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Impacts of delayed addition of N-rich and acidic substrates on nitrogen loss and compost quality during pig manure composting

Jishao Jiang[a,*], Kang Kang[b], Dan Chen[a], Ningning Liu[a]

[a] School of Environment, Henan Normal University, Key Laboratory for Yellow River and Huai River Water Environmental and Pollution Control, Ministry of Education, Henan Key Laboratory for Environmental Pollution Control, Xinxiang, Henan 453007, China
[b] College of Mechanical and Electronic Engineering, Northwest A&F University, Yangling, Shaanxi 712100, China

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ABSTRACT

Delayed addition of Nitrogen (N)-rich and acidic substrates was investigated to evaluate its effects on N loss and compost quality during the composting process. Three different delayed adding methods of N-rich (pig manure) and acidic substrates (phosphate fertilizer and rotten apples) were tested during the pig manure and wheat straw is composting. The results showed that delayed addition of pig manure and acidic materials led two temperature peaks, and the durations of two separate thermophilic phase were closely related to the amount of pig manure. Delayed addition reduced total N loss by up to 14% when using superphosphate as acidic substrates, and by up to 12% when using rotten apples as acidic substrates, which is mainly due to the decreased NH_3 emissions. At the end of composting, delayed the addition of pig manure caused a significant increase in the HS (humus substance) content, and the highest HS content was observed when 70% of the pig manure was applied at day 0 and the remaining 30% was applied on day 27. In the final compost, the GI in all treatments almost reached the maturity requirement by exceeding 80%. The results suggest that delayed addition of animal manure and acidic substrates could prevent the N loss during composting and improve the compost quality.

1. Introduction

Composting is a widely used and efficient technology for the disposal of organic waste (Jaafari et al., 2015; Zhang et al., 2017). It can convert the biodegradable components into nuisance-free, sanitary and humus-like materials, which could be used as soil conditioners, fertilizers, and soil remediation agents (Zhang et al., 2017). Nitrogen (N) loss, however, can become severe when materials with a high N content (i.e. animal manure) are decomposed (Gabhane et al., 2012). The N loss could lead to up the loss of 80% of the initial N during the whole composting process (Nakhshiniev et al., 2014). Therein, the N loss via NH_3 emission accounted for 16–74% of initial N during animal manure composting (Medina et al., 2002; Ren et al., 2010), which in turn decreases the quality of the compost as fertilizer, and causes air pollution (Wang et al., 2016). Therefore, preventing the nitrogen loss and NH_3 emissions in manure composting has attracted lots of attention in environmental research.

In recently years, the delayed addition of N-rich substrate (i.e. animal manure) has been suggested as an effective way to reduce N losses during composting (Dresboll and Thorup-Kritensen, 2005; Nigussie et al., 2017). During the split addition of N-rich substrate, the first addition at the beginning of composting could satisfy the turnover of carbon and raise the temperature of compost. The second addition after the thermophilic phase could increase the N and humus concentrations of compost (Nigussie et al., 2017). Split application of an N-rich substrate reduces N losses mainly via ammonia volatilisation.

In the composting process, NH_3 emission was mainly caused by the ammonization of organic nitrogen during the thermophilic stage (Jiang et al., 2015a; Pagans et al., 2006). Moreover, high pH during high-temperature stage shifts the equilibrium of NH_4-N and NH_3 and results in NH_3 emissions, which increase N loss (Bernal et al., 2009). Therefore, the addition of the acidic materials, such as phosphoric acid, superphosphate, sulfuric acid, bamboo charcoal, nitric acid, and olive pomace is a straightforward and efficient method to control the NH_3 emissions and prevent N loss (Haddadin et al., 2009; Ren et al., 2010; Yang et al., 2015). The optimum pH range for microorganisms is 6.7–9.0 (Bernal et al., 2009). Therefore, if the pH was too low after adding the acidic materials, the microbial activity might be inhibited, slowed down the temperature rise, and prolong the process of composting (Jiang et al., 2014). Also, some acidic materials, such as phosphoric acid and

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* Corresponding author.
E-mail address: jiangjishao@163.com (J. Jiang).

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superphosphate, could react with ammonium to form ammonium phosphate (Luo et al., 2013), resulting in a higher EC. Higher EC with more mineral salts could inhibit the activities of microorganism and decrease the quality of the compost (Wolkers-Rooijackers et al., 2013). Fortunately, split addition of N-rich substrate, as before mentioned, could provide a new strategy for solving the problems with adding acidic materials. However, there is no existing evaluation on the effects of split addition of acidic substrates, neither the split additions of pig manure and acidic substrates on N loss and compost quality during animal manure composting.

Thus, the objectives of this study were (1) to investigate the effects of the split additions of pig manure and acidic substrates on the N loss and NH_3 emissions, and to assess the effectiveness of the split additions of pig manure and acidic substrates on compost quality during pig manure composting.

