



Nitrogen Transformation and Loss During the Composting Process of Livestock and Poultry Manure With or Without Bio-fermentation Agent

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ABSTRACT

The composting experiment using chicken manure, pig manure, fungus chaff and biogas residue as mixed media was conducted for 30 days with or without amendment of the bio-fermentation agent. The nitrogen transformation, changes of compost temperature and organic carbon in the mixture were investigated during the whole process. The results demonstrated that addition of the bio-fermentation agent improved the compost temperature, prolonged the high-temperature stage, expedited the process of organic carbon decomposition and lowered the C/N ratio. The amendment of bio-fermentation agent was beneficial to the transformation of organic nitrogen to ammonium ($\text{NH}_4^+\text{-N}$) in the early composting stage (the first 9 d), but to the form of nitrate ($\text{NO}_3^-\text{-N}$) afterwards. Compared to the non-bio-fermentation agent treatment, the composting process was reduced by 9 d to maturity. The acid hydrolysis organic nitrogen (THN) was increased with the addition of bio-fermentation agent during the early composting period by increasing the hydrolysis of the protein. The formation of amino acid nitrogen (AAN) and amide nitrogen (AN) in the compost, with amendment of bio-fermentation agent in early stage, revealed the reason why the mineralization of organic N was fast during the composting process. Although the addition of fermentation agent accelerated the organic nitrogen to transform into available forms, it did not cause massive N loss in the whole composting process.

INTRODUCTION

With the rapid rise of the intensive livestock farming industry, the mass of livestock manure increased significantly. Environment pollution problems arising from inadequate disposal aroused widespread concern (Yang et al. 2001). Compost is a promising way to use agricultural waste at home and abroad, as compost protects the environment, promotes the development of circular agriculture and improves the soil fertility and quality. However, the traditional composting process has some disadvantages, such as a slow decomposing process, not completely harmless and a long maturity time. It does not meet the modern intensive farming manure production requirements, which were large capacity, critical environmental standards and safe disposal with short time. Therefore, a rapid commercial disposal process using physical, chemical and biological technique is highly valued and widespread used (He et al. 1992). Manures contain large amounts of nitrogen (N). During the process of composting, organic N translates into inorganic N by mineralization. There are some intermediate products such as amino acids, amide, etc. Conversion process in composting includes hydrolysis, ammonification, nitrification, denitrification, volatilization (as N_2 , NH_3 , N_2O), bio-absorb and fixation. Nitrogen translation on the one hand

relates to the conversion of N maturity of compost products and odour release. On the other hand, it relates to the loss of N in fertilizers and the compost products. Finding methods to promote decomposition without loss of nutrients is very important. In early studies, it showed that the addition of biological fermentation agent in livestock manure caused a fast temperature rise and a promotion in composting (Wang et al. 2009, Liu et al. 2003, Wang et al. 2011). More attention was paid to the loss of N in rapid decomposition of organic components. Consequently, the early studies were focused on the transformation of inorganic N (Yang et al. 2003, Huang et al. 2004, Huang et al. 2002) and more systemic studies were necessary in conversion of organic N, which is the key to N transformation. This paper studied the transformation of N in the animal manure with or without the addition of fermentation agent, through the organic N grouping, to provide a theoretical basis for rapid and harmless treatment of livestock manure.

MATERIALS AND METHODS

Material and composting process: The composting materials used in composting were fungus chaff, biogas residue, chicken manure, pig manure and mineral powder in the proportion of 30:5:5:5:1 (v/v). The above mixture (with/without fermentation agent) was transferred into two

fermentation tanks, with the size of 90 m in length and 1.8 m in width. The depth of the mixed material in the fermentation tank was 1.2 m. The mixture in the tank was turned over by a turning machine once daily (Tianshui Runde Methane Development Projects Co., Ltd). The duration of the experiment was 30 d. The applied fermentation agent contained decomposing bacteria (fungi, bacteria) and pyrolysis bacteria (bacteria, actinomycetes), with an effective number of bacteria $\geq 10^8$ cfu g⁻¹ and a mass ratio of agents added was 0.05%. The basic characteristics of the compost materials are given in Table 1.

