Comparison and Evaluation of Co-composting Corn Stalk or Rice Husk with Swine Waste in China

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Received: 12 January 2015 / Accepted: 23 July 2015 / Published online: 21 September 2015
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Abstract An experimental composting system was employed to study the effect of different proportions of corn stalk, rice husk and swine waste on composting efficiency and final compost quality. Three dry mass ratios were designed with biological agent addition as blank contrast. After 84 days of a static aerobic composting process, full-scale comparison was investigated in maturity, organic nutrient and sanitarian properties. The results showed that the treatment of corn stalk co-composting with swine waste at 1:1.5 ratio with the addition of a biological agent was the first to achieve maturity and had a higher level of organic fertiliser quality, and hygienic indicators of the compost product were satisfied within the relevant standards for harm. Meanwhile, the effect of the biological agent on acceleration of degradation was verified in corn stalk composting. This study found rice husk compost did not reach ideal high temperature. The maturity effect of the final product was relatively poor. Except the treatment of rice husk mixing swine manure at 1:2 ratio with biological agent, other treatments of rice husk had lower and less-effective products, no positive effect was observed in the rice husk compost. At the end of this paper some suggestions were given to develop new approaches for rice husk utilisation and reduce the cost of corn stalk co-composting.

Keywords Agricultural waste · Co-compost · Biological agent · Organic fertiliser quality

Introduction

China is a large agricultural country and has considerable crop straw resources. According to relevant data from the 2012 Chinese Rural Statistical Yearbook, yield of cornstalk and straw is approximately 66 % of the total crop residues [1]. Incorrect utilization (uncontrolled burning and abandoning) accounts for more than 30 % of treatment ways, which causes secondary pollution to the environment. Meanwhile, with the development of large-scale livestock farming, more and more wastes are produced, especially swine manure, which is the most significant, contributing 46.3 % of total livestock waste [2]. Pollution caused by livestock and poultry wastes has been a main source of agricultural non-point pollution in China. From the perspective of utilisation, crop straw and livestock manure containing rich nutrient elements are useful organic matter resources. Utilising and recycling these organic resources are urgent issues bearing great theoretical and practical significance in guaranteeing the urban and rural environment and promoting regional economic development.

Considering the combined treatment of these wastes, anaerobic biogas fermentation and aerobic composting are interesting alternatives [3]. Although anaerobic biogas fermentation conforms to the ecology principle, this technology has higher investment and operation cost and is influenced by the low winter temperature effect in China. Composting is an efficient way of agriculture waste disposal that can reduce pollutant amount, make the pollutant harmless and use it as a resource. So co-composting corn stalk and rice husk with swine manure is an economically

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and environmentally sound alternative. Aerobic composting is a widely used technique for solid waste treatment, the equipment for composting is developing rapidly [4–7]. In recent years, some studies focused on changes in biochemical indicators [5, 8], maturity [4], stability of compost products [6], and effects of product cultivation [9]. Domestic and foreign scholars conducted a series of studies on the theory and practice of solving the long-time fermentation problem of conventional composting, similar to adding the biological agent to accelerate decomposition during the composting process [10].

Compost quality is closely related to its stability and maturity, due to the wide range of starting materials and composting systems, no single method can be applied universally to all composts in evaluation of stability and maturity [11, 12]. Various parameters that had been used to assess the quality and maturity of composts include the carbon nitrogen (C/N) ratio of the finished product, water soluble carbon, cation exchange capacity, humus content, and the carbon dioxide evolution from the finished compost [5, 13–15]. Germination Index (GI), which was a measure of phytotoxicity, had been considered as a reliable indirect quantification of compost maturity [16]. Based on the previous literature, this study selected temperature, C/N ratio and GI as maturity indicators from physical, chemical and biological views. Furthermore, the value of *Escherichia coli* (*E. coli*) and mortality of ascarid egg were employed to present the sanitarian level of finished product in accordance with the requirements of Chinese sanitary standard for the non-hazardous treatment of night soil. Nutrient composition of end-products played an important role in fertiliser effect, organic matter (OM) content, total nitrogen (TN), total phosphorus (TP) and total potassium (TK) were chosen to characterise nutritional value in this study.