2. Materials and methods

2.1. Feedstock

Fresh pig manure and wheat straw were collected from a swine farm and local cropland respectively in the suburban districts of Xinxiang, Henan province. They were used as the raw materials for the aerobic composting experiments. The basic characteristics of them, respectively, are as follows: total organic carbon (TOC) was 389.0 and 421.6 g kg^{-1}; total nitrogen (TN) was 27.9 and 8.0 g kg^{-1}; the water content was 70.9% and 14.5%; and the C/N ratio was 13.9 and 52.7. Wheat straw was cut into small pieces with 3.0–5.0 cm length and was used to adjust the water content and C/N ratio to proper levels for composting.

Two additives including phosphate fertilizer and rotten apples were collected from in the Muye districts of Xinxiang, Henan province. The main component of phosphate fertilizer was calcium superphosphate (≥12%), and the pH was 3.1, purchased from the local market. The rotten apples were collected from the fruit store, with the moisture content of 72% and the pH was 4.0.

2.2. Composting experimental design

The composting experiment was carried out for 54 d in a self-built, aerated static composting boxes (0.65 m length, 0.50 m width, and 0.40 m height) made of PVC, and the detailed description of the box was in the reference (Jiang et al., 2015a). The experiment was conducted in a lab with a temperature variation between 18 °C and 25 °C during the experimental period.

Six treatments were conducted to evaluate the impacts of delayed addition of N-rich and acidic substrates on nitrogen loss and compost quality. Fresh pig manure and wheat straw were mixed at a ratio of 10:1 in fresh weight as-received basis. The mixture of pig manure and wheat straw were mixed thoroughly with one of the two acidic substrates. The content of phosphate fertilizer and rotten apples were set as 6% and 15% of the initial dry matter, respectively. The core material and additive of each treatment filed up layer-by-layer on the sieve plate of the reaction chamber but no compaction after under the homogenous conditions.

The pig manure was added to the composting mixtures in three different ways: (i) all pig manure was applied at the beginning of composting, (ii) 70% of the pig manure was applied at the beginning of composting, and the remaining was added after the thermophilic phase, and (iii) 30% of the pig manure was applied at the beginning of composting and the remaining was added after the thermophilic phase. The added amounts of acidic materials were in accordance with the amount of pig manure. To mitigate the inhibiting effect of the acidic materials, the additions of phosphate fertilizer and rotten apples were divided into four times on 0, 4, 27, 31 d when the split addition of pig manure. Details of all treatments are presented in Table 1. The temperature was monitored every day with a depth of 0.20 m inside the compost pile using a thermometer function of a programmable temperature controller (XMT616, Shanghai Renzhong Instrument and Electric Appliance Co., Ltd). Before each sampling, the pile was thoroughly turned manually. The water content of the stock material was adjusted to approximately 65% by water spray.

2.3. Sampling and analytical methods

Sampling of the compost was carried out seven times during the experiment (0, 9, 18, 27, 36, 45, 54 days) based on different stage during the composting process such as 1, 2, and 3 (1, 2, and 3 denote the thermophile, cooling, and maturity phases, respectively) characterized by temperature. Sampling was performed in triplicates by mixing material from each of five points on diagonals into every sample. A visual description of the sampling method is shown in Fig. 1. This representative sample from each box was divided into two parts. The first part was immediately stored at 4 °C until analysis, the second part was air-dried and passed through a 0.25 mm sieve and stored in a desiccator. The electrical conductivity (EC), germination index (GI) and pH were measured on an aqueous extract obtained from the fresh samples of the compost. The aqueous extract was obtained using the method described by Huang et al. (2004). EC and pH were measured using an EC meter and a pH meter, respectively. Chinese pakchoi (*Brassica campestris L. ssp. chinensis Makino*) seeds were used for the GI measurement. Ten Chinese pakchoi seeds were distributed on filter paper (Hangzhou Whatman-Xinhua Filter Paper Co., Ltd.) in Petri dishes (0.1 m diameter) and moistened with 5 mL of the compost extract. Three replicate dishes for each sample of different stages were incubated at 25 °C for 48 h. The number of germinating seeds and their root lengths were measured. Distilled water was used as a reference (Jiang et al., 2014). GI was used to assess phytotoxicity of the compost and calculated using Eq. (1)

Table 1
Detailed descriptions of all treatments.