Sampling: Samples containing the upper, middle and bottom layers were taken after 0, 3, 6, 9, 12, 15, 18, 21, 25 and 30 d, with two replicates. Part of the samples was stored in plastic bags at 4°C in a refrigerator, the other part of the samples was dried and sieved through 0.25 mm.

Laboratory test: Kjeldahl nitrogen method was used to test total nitrogen (TN). The group of organic nitrogen (N) was measured using the Bremmer method (Bremmer et al. 1965), which contains acid hydrolysis of nitrogen (THN) and non-acid hydrolysis of nitrogen (UTHN). THN contained amino nitrogen (AAN), amide nitrogen (AN), amino sugar nitrogen (ASN) and other non-knowledge (HUN). Ammonium (NH₄⁺-N) and nitrate (NO₃⁻-N) were measured using the potassium chloride extraction method (Bao 2008).

The rate of N loss: Nitrogen loss rate (N_L) was calculated using the equation: $N_L = 1 - H_0/H_n * N_n/N_0$, where, N_L represents the N loss rate; H₀ represents the ash content at the beginning of composting; H_n represents the ash content of different sampling periods; N_n represents the N content of different sampling periods; N₀ represents the N content at the beginning of composting.

Statistical analysis was carried out using SAS software (Ver. 9.2, SAS Institute, Cary, NC) for analysis of variance (ANOVA) and least significant difference at a P≤0.05 level.

RESULTS AND ANALYSIS

Changes in Temperature During Composting

There were three stages during the composting process,

heating stage, high-temperature stage and cooling stage, and the high-temperature stage was the most important one. The temperature increased rapidly from the beginning of the reaction in the treatment with a bio-fermentation agent addition (Fig. 1). The highest temperature appeared on day 9 (73°C) and then decreased slowly. On day 30 the temperature stabilized at about 33°C. The highest temperature appeared on day 14 in the treatment without a bio-fermentation agent, which was five days later, and 10°C lower than the treatment with the fermentation agent addition. The temperature stabilized at 30°C on day 30. Therefore, the addition of fermentation agent quickly raised the temperature, increased the maximum temperature of composting, prolonged the high-temperature stage of composting, thereby making the organic materials react more complete and promoting the process of composting.

Changes of Nitrogen During Composting

During the composting process, total nitrogen (N) in these two treatments decreased first and then rose afterwards (Fig. 2), which was consistent with Wang's report (Wang et al. 2007). Total N in the treatment with bio-fermentation agent addition, decreased rapidly from day 0-15 and slightly increased from day 15-30. The total N in the treatment without bio-fermentation agent addition, decreased rapidly from day 0-18 and slightly increased from day 18-30. Because of the decomposition and mineralization of organic N and volatilization of ammonia, N content decreased in the early stage of decomposing. Due to the reduction of organic C and N fixation, the total N slightly increased afterwards. Totally, total N content in these two treatments decreased by 17.73% and 21.67%, respectively. Analysis of variance showed that, at the end of 30 d decomposing, there was no significant difference between the final and initial N content in the treatment with bio-fermentation agent addition (P≤0.05), which was opposite to the treatment without bio-fermentation agent. Total N in the treatment of bio-fermentation agent addition was higher than that without bio-fermentation agent addition treatment, but the difference was not significant (P≤0.05).

Table 1: Physical and chemical properties of raw materials.

