Composting of high moisture content swine manure with corncob in a pilot-scale aerated static bin system

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Abstract

Pilot composting experiments of swine manure with corncob were conducted to evaluate the performance of the aerated static bin composting system. Effects of temperature control (60 and 70 °C) and moisture content (70% and 80%) were monitored on the composting by measuring physical and chemical indexes. The results showed that (1) the composting system could destroy pathogens, converted nitrogen from unstable ammonia to stable organic forms, and reduced the volume of waste; (2) significant difference of NH_4^+-N (P = 0.074), and (NO_3^- + NO_2^-)-N (P = 0.085) was found between the temperature control treatments; (3) anaerobic reaction in the treatment with 80% moisture content resulted in significant difference of pH (P = 0.006), total organic matter (P = 0.003), and germination index (P = 0.040) between 70% and 80%. Therefore, the optimum initial moisture content was less than 80% with the composting of swine manure and corncob by using the composting system.

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Keywords: Swine manure; Solid waste; Composting; Composting system; Moisture content; Temperature control

1. Introduction

Conventionally, swine manure is a kind of organic fertilizer used in agriculture in PR China. Not long ago, a national standard (CEPA, 2001a) and a professional legislation (CEPA, 2001b) were made for the livestock and poultry industry. Now, fresh swine manure is regarded as pollutant. Also, fresh swine manure is limited in agricultural use due to pathogens, unstable nutrients, and transportation and preservation difficulties (Li and Zhang, 2000; CEPA, 2001a; Imbeah, 1998). Therefore, the treatment and utilization of swine manure produced by intensive swine industry is a big problem in PR China.

Composting is an aerobic, biological process that uses naturally occurring microorganisms to convert biodegradable organic matter into a humus-like product. The process destroys pathogens, converts nitrogen from unstable ammonia to stable organic forms, and reduces the volume of waste (Imbeah, 1998). In fact, it develops according to the process and principle of organic matter decomposition in soil. Presently, it has become an important method to dispose of organic solid wastes (Stentiford, 1987; Wei, 2000).

In our previous work, active aeration was suggested to use in middle and small scale swine farms by comparing the performance of different aeration systems, including natural aeration, passive aeration, and active aeration, and economical consideration (Zhu et al., 2004). Then, aiming at avoiding too high temperature, reduction of labor costs, and operation convenience, a temperature–time based aeration control system and an aerated static bin composting system were developed (Zhu et al., 2003). Furthermore, two pilot-scale experiments were conducted to evaluate the effect of C/N ratio on the composting of swine manure, and another two to investigate the effect of bulking agents and aeration on the composting of swine manure (Zhu, 2003).

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The aim of this study was to evaluate the performance of the aerated static composting bin system and to investigate the effects of moisture content and temperature control on the composting.

2. Methods

2.1. Description of the experimental system

The experimental installation included composting bins (2 m, 1.5 m, and 1.6 m in length, width and height, respectively), fans (air flow, 1131 m³/h; pressure: 994 Pa; power, 1.5 kW), thermometric sensors, industry control computer, and self-programmed control software—TTime. The software controlled the fans whenever the core temperature of composting pile reached the setting value or the intervals met the setting value. Analog signals gathered by the thermometric sensors were converted to digital signals by A/D equipment and were transmitted to the industry control computer, and the signals then converted by D/O equipment were transferred to relays. The software automatically saved temperature data of the experimental piles per hour. The swine manure was from National Engineering Research Center-Animal Science (NERC-AS) swine farm; corncob was obtained from local farms. The characteristics of raw composting materials are shown in Table 1.

2.2. Operating methods

Groups and corresponding codes, initial moisture content and controlled temperature of the experiments are shown in Table 2. The corncob was smashed into about 5 cm in dimension. Then, the raw material was homogenized with swine manure according to an initial carbon and nitrogen ratio of 20. The initial moisture content of the mixture was adjusted (Table 2) and the mixture was put into composting bins. Composting proceeded 28 days and curing phase was of 28 days.

2.3. Sampling

Temperature at different locations of the piles, including bottom (20 cm from the floor), core, and surface (20 cm to the surface) temperature, and environmental temperature were monitored by the thermometric sensors. The TTime system automatically refurbished the data per 10 s, and saved per 1 h (Zhu et al., 2003). About 2 kg sample was collected at the different locations mentioned above and then homogenized. The samples were divided into two parts, each one with 2 kg. One part was stored at 4 °C. The other was air-dried, and then passed through 1 mm sieve.