No.	Code.	Descriptions of the treatments
1	P-100	All pig manure and phosphate fertilizer were applied on day 0
2	P-70/30	70% of the pig manure was applied at day 0 and the remaining 30% was applied on day 27. 35%, 35%, 15%, and 15% of phosphate fertilizer was added on day 0, 4, 27, 31, respectively
3	P-30/70	30% of the pig manure was applied at day 0 and the remaining 70% was applied day 27. 15%, 15%, 35%, and 35% of phosphate fertilizer was added on day 0, 4, 27, 31, respectively
4	A-100	All pig manure and rotten apples were applied on day 0
5	A-70/30	70% of the pig manure was applied at day 0 and the remaining 30% was applied day 27. 35%, 35%, 15%, and 15% of rotten apples was added on day 0, 4, 27, 31, respectively
6	A-30/70	30% of the pig manure was applied at day 0 and the remaining 70% was applied day 27. 15%, 15%, 35%, and 35% of rotten apples was added on day 0, 4, 27, 31, respectively

P and A denote the phosphate fertilizer and rotten apples, respectively.

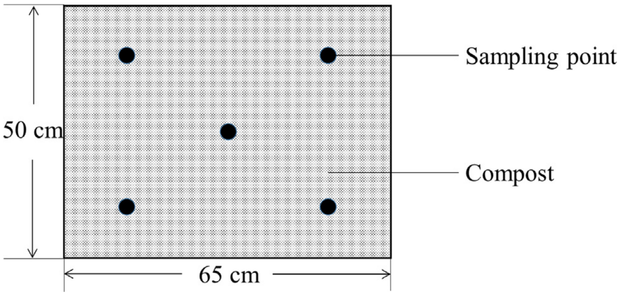

Fig. 1. Schematic diagram of the sampling method. Block diagram denote the planform of composting box; black dots denote the sampling points; shadow denotes the compost.

$$\mathrm{GI}\ (\%) = \frac{\text{Seeds germination in treatment } (\%) \times \text{Root length in treatment}}{\text{Seeds germination in control } (\%) \times \text{Root length in control}} \times 100\% \quad (1)$$

NH_3 was absorbed by a washing bottle with boric acid (2%) and then titrated using H_2SO_4. CO_2 was collected simultaneously with an absorption bottle with NaOH, and measured by HCl titration. The CO_2 absorption bottle was connected to the NH_3 absorption bottle with rubber tubing, to prevent the NH_3 from being absorbed in NaOH. The cumulative NH_3 emissions were calculated using the linear interpolation.

The TKN was measured by the Kjeldahl digestion method (Barrington et al., 2002). NH_4-N in the compost-KCl extract (1:10, v/v) was detected by NaOH distillation-H_2SO_4 titration. NO_3-N in the same extract was calculated by the difference between the values of adding Zn-$FeSO_4$ during distillation and NH_4-N. The total organic carbon (TOC) was determined by the potassium dichromate volumetric method. Humic substances (HS) were determined according to the method outlined by Laborda et al. (2008). The N and C loss during the composting was calculated as follows:

$$\text{N loss } (\%) = (N_{first} \times M_{first} - N_{last} \times M_{last})/(N_{first} \times M_{first}) \quad (2)$$

$$\text{C loss } (\%) = (C_{first} \times M_{first} - C_{last} \times M_{last})/(C_{first} \times M_{first}) \quad (3)$$

Here N_{first} and C_{first} are the first TN and C concentrations (g kg^{-1}), N_{last} and C_{last} represents the final TN and C concentrations (g kg^{-1}), and M_{first} and M_{last} are the initial and final dry mass weight (kg).

2.4. Data analysis

All data were presented in the form of mean ± STDV. Data were analyzed statistically using SPSS 17.0 (IBM SPSS Statistics Inc., Chicago, IL, USA) in using one-way ANOVA at with the significance level of $P < .05$. All of the figures were plotted with SigmaPlot software (version 12.5, Systat Software, Inc., San Jose, CA, USA).

3. Results and discussion

3.1. Temperature

Temperature is an important parameter for assessing the performance of the composting process, which could affect the decomposition rates and microbial activity (Zhang et al., 2015). Except for P-100 and A-100 treatments, other treatments all showed two temperature peaks, and the durations of thermophilic phase were closely related to the amount of pig manure been added.

Fig. 2a shows the changes of temperature during composting when phosphate fertilizer was used as the acidic additive. At the beginning of the composting, all the P treatments proceeded to the thermophilic phase (exceeding 50 °C) slowly within 4–9 days, The P-100 treatment is the slowest, which reached thermophilic phase at day 9. Jiang et al. (2014) observed a similar phenomenon when using chemically pure reagent (calcium superphosphate) during the composting of pig manure and wheat straw, where the addition of this phosphate containing feedstock inhibited the temperature increase. The reasons might be that the addition of phosphate fertilizer at the beginning of composting results in a lower pH and higher EC (6.0 and 4.8 mS cm^{-1}) than delayed addition (6.6 and 3.0 mS cm^{-1}), which inhibited the microbial activity, slowed down the temperature rise (Bernal et al., 2009). The split addition of phosphate fertilizer effectively eliminated the inhibition of acidic materials on microbial activity at the initial stage.