Although both corn stalk and rice husk could be employed as bulking agents of swine manure, it can be expected that, when mixed with the same nutrient-rich manure, they will differentially affect composting efficiency and final compost quality. It is necessary to elucidate the effect of different ratios of these raw materials on compost product characteristics, which can contribute to optimize composting performance. The main objective of this work is to study the effect of different proportions of corn stalk, rice husk and swine manure on composting efficiency and final compost quality in experiments conducted in laboratory scale.

In China, compost application is an age-old practice for better yield, and the potential of compost in soil fertility improvement has been demonstrated in China and elsewhere [17]. As far as some scattered farms are concerned, especially in mountainous and foothill areas, small-scale decentralised composting pattern can effectively reduce

transportation costs and achieve the target of synchronous treatment and utilisation on the spot. Regarding the process of decentralised composting, little attention has been given to providing technical references for farmers on some problems, for instance, how to select materials and rationally matching them, how to control and manage a compost process, necessary or unnecessary addition of a biological agent, or how to measure the compost quality, etc. These issues need further scientific research.

For these reasons, a series of composting additives was selected in this study to compare and evaluate the effect of corn stalk or rice husk co-composting with swine at three dry mass ratios. The same biological agent was added to the composting mixture with a blank contrast group. A full-scale study in maturity, organic nutrient and sanitarian properties was investigated to explain some physico-chemical evolutions during 84 days of a static aerobic composting process. Additionally, a comparison of composting quality was studied to analyse the effect of the biological agent on the co-composting of agricultural waste. The aim of this study was to determine the optimum mixture ratios for composting swine manure and crop straw, and to ascertain the usability of the biological agent, the achieved results can provide the references and analytical analysis for farmers in the application of microbial fermentation technology.

Materials and Methods

Experimental Materials

Swine manure, corn stalk and rice husk wastes from Chinese agriculture were chosen as raw materials for co-composting. Swine wastes were collected from a pig farm, while corn stalk and rice husk were acquired from an ecological farm in a suburb of Beijing, corn stalk was crushed to 3 centimetres long. Experiments were conducted in a rain shelter, the compost vessel was a 40L bucket with lid (diameter 350 mm, height 370 mm) which was 10 cm above the ground, and a 3 cm sponge to wrap the outside for isolation. In spite of the relatively simple composting reactors, the straw underwent optical changes completely to a typical pile process. There were 10-mm-diameter holes every 3 cm at the top and bottom of the reactor. Physical and chemical properties of the raw materials are displayed in Table 1. Two types of conditioning agents (corn stalk and rice husk) co-composted with swine waste at dry mass ratios of 1:1, 1:1.5 and 1:2. A complex biological agent was added to the mixture, the agent contained fungi, actinomycetes, *Lactobacillus bacillus* and so on. Using the dilution-plate count method, there were $8.7E + 9$ cfu/g viable bacteria examined in biological agent., composting

Table 1 Physical and chemical properties of raw materials for composting

Material	Water content (%)	pH	Organic matter (%)	C/N	Total P (%)	Total N (%)
Swine waste	65.4 (± 0.67)	8.12 (± 0.09)	56.45 (± 1.05)	12.52 (± 1.24)	0.345 (± 0.05)	2.09 (± 0.01)
Corn stalk	7.8 (± 0.08)	6.62 (± 0.03)	95.6 (± 2.38)	49.9 (± 4.51)	0.15 (± 0.02)	1.07 (± 0.002)
Rice husk	8.3 (± 0.07)	6.81 (± 0.04)	60.6 (± 1.14)	103 (± 8.24)	0.032 (± 0.0006)	0.48 (± 0.005)

The sample for determination of water content and pH was wet basis; the sample for determination of organic matter, total N and total P was dry basis; and values in parentheses are standard deviations of all physiochemical analyses of the raw materials, $n = 3$

reactors without addition were in comparison to the control. Each treatment had three repetitions. Raw material proportions for co-composting are shown in Table 2. The composting process ran from 5 July to 27 September in 2013, accounting to 84 days. Previous work had shown that this time-frame would be sufficient to complete the composting process to maturation [18].