2.4. Analytical methods

Moisture content, total organic matter (TOM), pH, NH₄⁺-N, (NO₃⁻ + NO₂⁻)-N, E. coli, roundworm eggs, and germination index (GI) were determined in the fresh samples; total Kjeldahl nitrogen (TKN), total organic carbon (TOC) and organic matter (OM), and humic substance (HS) were determined in air-dried samples. All analyses were carried out in triplicate.

Moisture content of raw materials and composting mixtures was determined by drying the samples at 105 °C for 24 h (Tiquia and Tam, 1998b). Ash was determined in an oven at 550 °C for 8 h and TOM was calculated according to the difference between ash and dry weight. pH was measured by using a digital pH meter (N464, Knick, German) in aqueous extract, which was obtained by mechanically shaking the samples for 1 h with double distilled water at a solid:water ratio of 1:10 (dry weight/volume) for 1 h. Inorganic nitrogen was extracted with 2 mol L⁻¹ KCl and the NH₄⁺-N was determined by distillation in alkaline medium (MgO). The same procedure was used for (NO₃⁻ + NO₂⁻)-N after reduction with Devarda’s alloy (Lu, 2000). The OC and OM were measured by potassium dichromate (K₂Cr₂O₇) and sulphuric acid (H₂SO₄) (Yeomans and Bremner, 1988). TKN, HS, and GI were measured according to Bremner (1996), Nanjing Agricultural University (1992) and Tiquia and Tam (1998a), respectively. E. coli and worm eggs were measured according to CEPA (1987). Solid C/N ratio was then computed based on the concentration of TOC and TKN. Weight loss during the composting was calculated by using the method suggested by Solano et al. (2001) and Veil et al. (1987).

2.5. Statistical analysis

Spss 10.07 (Spss Inc., 1999) was used for statistical analysis. T-test program was used for significant difference test of the treatments.

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Table 1

<table>
<thead>
<tr>
<th>Characteristics of raw composting materials a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw materials</td>
</tr>
<tr>
<td>Moisture content (%)</td>
</tr>
<tr>
<td>Organic carbon (g/kg)</td>
</tr>
<tr>
<td>Total nitrogen (g/kg)</td>
</tr>
<tr>
<td>Carbon and nitrogen ratio</td>
</tr>
</tbody>
</table>

a a ± b: a—Means, b—standard deviation.

Table 2

<table>
<thead>
<tr>
<th>Groups and corresponding codes, initial moisture content and controlled temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pile no.</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
</tbody>
</table>

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3. Results

3.1. Physical changes

At day 0, the swine manure looked filemot, formed conglomerate, had thick malodor and absorbed flies. From the 1st to 3rd day, the piles had screwworms and thick malodor. For nos. 1 and 2, the flies disappeared at about the 7th day. By the 14th day, the swine manure in the piles only smelled light odor. By about the 21st day, they became loose and easy-to-pulverize and smelled like the fragrant humus. For no. 3, the composting mixture became dark, and had thick malodor during the high-speed phase and the curing phase. By about the 56th day, the volume of the piles decreased by 34.56%, 33.74%, and 20.03%, respectively and the weight loss of piles was 34.71%, 39.05% and 20.42%, respectively.

3.2. Temperature

The temperature profiles of the piles 1 and 2 underwent three classic phases: heating phase, thermophilic phase, and cooling phase (Fig. 1). After 63 h heating phase, the temperature of the pile 1 reached its peak value of 70°C at 60 h and the duration of greater than 55°C was 450 h. The pile temperature fluctuated with the ambient temperature at about 670 h. However, the temperature of pile 2 reached its peak value of 60°C at 53 h, and the duration was 209 h. The pile temperature fluctuated with the ambient temperature at about 500 h. But anaerobic reaction occurred in the pile 3, and the pile temperature did not reach the setting value.

3.3. pH value

For nos. 1 and 2, pH value appeared to be the same, which increased after entering thermophilic phase, then followed by gradual decrease, and increased slightly during the curing phase. It was 7.13 at the composting raw mixture; peak value, 7.98 and 8.24 at the 7th day, and 8.65 and 8.27 in the final composts, which matched the suggested criteria (Fong et al., 1999; Li et al., 1999). For no. 3, pH value decreased in the high-speed phase and maintained below 7. Statistical analyses showed that there was no significant difference between piles 1 and 2 ($P_{12} = 0.614$), but significant between piles 2 and 3 ($P_{23} = 0.006$).

3.4. Moisture content

The moisture content in the raw mixture was 70.39%, 71.06% and 80.53% in nos. 1–3, respectively. It gradually decreased and reached 35.87%, 32.36% and 71.86%, respectively in the final composts. According to the description of the former text, anaerobic reaction occurred in the composting mixture due to its too high moisture content, because the jammed hole baffled the transportation of air in the composting mixture (Wei, 2000; Li, 1998).