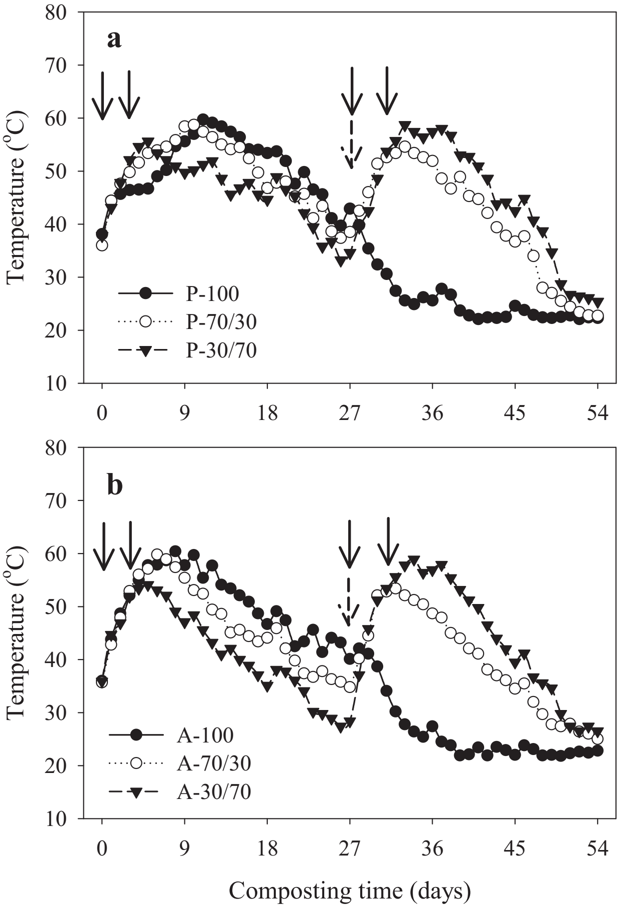

Fig. 2. Changes in temperature during the composting process. (a) Substrates with phosphate fertilizer, and (b) substrates with rotten apples; black arrows indicate the time of the addition of pig manure; dotted arrow indicates the time of the acid substrate (phosphate fertilizer or rotten apples).

Different from phosphate fertilizer, addition time of pig manure and rotten apples did not affect the compost temperature during the first active phase during the composting. The three treatments reached thermophilic phase on day 4 (Fig. 2b). Rotten apples not only contains soft acid but is also rich in other nutrients such as soluble sugar, vitamins, minerals and fiber (Lavelli and Kerr, 2012). Thus, the heat was generated via the rapid consumption of easily degradable organic matters, which were used as the nutrients for microbial activity and growth (Chan et al., 2016).

3.2. CO_2 emissions

CO_2 emissions is another important parameter for evaluating the degree to which composting had proceeded (Wang et al.,

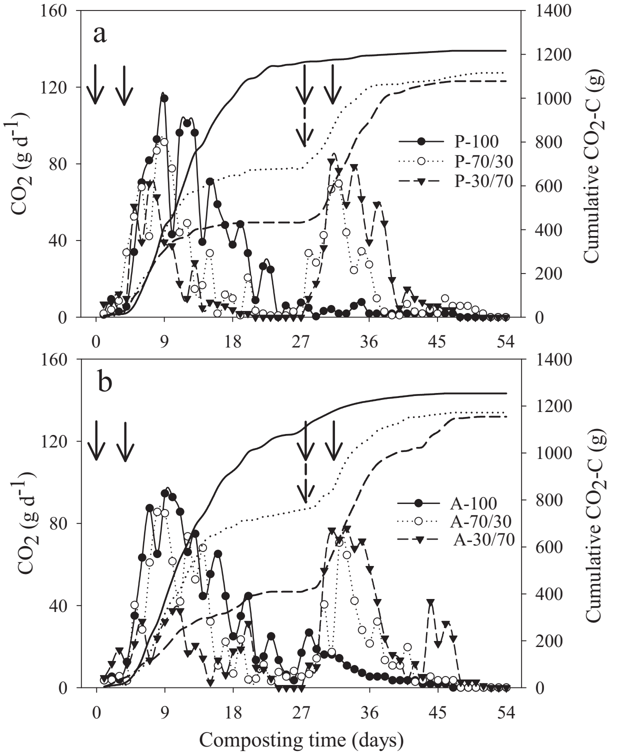

Fig. 3. Changes in CO_2 emission and cumulative CO_2-C during the composting process. (a) Substrates with phosphate fertilizer, and (b) substrates with rotten apples; arrows indicate the time of the second addition of pig manure; black arrows indicate the time of the addition of pig manure; dotted arrow shows the time of the acid substrate (phosphate fertilizer or rotten apples).