Index	Pig manure	Chicken manure	Fungus chaff	Biogas residue
pH	7.91	7.16	6.20	8.32
ES/μs·cm ⁻¹	4860	10440	4650	2980
TN/g·kg ⁻¹	27.82	20.70	23.74	17.19
TP/g·kg ⁻¹	19.92	16.86	6.32	5.30
TK/g·kg ⁻¹	15.73	26.20	12.18	7.87
TOC/g·kg ⁻¹	320.25	250.12	350.31	480.27

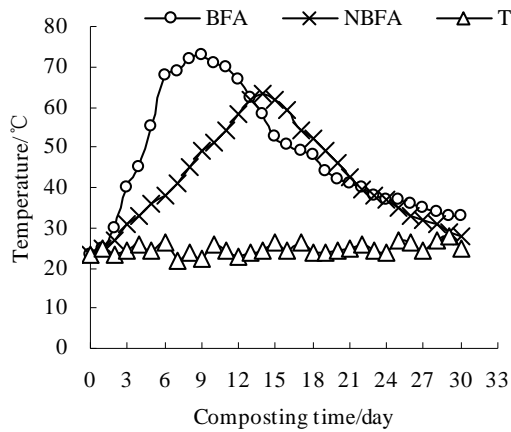


Fig.1: Changes of temperature during composting. BFA: with bio-fermentation agent, NBFA: without bio-fermentation agent, T: air temperature.

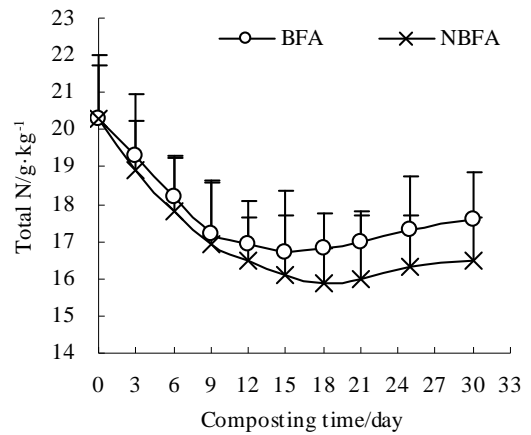


Fig. 2: Changes of N during composting. BFA: with bio-fermentation agent, NBFA: without bio-fermentation agent.

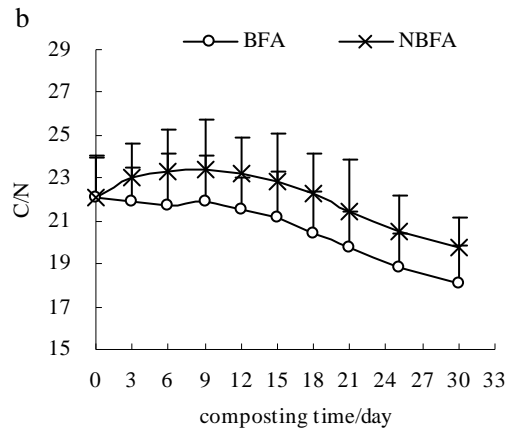
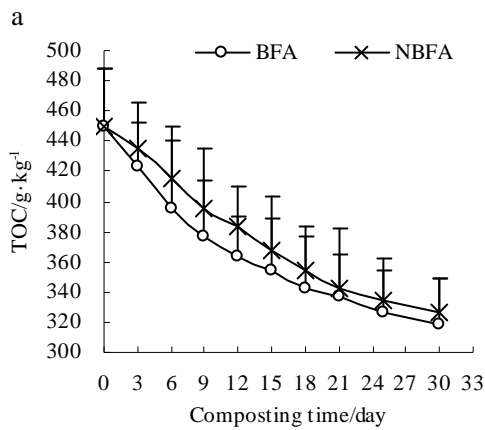


Fig. 3: Changes of (a) TOC and (b) C/N during composting. BFA: with bio-fermentation agent, NBFA: without bio-fermentation agent.