Experimental Method

This study adopted turning piles to increase airflow rate. This turning was performed every second day in the first week; afterward, it was performed once a week. A thermometer was placed 25 centimetres deep in the middle of the pile body to measure the temperature. Measurements were taken twice per day at 9:00 and 15:00 in the first week; afterward, they were taken once per day at 15:00. Measurement precision was improved by averaging the testing values of various points of the full pile, monitoring environmental temperature change at the same time. During the composting process, water content remained within the range of 50–60 % [19, 20]. For further moisture

control, additional water was sprayed during the pile turning. Excess water, leached from the piles, was collected and added again to the piles. Using a four-classification sampling method to collect 50 g samples on days 0, 3, 7, 14, 21, 28, 35, 42, 49, 56, 63, 70, 77 and 84, the sample was divided into two parts. One was stored in a freezer at 4 °C; the other was allowed to air dry. Fresh samples stored in a freezer were applied to determine the indicators including water content, GI, value of *E. coli* and mortality of ascarid egg. The air-dried sample was ground and sifted to measure some indicators including TN, C/N ratio, TP and OM content.

The dry matter of the samples was determined after 12 h at 105 °C. OM was assessed by determining the loss on ignition at 430 °C for 24 h [21]. The fresh samples were analysed for GI in a 1:10(w/v) water-soluble extract, *E. coli* were fermented by the multiple-tube fermentation technique, and mortality of ascarid egg were counted using the saline saturated solution floating concentrated technique [22, 23]. TN and TC were determined by automatic microanalysis [24], then C/N ratio was calculated by them, and TP and TK were measured by inductively coupled

Table 2 Raw material proportions for composting

Treatment scheme	Symbolic names	Swine waste	Corn stalk	Rice husk	Biological agent
Corn stalk: swine waste = 1:1	C1	2000	750.5	–	13.75
Corn stalk: swine waste = 1:1 (without addition)	C1#	2000	750.5	–	–
Corn stalk: swine waste = 1:1.5	C2	2000	500.3	–	12.5
Corn stalk: swine waste = 1:1.5 (without addition)	C2#	2000	500.3	–	–
Corn stalk: swine waste = 1:2	C3	2000	375.3	–	11.9
Corn stalk: swine waste = 1:2 (without addition)	C3#	2000	375.3	–	–
Rice husk: swine waste = 1:1	R1	2000	–	750.5	13.75
Rice husk: swine waste = 1:1 (without addition)	R1#	2000	–	750.5	–
Rice husk: swine waste = 1:1.5	R2	2000	–	500.3	12.5
Rice husk: swine waste = 1:1.5 (without addition)	R2#	2000	–	500.3	–
Rice husk: swine waste = 1:2	R3	2000	–	375.3	11.9
Rice husk: swine waste = 1:2 (without addition)	R3#	2000	–	375.3	–

wet weight, unit: gram

“–” mean without addition

plasma-atomic emission spectrometry (ICP-AES) with a microwave digestion method [21]. GI value was determined with *Lepidium sativum* L. seed using the method described by Zucconi et al. [25]. Twenty seeds were seeded in triplicate in a petri dish containing filter paper wetted with 5 ml of 1:10 compost: water extracted from different composts. A petri dish containing a filler paper wetted with deionised water was kept as a control. After incubation at 25 °C for 48 h, the seed germination percentage and root length of the germinated seeds were recorded. The germinated index (GI) was calculated using the following expression: $GI(\%) = (\% \text{ seed germination} \times \% \text{ root growth})/100$.

Statistical Analysis

Microsoft Excel 2010 and SPSS18.0 were used for statistical analysis. One-way ANOVA analysis was used to analyse the effect of treatment schemes on various parameters, and the Duncan multiple testing method for comparison between treatment schemes. A significant difference test was adopted at $P = 0.05$.

Results

Maturity Indicators

Maturity is the main factor in measuring compost product quality, it ensures secure use as well. Based on the existing research results [3–5], this study chose temperature, C/N ratio and GI as maturity indicators.