2004). As shown in Fig. 3, the split addition of the pig manure showed two peak emissions, which was in accord with the changes of temperature (Fig. 2). During the first temperature peak, the maximum CO_2 emissions were 114.1 in P-100 and 94.6 g d^{-1} in A-100 at day 9, respectively. In the second temperature peak, the peak values were 81.5 g m^{-3} in P-30/70 and 85.4 g m^{-3} A-30/70, respectively. During the entire composting process, the low CO_2 emissions in P-100, P-70/3, P-30/70, A-100, A-70/30, and A-30/70 treatments were 22.5, 20.6, 19.9, 25.5, 23.9 and 23.6 g m^{-3}, respectively.

The total amounts of CO_2-C emissions over the period of the 54 days were 1216, 1116, and 1078 g in P-100, P-70/30 and P-30/70, respectively, equivalent to 37.9%, 34.8% and 33.6% of the initial total C (Table 2). Moreover, those in rotten apples were 1254, 1172, and 1156 g, respectively, equivalent to 39.1%, 36.5% and 36% of the initial total C (Table 2). The cumulative C losses in the form of CO_2 measured in this study were higher than those in previous forced aeration composting studies (11.4–22.5%) under small-scale laboratory conditions (Chowdhury et al., 2014) but similar to values (29.6–48.9%) reported by Nigussie et al. (2017). Analysis of variance showed that cumulative CO_2 emissions were significantly affected by the timing of pig manure addition ($P < .01$). Postponing the addition of pig manure reduced CO_2 emissions irrespective of phosphate fertilizer and rotten apples, but there was no significant difference between the two acidic materials ($P > .05$).

3.3. NH_3 emissions

Fig. 4 shows the changes in NH_3 emissions from all treatments during days 1–54. As a result of the severe degradation and concomitant high temperatures, the NH_3 emissions from every treatment sharply increased and decreased sharply after that. Due to the amount of pig manure initially added to the compost was not identical, hence the specific trends in temperature change vary, however, the general trends are comparable with those reported in previous composting studies (Jiang et al., 2015b; Wang et al., 2014). As for CO_2 emission, the peak NH_3 emission was recorded immediately after the additions of pig manure. Statistical analysis showed a significant positive correlation between NH_3 and CO_2 ($P < .001$). It indicated that the emissions of NH_3 and CO_2 were synchronous, especially during the thermophilic phase which was accord with the previous study (Chowdhury et al., 2014). During days 1–54, the average NH_3 emissions in P-100, P-70/30, P-30/70, A-100, A-70/30, and A-30/70 treatments were 377, 326, 320, 712, 617 and 602 mg d^{-1}, respectively.

The cumulative NH_3-N in P-100, P-70/30, P-30/70, A-100, A-70/30 and A-30/70 treatments were 20.4, 17.6, 17.4, 38.4, 33.5, and 32.6 g, respectively, equivalent to 10.9%, 9.1%, 9.0%, 19.9%, 17.4% and 16.9% of the initial total N (Table 2), which was in a similar range with the results (0.8–26.5%) reported by Chowdhury et al. (2014) from pig manure and barley straw composting. When using superphosphate and rotten apples as acidic substrates, split addition decreased the NH_3 emissions by 17% and 13% compared to the treatment where all added at the beginning of composting.

95% of NH_3 was emitted during the first 27 days when all N-rich substrate was added at the beginning of composting. When 70% and 30% were added to the compost, the NH_3 emissions were 70% and 35%, respectively (Fig. 5). Statistical analyses showed that delayed addition of pig manure significantly reduced the NH_3 emissions compared to 100% addition at the beginning ($P < .05$), but there was no significant difference between the delayed additions when used the same acidic material ($P > .05$). The reasons for the reduction of NH_3 emission relative to 100% addition at the beginning was explained from two sides: the supply of substrate (pig manure) and the acid character of acid materials. When all pig manure was added at the beginning, high initial contents of NH_4-N and water water-soluble organic carbon was supporting the growing of microorganisms, and therefore was more prone to NH_3 volatilisation than the split treatments (Nigussie et al., 2017). Although the treatments of split addition showed the two temperature peaks, but compared to the 100% treatment, the emission peak of NH_3 postponed, and the cumulative amount did not decrease between split treatments with the 70/30 and 30/70 treatments, possibly due to the lack of substrates. Furthermore, superphosphate and rotted apples were acid materials, and could inhibit the NH_3 emissions (Jiang et al., 2014). In addition, superphosphate could react with ammonium to form superphosphate (Zhang et al.,

Table 2
Carbon and nitrogen mass balances after 54 d of composting.