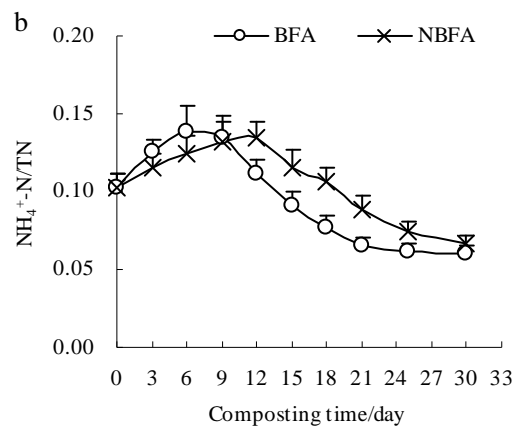
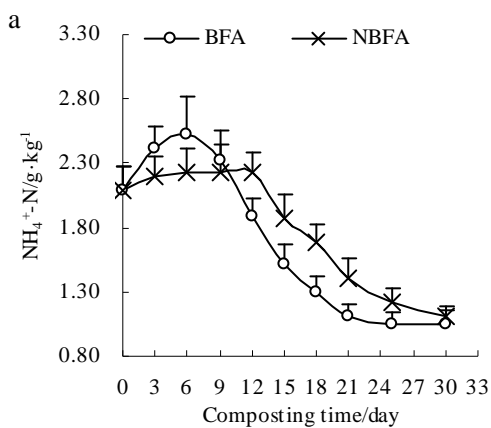


Fig. 4: Changes of (a) NH₄⁺-N and (b) ratio NH₄⁺-N/TN during composting. BFA: with bio-fermentation agent, NBFA: without bio-fermentation agent.

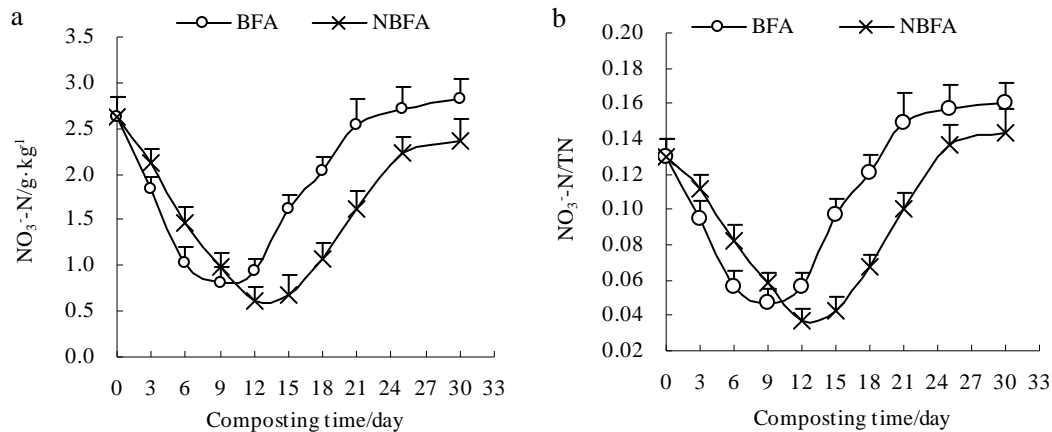


Fig. 5: Changes of (a) $\text{NO}_3\text{-N}$ and (b) ratio of $\text{NO}_3\text{-N}$ /TN during composting. BFA=with bio-fermentation agent NBFA= without bio-fermentation agent.

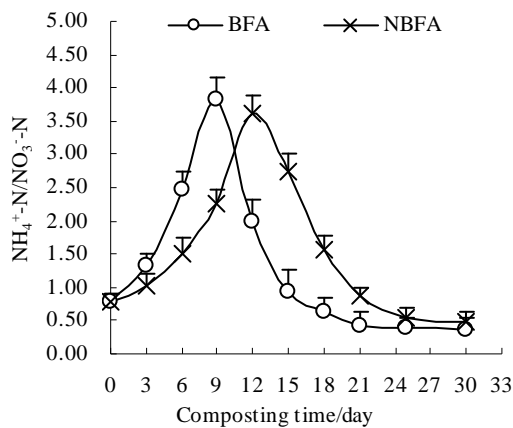


Fig. 6: Changes of $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ during composting. BFA:with bio-fermentation agent, NBFA: without bio-fermentation agent.