3.5. TOC, TKN, and solid C/N ratio

TOC of piles 1 and 2 decreased significantly from 398.94 to 324.17 g/kg and 398.47 to 318.11 g/kg, respectively during the composting. KTN increased from 19.94 to 20.69 g/kg and 19.92 to 21.39 g/kg, respectively, which was caused by more decrease in TOC than that in KTN. Thus, solid C/N ratio of piles 1 and 2 decreased from about 20 to 15.67 and 14.87, respectively (Fig. 2). The decrease of the TOC, TKN, and solid C/N ratio of piles 1 and 2 mainly occurred during the high-speed phase. Statistical analyses showed...
that there was no significant difference between piles in TOC ($P_{12} = 0.323$), TKN ($P_{12} = 0.436$) and solid C/N ratio ($P_{12} = 0.319$).

3.6. TOM

TOM content decreased with the composting and stabilized in the curing phase (Fig. 3). There was no significant difference between the piles 1 and 2 ($P_{12} = 0.906$), but significant between the piles 2 and 3 ($P_{23} = 0.003$). The decrease of the TOM mostly occurred from day 0 to 28. This might be caused by easy-to-degradation TOM decomposition in the initial 28 days. However, difficult-to-degradation TOM, such as lignin, would be gradually decomposed in curing phase (Li et al., 1999; Solano et al., 2001).

3.7. NH$_4^+$-N and (NO$_3^-$ + NO$_2^-$)-N

In piles 1 and 2, NH$_4^+$-N increased at first and then decreased (Fig. 4a). But, there was significant difference between the piles ($P_{12} = 0.074$). NH$_4^+$-N content reached its peak value at 14th day due to easy-to-degradation TOM decomposing; however, it gradually decreased after that. In the final composts, NH$_4^+$-N content was 6.45 g/kg and 2.26 g/kg in the piles 1 and 2, respectively, which was consistent with other reports (Fong et al., 1999; Li et al., 1999; Li, 1998). (NO$_3^-$ + NO$_2^-$)-N increased generally (Fig. 4b) and was 133.47 and 247.41 mg/kg in the final composts for piles 1 and 2, respectively. The increase of the (NO$_3^-$ + NO$_2^-$)-N content might be caused by nitrification and nitrification of microorganisms. But there was significant difference between the piles ($P_{12} = 0.085$).

3.8. Humic substance

Humic substance, a brown or black organic substance consisting of partially or wholly decayed vegetable or animal matter, is characterized by its stability (Wei, 1987; Qin, 1987). It was reported that composting was the process that polymerize the decomposed organic matter into humic substance (Li and Zhang, 2000). In this study, the humic substance carbon did not show consistency among the piles compared with that in the initial raw mixture (Table 3). This phenomenon might result from the characteristics of the humic substance, which was formed in time-limited composting by microorganisms and was different from that in nature. Humic substance formed in the composting could be decomposed partly by microorganisms (Li, 1998). However, the proportion of humic carbon to TOC increased with the composting.

<table>
<thead>
<tr>
<th>Pile no.</th>
<th>Initial</th>
<th>End of HSP</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HC$^a$ (g/kg)</td>
<td>HC/TOC$^b$ (%)</td>
<td>HC (g/kg)</td>
</tr>
<tr>
<td>1</td>
<td>159.20</td>
<td>39.91</td>
<td>153.45</td>
</tr>
<tr>
<td>2</td>
<td>158.99</td>
<td>39.90</td>
<td>150.93</td>
</tr>
</tbody>
</table>

$^a$ HSP = high-speed phase.

$^b$ HC = humic carbon.

$^c$ HC/TOC = the percentage of humic carbon and total organic carbon.
3.9. GI

GI is an indicator that can evaluate phytotoxicity and stability by determining relative seed germination and relative root elongation. It is generally considered that phytotoxicity is eliminated when GI reaches 80–85% (Tiquia and Tam, 1998a). In this study, GI gradually increased during the composting (Fig. 5) and in the final compost, GI was 82.96%, 85.85% and 43.59% in piles 1–3, respectively. Significant difference was found between piles 2 and 3 (P<0.040), but not between piles 1 and 2 (P>0.810).