Treatments	C loss (%)	CO_2-C emitted/initial TOC (%)	N loss (%)	NH_3–N emitted/initial TN (%)
P-100	58.0	37.9	40.8	11.4
P-70/30	54.2	34.8	36.2	10.1
P-30/70	53.8	33.6	35.2	9.0
A-100	55.4	39.1	49.8	20.5
A-70/30	52.1	36.5	45.7	16.4
A-30/70	51.8	36.0	43.7	15.7

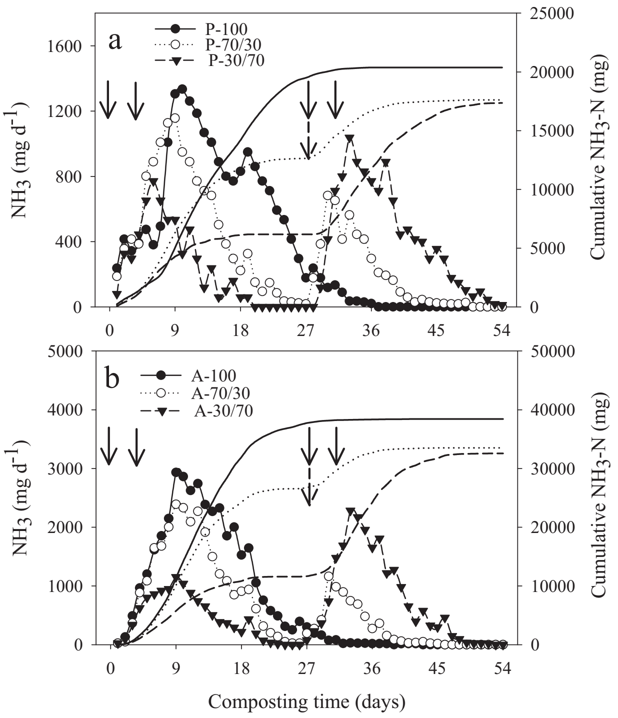

Fig. 4. Changes in NH_3 emission and cumulative NH_3-N during the composting process. (a) Substrates with phosphate fertilizer, and (b) substrates with rotten apples; arrows indicate the time of the second addition of pig manure; black arrows indicate the time of the addition of pig manure; dotted arrow indicates the time of the acid substrate (phosphate fertilizer or rotten apples).

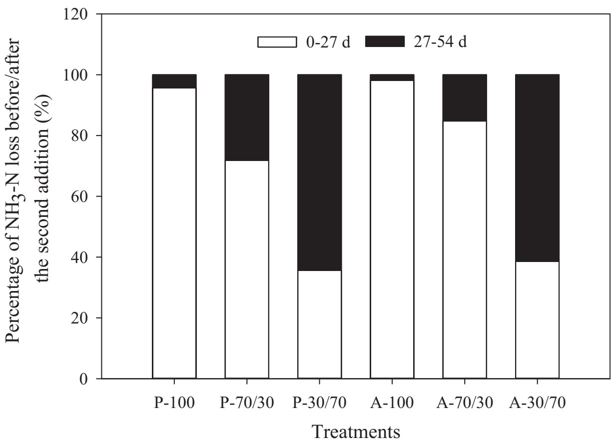

Fig. 5. The percentage of NH_3-N loss before/after the second addition. The black bars indicate the percentage of NH_3-N loss before the second addition (during the 0–27 d); the white bars indicate the percentage of NH_3-N loss after the second addition (during the 27–57 d).

2013), and significantly reduce the NH_3 emissions, relative to that of the rotten apples ($P < .001$), which was also observed in a previous study (Jiang et al., 2014).

3.4. Nitrogen change and N loss

At the end of the composting, the TN, NO_3-N and NH_4-N concentrations were significantly affected by the delayed addition of pig manure ($P < .05$) (Table. 3). When 30% of pig manure was added at first application, the TN concentration both increased by 9% with superphosphate and rotten apples, and that values of NH_4-N were 26% and 175%. However, the NO_3-N contents increased by 100% and 57% of superphosphate and rotten apples as additives, respectively, when 70% of pig manure was added at the beginning of composting.