Changes in TOC and C/N During Composting

The TOC content decreased throughout the composting process (Fig. 3a) in both the treatments, which is consistent with the research by He et al. (He et al. 2005). In the first 12 days, the TOC content in the treatment with fermenting agent addition, decreased more rapidly than that in the treatment without fermenting agent, by 18.99% and 14.76% respectively. At the end of the decomposing (day 30), TOC in the treatment with fermenting agent addition, decreased by 29.22%, while that in the treatment without fermenting agent addition declined by 27.44%. Overall, the fermentation agent contained thermophilic bacteria and mesophilic bacteria which increased the temperature, promoted the reactions and the mineralization and decomposition of organic carbon during the decomposing process.

The C/N ratio declined in both the treatments (Fig. 3b), which was consistent with the report by He et al. (He et al. 2005). The C/N ratio in the treatment with fermenting agent addition, decreased more than that in the non-fermenting agent treatment. The reason was, that the ferment accelerated the process of organic C decomposition. Generally, C/N ratio less than 20 can be considered as maturity. This study showed that C/N ratio was less than 20 on day 21 in the treatment with fermenting agent addition, and on day 30 in the treatment without fermenting agent. Therefore, the fermenting agent promoted the composting process.

Changes in Inorganic N During Composting

Changes in $\text{NH}_4\text{-N}$ during composting: Ammonium nitrogen content in the treatment with the fermenting agent addition, gradually increased to the highest in 6 days, decreased from 6 to 21 d, and kept consistent after 21 d (Fig. 4a). In the treatment without fermenting agent addition, $\text{NH}_4\text{-N}$ almost did not change in the early 12 d before a decrease. The result showed that the fermenting agent exacerbated ammonification of organic N at the early stage of composting, resulting in a large amount of $\text{NH}_4\text{-N}$. With the enhancement of nitrification, $\text{NH}_4\text{-N}$ translated into nitrate and some of the $\text{NH}_4\text{-N}$ volatilized as NH_3 . The $\text{NH}_4\text{-N}$ of both treatments decreased in the later stage of composting. Changes in $\text{NH}_4\text{-N}/\text{TN}$ during composting of both the treatments were similar, increasing first and then decreasing with time (Fig. 4b). Overall, after composting for 9 d, $\text{NH}_4\text{-N}$ in the treatment with fermenting agent addition, was lower than that in the non-fermenting agent treatment, indicating that fermentation agent addition, accelerated organic N ammonification at an early stage, as well as advanced nitrification at middle and later stages during the

composting process.

Changes in NO_3^- -N during composting: NO_3^- -N content decreased initially and increased afterwards during composting in both the treatments (Fig. 5a). In the first 9 d, NO_3^- -N content in the treatment with fermenting agent addition, was slightly lower than non-fermenting agent treatment. The reason was, at the early stage of decomposing, fermenting agent addition led to more heat produced by microbial decomposition which inhibited the growth of nitrifying bacteria and nitrification (Bao et al. 2007). At the last stage of the decomposing process, the temperature was decreased and then became stabilized, so the rate of nitrification was increased, leading to the rapid increase in NO_3^- -N. After 9 d of decomposing, NO_3^- -N content in the treatment with fermenting agent addition, was higher than that in non-fermenting agent treatment.

Changing trends in the rate of NH_4^+ -N/TN was the same with its content, which was increased first and then decreased (Fig. 5b). At the heating stage, the fermenting agent promoted the decomposition of organic matter to produce ammonium and inhibit nitrification. As the temperature falls in the later stages of composting, it tended to promote nitrification.

