kg. According to the study of Bernal et al. (1998), at the end of composting, when NH_4^+-N content is lower than 0.4 g/kg, compost can be considered to have reached maturity. Statistical analysis showed that

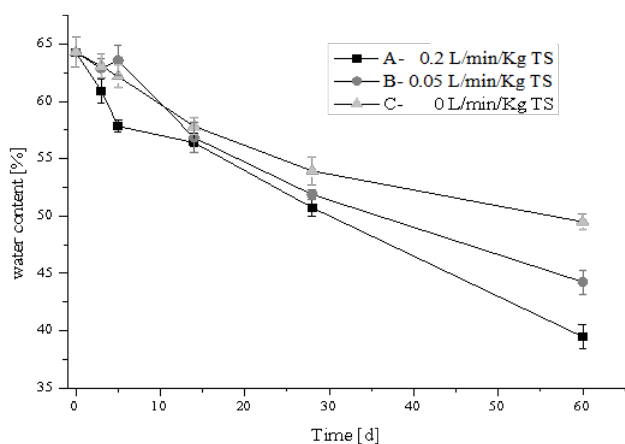the differences in NH_4^+-N content for the three treatments are not significant ($p > 0.05$).

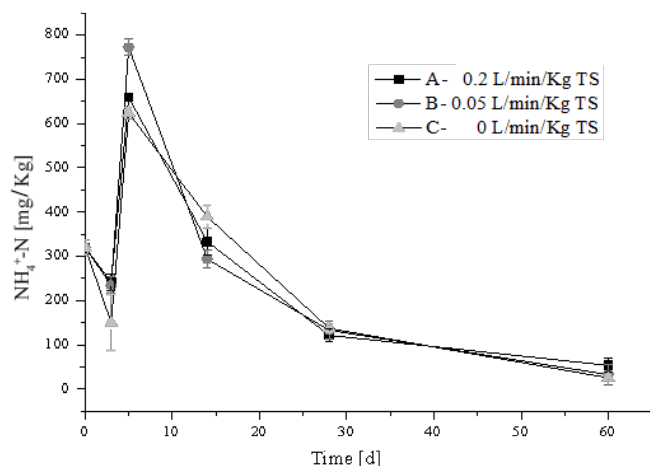**Figure 5.** Changes of water content during composting

Figure 6. Changes of NH_4^+-N during composting

During the warming period, the NO_3^--N content of compost produced under treatment A, B, and C decreased to 375.9 mg/kg, 155.8 mg/kg and 254.1 mg/kg, respectively (Figure 7). After the warming period, the NO_3^--N content of all composts increased. At the end of composting, the NO_3^--N content of composts produced under treatments A and B were 816 mg/kg and 710 mg/kg, respectively. However, the NO_3^--N content of compost produced under treatment C was only 510 mg/kg. These results showed that treatments A and B, owing to the supply of oxygen, may be more conducive to the generation of NO_3^--N. Statistical analysis showed that the differences in NO_3^--N content for the three treatments were significant after the fourteenth day ($p < 0.05$).

Figure 8 shows that the NH_3 emission trends of composts produced under treatments A and B were consistent. During the high-temperature period, the NH_3 emissions for treatments A and B reached their maximum values of 38.25 mg/h and 14.03 mg/h, respectively. The result showed that the peak of NH_3 emissions coincided with the maximum of temperature and oxygen uptake rate, and was confirmed by
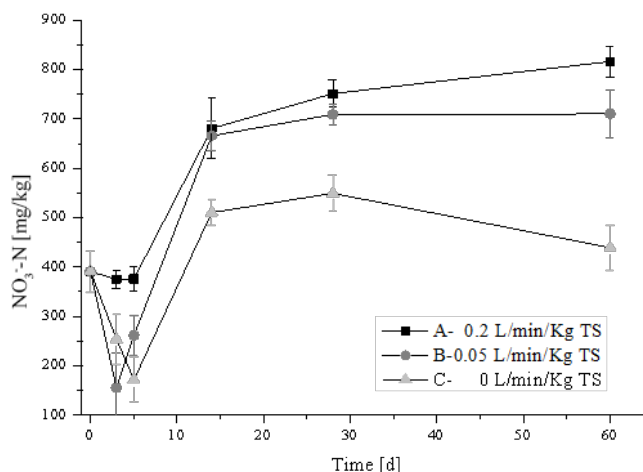