In this study, the measured N loss was ranged from 35.2 to 49.8% of the initial N (Table 3), which was in accord with the range of the previous studies (Barrington et al., 2002; Steiner et al., 2010). The highest N losses were observed when 100% pig manure was added at the beginning of composting, irrespective of the acidic materials. Split addition reduced total N loss by up to 14% when superphosphate was used as acidic substrates, and by up to 12% when rotten apples were used as acidic substrates, and the decrement was comparable with the composting of municipal waste reported by (Nigussie et al. (2017). However, no significant effect on N loss was found by delaying the addition of substrates during the wheat straw and clover composting (Dresboll and Thorup-Kristensen, 2005). This was probably caused by the different of characteristics of the substrate, especially the NH_4-N content. Pig manure has higher levels of ammonium and easily mineralizable nitrogen compounds than clover grass. The NH_4-N concentration of pig manure was >1.0 g kg^{-1}, but the NH_4-N concentration in clover grass was only 0.4 g kg^{-1} (Dresboll and Thorup-Kristensen, 2005). Hence, the effect of the split application of clover grass on N loss is less apparent than pig manure in the present study, because nitrogen has to be mineralised before its volatilisation. Furthermore, the initial pH was slightly higher with splitting application of clover grass than that of the 100% initial addition treatment (Dresboll and Thorup-Kristensen, 2005). Because adjusting the pH is very important for controlling N-losses by NH_3 emissions, particularly high at pH > 7.5 (Bernal et al., 2009), there might be no effect by split application of clover on N loss compared to all clover adding at the beginning. In the present study, the addition of acidic materials decreased the initial pH of compost, and reduced the NH_3 emission, retained N.

Many studies about composting proved that the addition of additives is an efficient and straightforward method for reducing the N loss and mitigating the NH_3 emissions (Jiang et al., 2014; López-Cano et al., 2016). However, some additives (phosphogypsum, biochar, superphosphate, etc.) could cause some disadvantages, such as high EC, high C/N, low pH, which may be affect the composting process and the compost quality (Luo et al., 2013; Jiang et al., 2014; López-Cano et al., 2016). This study proved that the split addition of acid materials eliminated the adverse factors (low pH and high EC) when applied all acid materials in the initial stage. Further studies, therefore, are needed to determine the effects of the split application of different additives on the composting process and compost quality.

3.5. HS contents

Humus (HS) contents could be used as an indicator of the quality of the compost and the stability of the composting process (Bernal et al., 2009). The initial HS content was significantly affected by the timing of the pig manure addition ($P < .01$) irrespective of the acidic materials (Fig. 6). The initial HS contents change with the amount of pig manure and were about 30%, 20% and 10% in treatments of 100, 70/30, and 30/70, respectively. Especially, the higher amount of pig manure added, the higher the HS contents were observed. Changes in HS by all treatments were similar, decreased gradually with the composting time, until the second addition of pig manure. At the end of composting, split application of pig manure increased the HS ($P < .01$) significantly, and the highest HS content in P-70/30 and A-70/30 treatments (Fig. 6). Since lignin was the main structural composition of humus, so a large amount of organic material was degraded, resulted in the decrease of lignin content (Amir et al., 2006; Veeken et al., 2000). Jiang et al. (2014) also found a significant

Table 3
Chemical properties of the composts after 54 d of composting period (mean ± standard error of the mean; n = 3).

Treatments	TOC	TN	NH_4-N	NO_3-N	pH	EC
	g kg^{-1}				–	mS cm^{-1}
P-100	289 ± 12.3	28.7 ± 3.5	3.1 ± 0.7	0.6 ± 0.1	8.3 ± 0.9	4.6 ± 0.4
P-70/30	276 ± 5.6	29.7 ± 4.8	3.6 ± 0.4	1.2 ± 0.5	8.4 ± 0.2	4.5 ± 0.3
P-30/70	312 ± 14.1	31.2 ± 2.9	3.9 ± 0.4	0.8 ± 0.2	8.1 ± 0.4	5.2 ± 0.1
A-100	275 ± 6.8	26.5 ± 6.5	0.4 ± 0.1	0.7 ± 0.1	8.8 ± 0.1	3.3 ± 0.1
A-70/30	274 ± 8.7	28.4 ± 4.1	0.5 ± 0.1	1.1 ± 0.4	8.7 ± 0.5	3.3 ± 0.1
A-30/70	296 ± 12.1	28.9 ± 1.9	1.1 ± 0.7	0.7 ± 0.3	8.3 ± 0.2	3.5 ± 0.4