Changes in NH_4^+ -N/ NO_3^- -N during composting: Relative change of NH_4^+ -N and NO_3^- -N was an important symbol of composting (Garcia et al. 1991). Bernal et al. (1998) suggested that when the ratio of NH_4^+ -N/ NO_3^- -N was less than 0.16, the compost had reached maturity. There are different point of views with regard to this (Zhang et al. 2003). Some researchers believed that when the ratio of NH_4^+ -N/ NO_3^- -N was not more than 0.5, composting reached maturity. NH_4^+ -N and NO_3^- -N contents in both the treatments in the experiment, showed a declining trend after an initial increase (Fig. 6). NH_4^+ -N/ NO_3^- -N showed a maximum on day 9 of composting in the treatment with fermentation agent addition, while in the no fermentation agent addition treatment, it was day 12. This was consistent with the time for the lowest point and the highest point of ammonium nitrate. In the treatment with fermentation agent addition, the ratio of NH_4^+ -N/ NO_3^- -N was 0.43 at day 21, indicating the compost reached maturity standards (≤ 0.5), while it was 0.46 on day 30 in the non fermentation agent treatment. Thus, fermentation agents accelerated the decomposition of decaying material and nitrogen transformation, producing a rapid decomposition.

Changes in Organic Nitrogen During Composting

Changes in THN during composting: The source and sink of exchangeable ammonium and NO_3^- -N, organic N has drawn researchers a great concern for a long time (Balabane

1995). Bremner divided the organic material in decomposition materials into two parts: acid hydrolysis of nitrogen (THN) and non-acid solution of nitrogen (UTHN). THN/TN in both the treatments increased first and then decreased (Fig. 7a). In the treatment with fermenting agent addition, THN/TN increased to the highest at day 9; while in the treatment without the fermenting agents, it was at day 15. After decomposed, THN/TN in both the treatments was decreased and there was no significant difference among these two treatments ($P \leq 0.05$).

THN can be divided into amino nitrogen (AAN), amide nitrogen (AN), amino sugar nitrogen and nitrogen and other non-knowledge (HUN). Rate of AAN/THN slightly rose in the early stage and decreased afterwards during the composting (Fig. 7b). In the treatments of fermenting agent addition, AAN/THN ratio reached the maximum at day 9, increased from 21.36% to 24.76%, and then declined. At the end of the composting, it accounted for 17.28% of THN. In the treatment without fermenting agents, AAN/THN ratio reached the maximum at day 15, accounting for 16%, but overall there was little change. Comparing these two treatments, in the early 12 d of composting, AAN/THN in the treatment with fermentation agent addition was higher than that in no fermentation agent added treatment, but after 12d, the results contrast and there was a significant difference between them ($P \leq 0.05$). The result showed that the fermentation agent promoted the conversion of amino nitrogen to other forms in the last stages of composting.

During the composting process, the rate of AN/THN in both the treatments rose at early stage (Fig. 7c) and slightly changed at the later stage. In the treatment with fermentation agent addition, AN/THN reached to the highest (22.7%) at 9 d, while in the treatment without fermentation agent, AN/THN reached to the highest (20.6%) at 15 d. Based on changes that can be seen on AAN and AN in acid hydrolysis, it can be said that fermentation agent promoted the hydrolysis of proteins, in favour of a certain period of composting AAN and amide state form nitrogen (AN) and other intermediate products.