Temperature

To the composting system, temperature was the apparent manifestation of its state. Figure 1 showed three stages of composting temperature: mesophilic stage, thermophilic stage and cooling maturation stage. There were no significant difference between different raw material ratios, The trend of variation in temperature was only related to compost material. The average ambient air temperature during the experimental period was 29.1 °C. Figure 1a present that C1 treatment reached above 50 °C on day 3 because of the richer organic matter, then kept that state for 14 days. Other corn stalk treatments reached above 50 °C successively and maintained the high temperature for 14 or 16 days. With the reduction of volatile solids during the composting process, the temperature of the composting body decreased, and treatment schemes of microorganism inoculants experienced fast heating and cooling. Temperature increased slightly on day 56 due to the repeating

fermentation. The temperature of corn stalk treatment schemes satisfied Chinese sanitary standard for the non-hazardous treatment of night soil (GB7959-2012) [23]. Figure 1b showed rice husk composting had a slower rate of warming at the beginning, and achieved the highest temperature on day 8 which was below 50 °C, then temperature began to decline on day 18.

C/N Ratio

Figure 2 showed C/N ratio had a downturn during the composting process. The reason was that during the process, carbon source was consumed, converting to carbon dioxide and humus. While nitrogen source was partially released in the form of gas, which then was partially transformed into nitrites and nitrates via nitrification, other compounds were absorbed by organisms. From Fig. 2a, at the end of the composting process, the C/N ratios of corn stalk treatment schemes were below 20, while rice husk ratios were above 25. The solid carbon nitrogen ratio currently is considered a traditional indicator for measuring compost maturity. Some studies took C/N ratio below 20 as a maturity standard [26]. However, due to large differences in composting material, this conclusion was only regarded as a necessary requirement for maturity. Morel et al. [27] suggested adopting a T value (T value meant the final C/N ratio divided by the initial ratio) to evaluate maturity degree, particularly when the T value was less than 0.6. There were also studies considering T value within the scope of 0.53–0.72 or 0.49–0.59 [28]. The T value of the C2 treatment was below 0.6 on the 56th composting day, which might be thought maturity. The same situation happened to the C1, C2#, C3, and C3# treatments at the 70th composting day. The T value of the C1# treatment was below 0.6 at the end of the composting. The T values of the rice husk treatments were all above 0.65, their maturity degrees were not ideal.

By significance test, during the composting phase, the corn stalk treatment with addition of the biological agent had a significant differences ($p = 0.034$). Ranging from small to large, these were C2, C3 and C1. Among the treatments without the addition, the C1# treatment was significantly larger than C2# and C3# ($p = 0.029$). There were significant differences between two treatments of the same proportion with laws $C1 < C1\#$ ($p = 0.025$), $C2 < C2\#$ ($p = 0.018$), $C3 < C3\#$ ($p = 0.043$), there were no significant differences among all the treatments of rice husk ($p = 0.257$). This result explained the effect of biological agents on the co-composting of corn stalk, and the 1:1.5 ratio was favoured over other treatments; the same biological agent effect did not happen in all of the rice husk treatments.

Fig. 1 Temperature changes during composting. **a** corn stalk, **b** rice husk

Fig. 2 C/N ratio changes during composting, mean $\pm$ SD, **a** corn stalk, **b** rice husk

Seed Germination Index (GI)

Immature compost product restrained the growth of the plant [29]. Zucconi et al. [25] and Rittaldi et al. [30] considered compost product maturity when GI value reached 50 % and plants were able to mitigate the product's toxicity. When GI value was more than 80–85 %, the compost product was thought completely non-toxic to plants. Table 3 indicated that all treatments had marked

increases during the composting process. Experimental results showed that the GI value of the C2 treatment exceeded 50 % on day 56, which meant maturity. This conclusion was consistent with the evaluation result of the T value from carbon nitrogen ratio, other treatments of corn stalk reached maturity at the end of the composting, judging from the GI value. Additionally, by significance test, as to treatment of the addition agent, C2 treatment was significantly larger than C1 and C3 treatments. Considering

Table 3 The significance test of seed germination index in different treatment schemes (mean $\pm$ SD)