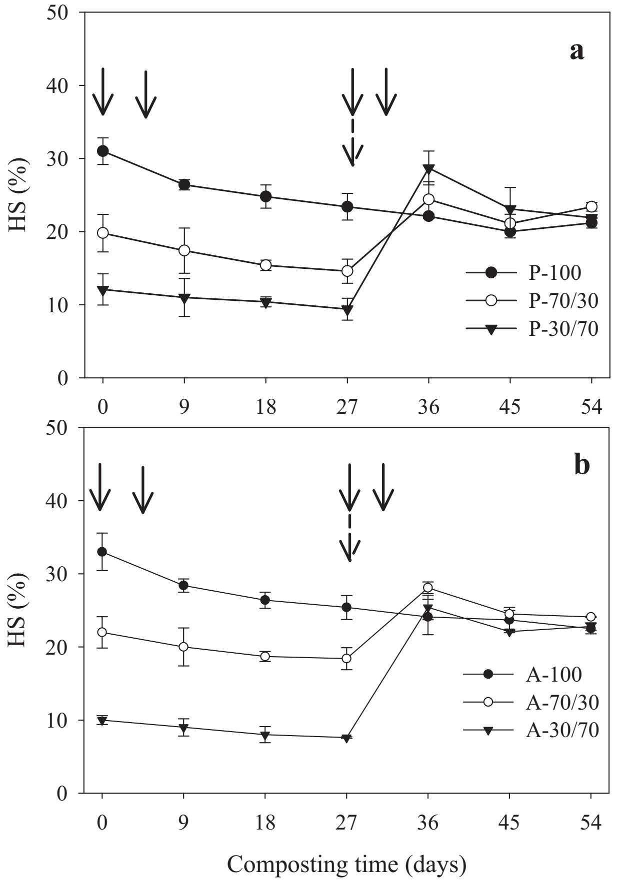

Fig. 6. Changes in HS during the composting process. (a) Substrates with phosphate fertilizer, and (b) substrates with rotten apples; arrows indicate the time of the second addition of pig manure; black arrows indicate the time of the addition of pig manure; dotted arrow indicates the time of the acid substrate (phosphate fertilizer or rotten apples).

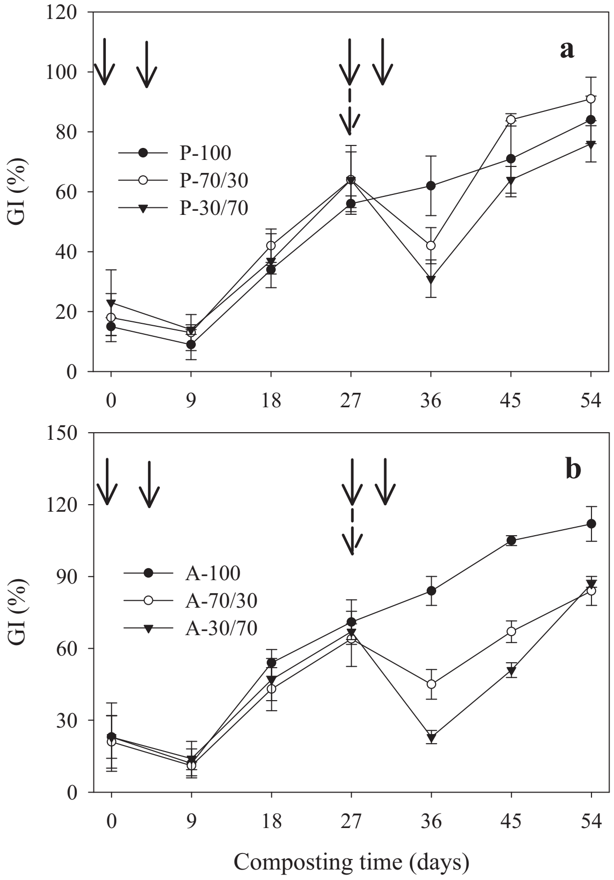

Fig. 7. Changes in GI during the composting process. (a) Substrates with phosphate fertilizer, and (b) substrates with rotten apples; arrows indicate the time of the second addition of pig manure; black arrows indicate the time of the addition of pig manure; dotted arrow indicates the time of the acid substrate (phosphate fertilizer or rotten apples).

positive correlation between HS and TOC during the pig manure composting. In this study, the relationships between HS and TOC contents in P-100, P-70/30, A-100, and A-70/30 treatments were accord with this rule, but not the treatments of P-30/70 and A-30/70. This could be explained by the fact that the second temperature peak lasted for eleven days in P-30/70 and A-30/70 treatments, which were not beneficial to the humification (Bernal et al., 2009).

3.6. GI

GI is a biological index for estimating the degree of maturity based on phytotoxicity tests (Zucconi et al., 1981). Because of the production of fatty acids or NH_3 (Sundberg et al., 2004), GI in all treatments exhibited a decrease at day 9 (Fig. 7), which was also reported in other composting studies (Li et al., 2012). Then, GI increased gradually until the split addition of pig manure, which resulted in a decrease again. In the final compost, the GI in all treatments almost reached the maturity requirement by exceeding 80%. The GI in P-30/70 treatment was less than 80%, which might because that the high EC (5.2 mS cm^{-1}) (Table. 3) inhibited the germination of seed.

4. Conclusion

Irrespective of the acid materials used, delayed addition of pig manure and acidic materials led two temperature peaks, and reduced the nitrogen loss by inhibition of the NH_3 emissions. Delayed addition reduced the total N loss by up to 14% when using superphosphate as acidic substrates, and by up to 12% used rotten apples as acidic substrates. In the final compost, delayed addition of pig manure increased the HS content and improved the compost quality. These findings therefore suggested that delayed addition of nitrogen-rich and acid substrate could be an effective option for improving the fertilising value of livestock manure compost.

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