In the mid stage of fermentation (9-21 d), fermentation agent increased ASN/THN (Fig. 7d) and there were significant differences compared to the treatment without fermentation agent ($P \leq 0.05$). The data showed that in a certain period of composting, microbial fermentation agents promoted the conversion of organic N to the amino sugar N. Compared to the treatment without fermentation agent, fermentation agent reduced HUN in THN at early stage (0-15 d) and increased HUN in THN in the later stage (15-30 d) (Fig. 7e). These proved that microbial fermentation agent promoted HUN transformation, so that the proportion of

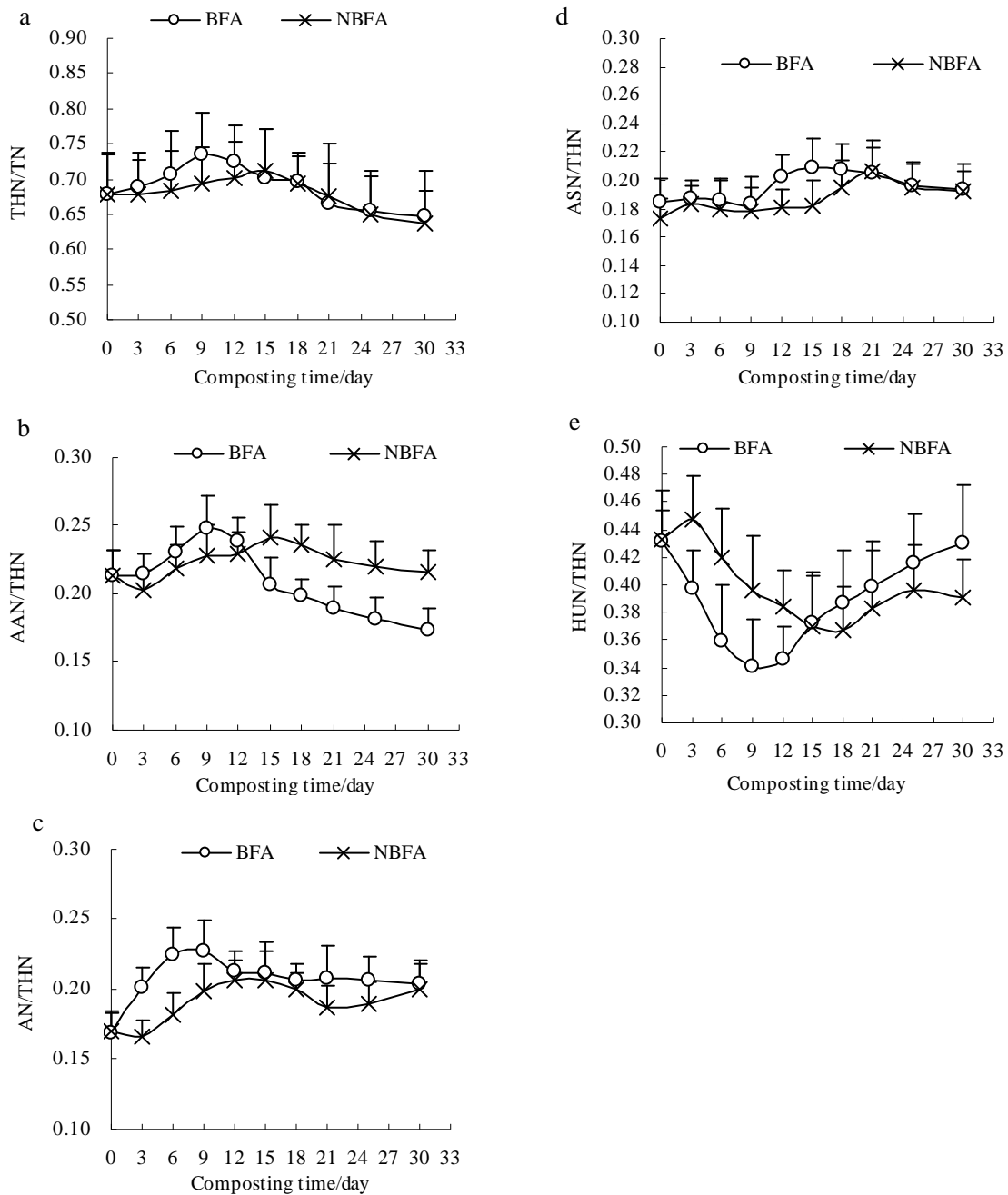


Fig. 7: Changes of (a) THN/TN, (b) ANN/THN, (c) AN/THN, (d) ASN/THN and (e) HUN/THN during composting. THN can be divided into AAN, AN, ASN and HUN. BFA= with bio-fermentation agent, NBFA= without bio-fermentation agent.