Figure 7. Changes of NO_3^--N during composting

previous studies by Pagans et al. (2006) and de Guardia et al. (2008). Then NH_3 emissions declined with the decomposition of organic matter and strengthening of nitrification. During the late phase of composting, NH_3 emissions were close to zero. NH_3 emissions from compost produced under treatment C was very low during the whole composting phase and was only 0.85 mg/h during the high-temperature period. The aeration strategy used influences gaseous emissions during composting. This result is consistent with a previous study, which observed that NH_3 emissions increased with higher aeration rates (Shen et al., 2011). The findings of Shen et al. (2011) and Chowdhury et al. (2014) are also in agreement with those of other authors.
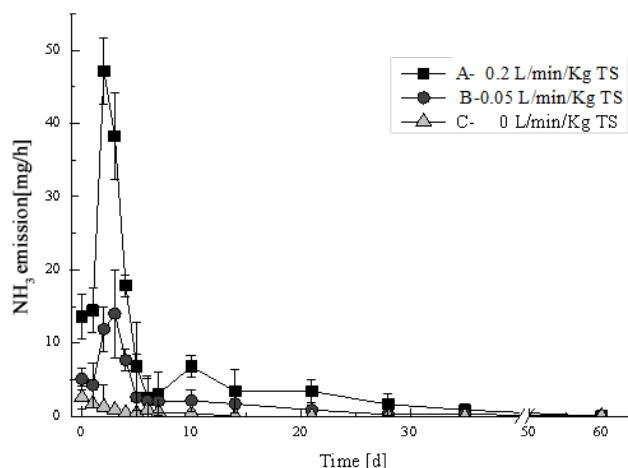

Figure 8. Changes of NH_3 during composting

In the early composting phase, mesophilic microorganisms can rapidly decompose organic matter, and nitrification bacteria can turn ammonia and ammonia compounds into NO_3^-, causing declines in the pH and NH_4^+-N content and increases in the NO_3^--N content of each compost. Treatment A had the highest aeration rate; therefore, the loss of NH_4^+-N in the form of NH_3 was greatest under these conditions. Recently, a design has been suggested that includes a compost bio-filter for the capture of NH_3 emissions and their

conversion to NO_3^- during manure digestion (Posmanik et al., 2013).

When Michel Jr and Reddy (1998) researched the impact of different O_2 replenishment amounts on compost, they found that NH_3 emissions increased when the O_2 replenishment amount increased. This is consistent with the results of our study. Figure 8 shows that aeration rate has a major impact on NH_3 emissions in the early phase of composting. Jiang et al. (2011) also found that aeration rate was the most important factor which could affect the NH_3.

3.4. TOC/TN, TOC and TN

The carbon to nitrogen ratio (TOC/TN) showed a clearly decreasing trend from initial values of approximately 21 to final values of 12.41, 12.97, and 13.67 for compost produced under treatments A, B, and C, respectively (Figure 9). In each pile, this ratio decreased slowly throughout the composting process. The final TOC/TN ratios were an indication of compost stability and compost maturity, and they were between 10:1 and 15:1 for the final composts (Ogunwande and Osunade, 2011). The initial TOC/TN ratios were consistent with values determined by Rasapoor et al. (2009) for a wide range of organic wastes, while final values for the three piles were lower than 20, which is thought to be the threshold limit for compost maturity. The low C/N ratio of the final compost was mainly a result of the degradation of the organic carbon (Zhu, 2007).
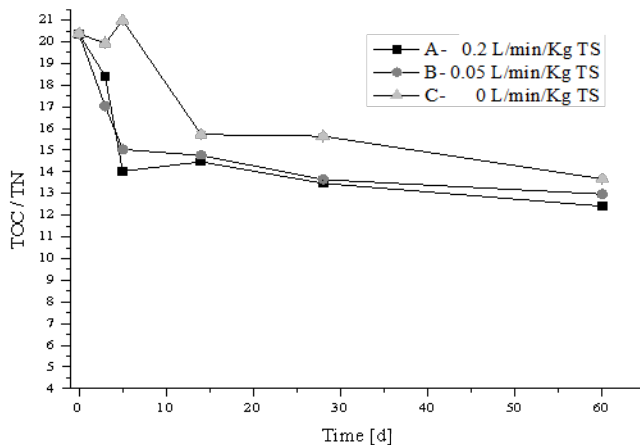