Treatment scheme	7 days	28 days	56 days	84 days
C1	25.1 $\pm$ 3.2(c)	34.6 $\pm$ 4.3(bc)	42.7 $\pm$ 5.9(bc)	73.7 $\pm$ 9.3(ab)
C1#	21.4 $\pm$ 2.4(c)	25.6 $\pm$ 2.6(c)	38.5 $\pm$ 5.1(d)	65.6 $\pm$ 7.1(c)
C2	37.8 $\pm$ 5.2(a)	45.7 $\pm$ 6.3(a)	59.4 $\pm$ 7.6(a)	76.1 $\pm$ 8.5(a)
C2#	29.8 $\pm$ 4.1(bc)	33.4 $\pm$ 4.2(bc)	40.8 $\pm$ 5.4(cd)	73.2 $\pm$ 8.1(bc)
C3	33.5 $\pm$ 4.6(ab)	39.5 $\pm$ 4.5(ab)	47.5 $\pm$ 6.3(b)	74.8 $\pm$ 8.7(ab)
C3#	30.3 $\pm$ 3.4(ab)	35.3 $\pm$ 3.9(ab)	43.1 $\pm$ 4.3(bc)	70 $\pm$ 7.4(b)
R1	13.5 $\pm$ 1.5(ab)	23.6 $\pm$ 2.4(ab)	32.7 $\pm$ 3.4(ab)	36.9 $\pm$ 4.1(bc)
R1#	10.1 $\pm$ 1.1(ab)	18.9 $\pm$ 2.0(b)	26.3 $\pm$ 2.8(b)	32.1 $\pm$ 3.4(c)
R2	16.3 $\pm$ 1.7(ab)	25.7 $\pm$ 2.7(ab)	34.6 $\pm$ 3.2(ab)	40.3 $\pm$ 4.5(b)
R2#	15.2 $\pm$ 1.9(ab)	23.4 $\pm$ 2.5(ab)	31.5 $\pm$ 2.9(ab)	39.6 $\pm$ 4.2(bc)
R3	23.5 $\pm$ 2.1(a)	32.8 $\pm$ 3.4(a)	41.7 $\pm$ 3.7(a)	50.4 $\pm$ 8.3(a)
R3#	18.7 $\pm$ 1.9(ab)	29.5 $\pm$ 3.1(ab)	38.4 $\pm$ 3.5(ab)	42.4 $\pm$ 4.6(ab)

Same letters indicate insignificant differences among the treatment schemes in the same column; different letters indicate a significant difference ($p < 0.05$)

treatments without the addition, C1# treatment was significantly smaller than C2# and C3#. Between treatments of the same proportions, the C2 and C2# treatments had significant differences. For rice husk, only the R3 treatment achieved the maturity requirement ($>50\%$). A significance test showed that a significant difference existed between the R3 and R1 treatments as well as between the R3# and R1# treatments; other treatments had no significant difference during the composting phase. These results reflected the fact that the 1:2 proportion treatment (with and without addition of the biological agent) was favoured over the 1:1 treatments on degradation regarding the rice husk co-composting with swine manure.

Maturity Degree Comparison

By integrating and referring to the ideas of domestic and overseas scholars [31, 32], this study built an index system to evaluate and compare end-product's maturity, including track days for maintaining temperature above 50°C , GI value and degradation rate of C/N which required dividing the difference of initial and final C/N by final C/N (Table 4). The compost product was compared and contrasted with classification standards in Table 4, maturity level was reached qualitatively. Some conclusion were drawn by contrast: the level of corn stalk was higher than rice husk, the C2 treatment was the most optimal scheme (Best –maturity), and C1# was relatively worse (Basic-maturity). For rice husk, the R1 and R1# treatments were

limited to immaturity, the others were at the basic-maturity level. These results illustrated that organic matter becomes stable with the action of mineralisation and humification, but the compost products of rice husk were in lower maturity.

Organic Nutrient Indicators

The nutritional value of compost products directly affects their organic fertiliser quality. Some parameters such as OM content, TN, TP and TK were often used to characterise nutritional value.