HUN decreased. In the later stage, due to the further transformation of N, under the action of microorganisms, such as rot microbial colonization and a fixed combination of substances, HUN increased further. This conversion of N is still a hydrolysis N, so it did not affect the validity of N.

Changes in UTHN during composting: Rate of UTHN/TN

gradually increased in both the treatments (Fig. 8). There were significant differences in these two treatments compared to the raw materials at 30 d. During the whole composting process, UTHN in the treatment with fermentation agent, addition was lower than that without fermentation agent. It can be concluded that fermentation agent was

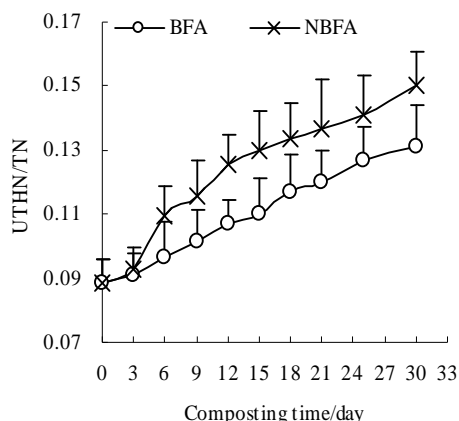


Fig. 8: Rate of UTHN/TN. BFA: with bio-fermentation agent, NBFA: without bio-fermentation agent.

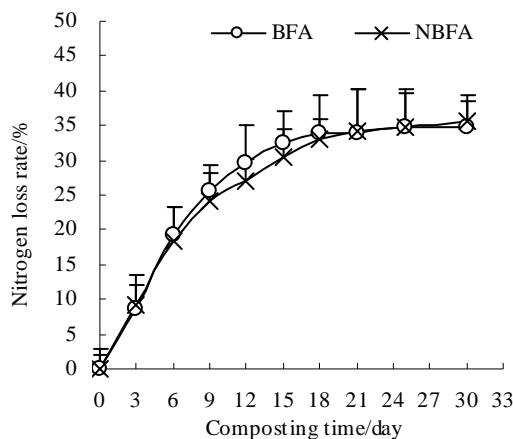


Fig. 9: Changes of nitrogen loss rate during composting. BFA: with bio-fermentation agent, NBFA: without bio-fermentation agent.

conducive to the further transformation of UTHN.

Changes in N Loss Rate During Composting

In both the treatments, N loss gradually increased with time (Fig. 9). At the end of composting (30 d), N loss was more than 30%, which was similar to Cao's report (Cao et al. 2004). In the first 15 d, the rate of N loss to time was fast and then turned to be gradually levelled off in the following 15 d. There was no pronounced difference between these two treatments, indicating that biological fermentation did not cause excessive loss of N while promoting composting and N transformation. This may be probably due to the high level of AN in the treatment with fermentation agent addition.

CONCLUSIONS

1. Fermentation agent prolonged the high-temperature

stage of the composting, accelerated the decomposing process and made the organic material adequately harmless.

2. Organic carbon and C/N showed a declining trend during the decomposing and the treatment with a fermentation agent composted faster than that without a fermentation agent.
3. Fermentation agent accelerated the conversion of ammonium nitrogen, increased the content of nitrate nitrogen in last stage of decomposing and made the ratio of $\text{NH}_4^+\text{-N}/\text{NO}_3^-\text{-N}$ quickly reach maturity index ($P \leq 0.5$).
4. Fermentation agent promoted the formation of organic nitrogen and amino nitrogen, and reduced the nitrogen content of non-acid hydrolysis at the early stage of decomposing.

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