3.10. Sanitarian indicators

If thermophilic duration were long enough, pathogens and parasites would be killed or partly killed. In this study, after 7 days composting, the value of E. coli met the standard and all of roundworm eggs were destroyed after 63 days composting (Table 4). The durations of the thermophilic phase of piles 1 and 2 were long enough to meet the national standard of GB 7959-87 (Table 4). Pile 3 did not reach the set temperature.

4. Discussion

According to the national standard GB 7959-87, the duration of the thermophilic phase should maintain either more than 50–55 °C 5–7 days or more than 55 °C 3 days. In this study, the durations of more than 55 °C of piles 1 and 2 were 698 and 450 h, respectively, except that pile 3 did not reach the set temperature. At the same time, the number of E. coli and roundworm egg of piles 1 and 2 also met the sanitary standard for the non-hazardous treatment of night soil (CEPA, 1987). That it to say, the successful composting of piles 1 and 2 realized the sanitary of swine manure.

In this study, 60 and 70 °C treatments were set for temperature control, and 70% and 80% for moisture content. Temperature is a mirror, which is the reflection of metabolism of microorganisms in composting mixtures, and also affects the metabolism of microorganisms and the process of composting. The range of optimum temperature for development and propagation of mesophilic and thermophilic bacteria is 30–40 and 45–60 °C, respectively (de Bertoldi et al., 1983; Finstein and Morris, 1975). It is well known that the speed of organic matter decomposition in thermophilic phase is faster than that in mesophilic range. Also, thermophilic composting can effectively destroy pathogens and parasites. Therefore, thermophilic composting is widely used. But, the pile ultimate temperature can be 75–80 °C without any control. When the temperature exceeds 60 °C, the development of the microbiology would be suppressed, even destroyed (de Bertoldi et al., 1983; Finstein et al., 1983; Mackinley and Vestal, 1985a,b; MacGregor et al., 1981; Storm, 1985). Hence, it was suggested that the optimum range of the composting was 55–60 °C. The results of this study showed that control of upper limit of temperature or not could result in the significant difference of NH$_4^+$-N (P<0.074) and (NO$_3^-$+NO$_2^-$)-N (P<0.085), also postponed the end of the high-speed phase. The results could be caused by the suppression of microbial populations by 70 °C, even by the suppression of aminate bacteria and nitrobacteria. This finding is not common.

The objective of setting of high moisture with 70% and 80% was to pave the way for composting of high moisture manure, such as separated swine manure. But anaerobic reaction occurred in the treatment of 80% moisture content, which resulted in significant difference between piles 2 and 3 on pH (P<0.006), TOM (P<0.003), and GI (P<0.040). The results suggested that the optimum initial moisture content was less than 80% with the composting of swine manure and corn cob by using the aerated static composting system.

Composting is an aerobic, biological process that uses naturally occurring microorganisms to convert biodegradable and unstable organic matter into a stable humus-like product (Imbeah, 1998). The essence of the composting is

Table 4
The number of E. coli and roundworm egg of piles 1–3

<table>
<thead>
<tr>
<th>No.</th>
<th>E. coli</th>
<th>Rate of roundworm eggs destroyed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 day</td>
<td>3 days</td>
</tr>
<tr>
<td>1</td>
<td>0.0000004</td>
<td>0.00043</td>
</tr>
<tr>
<td>2</td>
<td>0.0000004</td>
<td>0.00011</td>
</tr>
<tr>
<td>3</td>
<td>0.0000004</td>
<td>0.00011</td>
</tr>
</tbody>
</table>

*HSP = high-speed phase.

*$^a$ N/A = none available.
to provide an optimum environment for microbiological development and propagation. But the period of the composting about this consideration could not meet the need of the practice. For example, according to suggested maturity indicators, maturity composts of piles 1 and 2 could be obtained at about day 56 except the pile 3 (Fong et al., 1999; Li et al., 1999; Wei, 2000). More concerns are arisen to inoculate exterior microbiological resource. In order to shorten the period of the composting, further work would be concerned on this aspect.

5. Conclusions

The swine manure reached maturity, realized non-hazardous treatment and reduced the volume of the waste by the aerated static bin composting in less than 80% initial moisture content. Control of upper limit of pile temperature resulted in significant difference of NH$_4^+$-N ($P_{12} = 0.074$) and ($NO_3^- + NO_2^-$)-N ($P_{12} = 0.085$) between 60 °C and 70 °C treatments. The optimum initial moisture content of the mixture was less than 80% with the composting of swine manure and corncob by using the composting system. Anaerobic reaction occurred in 80% initial moisture content, which led to significant difference of pH ($P_{23} = 0.006$), total organic matter ($P_{23} = 0.003$), and germination index ($P_{23} = 0.040$) between 70% and 80% treatments.

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