Figure 9. Changes of TOC/TN during composting

Throughout the entire composting process, the total organic carbon (TOC) of all composts declined (Figure 10). In the early composting phase, TOC decreased significantly for all treatments. At fifth day, the TOC content of compost produced under treatments A, B and C decreased to 216.89 g/kg, 258.89 g/kg and 316.80 g/kg, respectively, from the initial 389.91 g/kg. During the cooling period, the TOC content change for each treatment was smooth. At the end of composting, the TOC content for treatment A was slightly lower than B or C, and the TOC contents for treatments A, B and C decreased to 249.79 g/kg, 264.41 g/kg and 265.63 g/kg, respectively. As seen from our results, the influence of

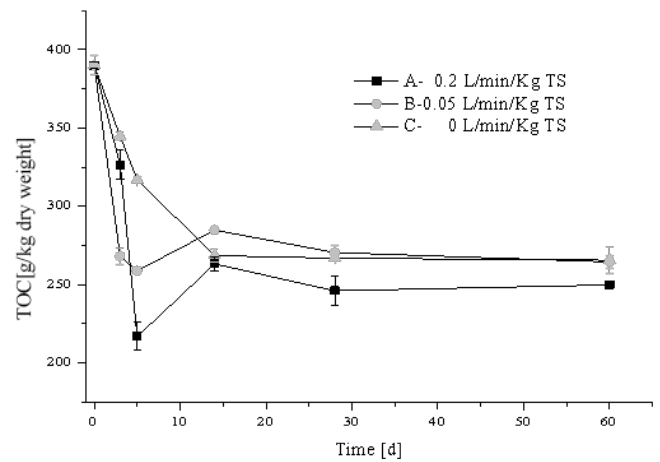ventilation on the TOC content change during the composting process was not significant.

Figure 10. Changes of TOC during composting

Total nitrogen content (TN) is a significant indicator of the fertilizer efficiency of compost products. Figure 11 shows the changes in TN during composting with each treatment: TN decreased at the beginning of composting, then increased. During the high-temperature phase, the minimum TN for treatments A, B, and C declined from 19.15 g/kg to approximately 15 g/kg at the fifth, third and fifth days, respectively. During the composting process, the loss of CO_2 and the microbial mineralization of organic matter led to a reduction in dry matter content; this was greater than the loss of TN. At the end of composting, the TN had increased; the TN of compost produced under treatment B (20.38 g/kg) was greater than that of treatments C (19.43 g/kg) or A (20.12 g/kg). Figure 11 shows that the increase in TN for treatment C was larger than the loss of nitrogen.
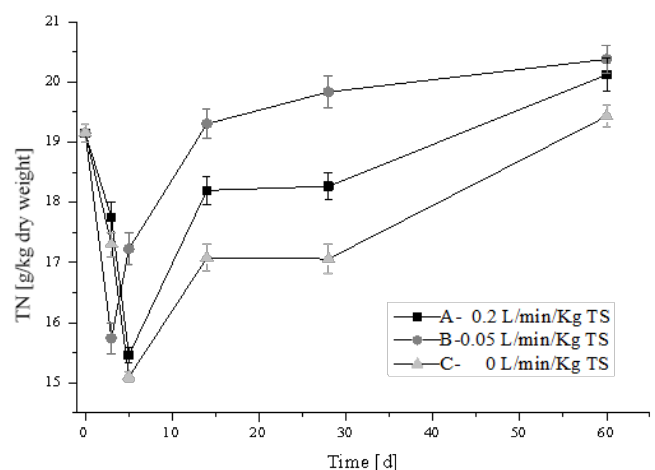

Figure 11. Changes of TN during composting

3.5. Nitrogen Loss Under Different Treatments

The nitrogen loss measurements for compost generated under the three different aeration rates are shown in Table 2.

Table 2. The loss of nitrogen during composting with different aeration rate

Treatment	Initial TN	Final TN	Nitrogen loss	Nitrogen loss rate	NH$_3$ emission	NH$_3$ emission rate
	(g/kg VS)	(g/kg VS)	(g/kg VS)	（%）	(g/kg VS)	(%)
A	437.78	409.28	28.5	6.51	5.81	20.38
B	437.78	418.39	19.39	4.43	1.91	9.85
C	437.78	434.11	3.68	0.84	0.21	5.71

Note: Nitrogen loss rate: Nitrogen loss/Initial TN.

NH$_3$ emission rate: NH$_3$ emission/Nitrogen loss.

The nitrogen loss for treatment A was the largest and the total amount of nitrogen lost (in the form of NH$_3$ emissions) was 20.38%. The NH$_3$ emission rates for treatments A and B accounted for 9.85% and 5.71% of nitrogen loss, respectively. The amounts of nitrogen lost and the rate of nitrogen loss with treatment C, for which the aeration rate was 0 L/kg/min, were 3.68 g and 0.84%, respectively. This result indicates that NH$_3$ emissions are influenced by aeration rates. Statistical analysis shows that the aeration rate has a significant effect on nitrogen loss and NH$_3$ emissions from compost. The results for treatments A and B were similar to those of Guo et al. (2012). Higher aeration rates can cause higher nitrogen losses.

3.6. Seed Germination Rate

The seed germination index (GI) is an important factor in judging the maturity of compost. The composting process produces large amounts of substances that are toxic to plants, and the amounts of these toxic substances are gradually reduced as the compost matures is increased (Hase and Kawamura, 2012). When the seeds germinate with a GI greater than 50%, the compost is considered to be mature (Zucconi et al., 1981). On the sixty-third day, the GIs of composts produced under treatments A, B, and C were 53.54%, 64.81%, and 39.51%, respectively, and on day 0, the GI of the feedstock was 18.56% (Figure 12). Thus, treatments A and B produced mature compost, but treatment C (static composting) did not. Increasing dissolved oxygen is an important factor in achieving successful aerobic composting. Ventilation is one of the main measures used to increase dissolved oxygen. Treatments A and B can promote sufficient contact between the compost medium and the air to provide oxygen for the aerobic microorganisms, thus increasing microbial activity and accelerating maturation. Statistical analysis showed that ventilation could significantly affect the seed germination index (p<0.05).

4. Conclusion

The present study suggested that different aeration rates had a significant impact on temperature during the high-temperature period of composting. The ventilation rate significantly influenced the water content, pH, NO$_3^-$-N, and nitrogen loss of samples. The cumulative volatilization of NH$_3$ increased with an increase in the aeration rate: a higher
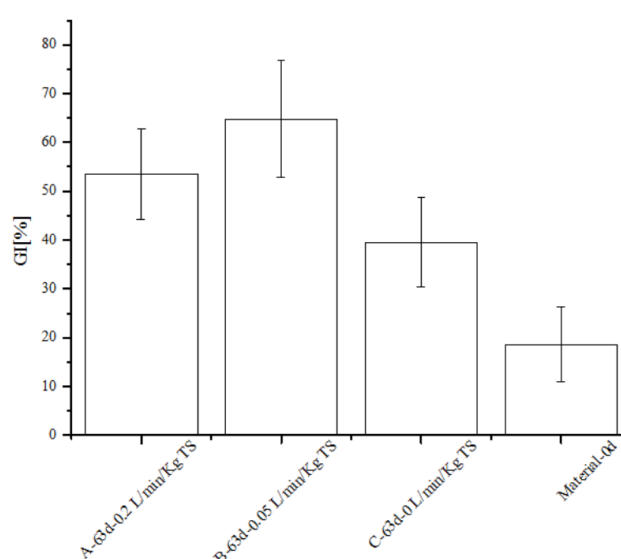
Note: Values were averages of three replicates±SD.
Figure 12. Seed germination rate of different sample of compost

aeration rate led to a higher NH$_3$ emission rate. The ventilation method could improve the degree of fertilizer maturity and therefore increase GI.

Based on our research, we hold the opinion that proper ventilation can increase the nitrogen content to increase the quality of the compost when static aeration technology is used for composting, and we recommend that the optimal ventilation quantity is about one time volume of fermentation heap. In the future, the relationship of carbon loss and nitrogen loss should be carried out during the composting.

Author Contributions

Z-Q Xiong and G-X Wang contributed equally to this work. W-D Wang and J-D Gu designed the experiment. Z-Q Xiong, G-X Wang and Z-C Huo carried out experiment of composting. G-X Wang, Z-Q Xiong and Z-C Huo measured the physicochemical parameters of compost sample. G-X Wang, Z-Q Xiong and W-D Wang carries on the statistical analysis to the measured data. G-X Wang, Y Li, Z-Q Xiong and Z-C Huo wrote the paper. W-D Wang, L Yan, J-D Gu, Y-M Gao, and Y-J Wang gave the comments on the draft of the article. All of us comments on the final manuscript.

Conflict of Interest and Funding

No conflict of interest was reported by the authors.

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