OM Content

Figure 3 showed OM content was 40.0–75.0 %, which was within the suitable scope of 20.0–80.0 % suggested by Lopez Zavala et al. [33]. Figure 3 demonstrated that the OM content took on the declining-ascending trend in both corn stalk and rice husk and then began to flatten after the 56th day. This indicates that microbes absorbed carbon source contained in the soluble organic matter and decomposed OM while emitting carbon dioxide. The variable amplitude of the corn stalk OM content was 12–20 %. The OM content decrease of treatment schemes in order was C2 (decreased 18.71 %), C2# (17.56 %), C1 (16.41 %), C1# (15.59 %), C3 (12.81 %) and C3# (11.99 %). The variable amplitude of the OM content of rice husk was 10–13 %, and the R3 treatment had a

Table 4 Classification of compost maturity level

	Best-maturity	Better-maturity	Basic-maturity	Immaturity
Days maintained above 50°C/d	16	13	10	7
Degradation rate of C/N/ %	60	50	30	12
GI/ %	80	60	50	30

Fig. 3 Organic matter content changes during composting, mean $\pm$ SD, **a** corn stalk, **b** rice husk

Fig. 4 TN changes during composting, mean $\pm$ SD, **a** corn stalk, **b** rice husk

relatively high decrease. By significance test, as to treatment of the addition agent, the C2 treatment was lighter than the C1 and C3 treatments ($p = 0.026$), and treatment without addition had no difference ($p = 0.067$); between treatments of the same proportions, treatment with the addition agent was lighter than treatment without addition. In terms of rice husk, due to lesser content of biodegradable organic carbon in rice husk, swine manure had higher content, OM content reduction came from degradation of swine manure, so there were no differences among rice

husk treatments ($p = 0.103$). The compost product of corn stalk and rice husk satisfied the Chinese agriculture industry standard for microbial organic fertilizer (NY884-2012) [34], i.e., approximately 40 % OM content.

TN

Figure 4a showed that TN rose during the composting process, presenting a significant concentration effect [35]. However, the opposite trend appeared in Fig. 4b, i.e.,

serious nitrogen loss. The increase of TN was an important characteristic for compost product to reflect maturity and quality. TN content decrease in the rice husk compost process indicated the unfavourable position of nitrogen maintenance.

Through a significance test, corn stalk treatments with the addition agent in proper order were $C2 > C3 > C1$, this result explains the higher nitrogen degradation rate compared with the loss rate. There were no difference in treatments without the addition agent ($p = 0.127$), between treatments of same proportions, and TN of treatments with the addition agent was higher than treatment without addition ($p = 0.015$). Differences in rice husk treatments were not obvious ($p = 1.171$), there were difference between treatment R3 and R1# ($p = 0.022$).

TP and TK

Absolute content of phosphorus in composting remained unchanged, but with the effect of microbial fermentation, degradation and transformation of dissolved organic matter and emissions of ammonia led to the decline of dry mass weight, and the relative content of TP increased indirectly. Figure 5 showed the upwards trend of TP in both corn stalk and rice husk treatment. TP content of corn stalk rose approximately 15 %, rice husk treatments had no significant change (up just 5 %) because of the limit reduction of dry mass weight. By significance test, TP of the C2 treatment was significantly larger than of the C1 and C3 treatment ($p = 0.041$), treatments without the addition agent had no differences ($p = 0.067$). Between treatments of same proportions, treatment with the addition agent was

higher than treatment without addition. Differences in rice husk treatments were not obvious ($p = 0.351$). This result was consistent with the OM content test. According to statistical results, there was a negative correlation between TP and OM content in corn stalk treatment and rice husk treatment (corn stalk: $r = -0.938$, $p < 0.01$; rice husk: $r = -0.847$, $p < 0.001$). This demonstrated the greater degradation of OM and the higher content of TP.

TK and TP promoted each other, TK changed to a relatively small extent (see Fig. 6). A possible reason was that potassium moved more easily than phosphorus; i.e., uneven distribution of potassium occurred in the pile with water flow. The significance test and statistical result of TK were consistent with TP.

Organic Fertiliser Quality Comparison

Based on the grade standard of organic fertiliser quality in China (see Table 5), this study evaluated the organic fertiliser quality of compost product [36]. Result in Table 6 showed organic fertiliser quality of the corn stalk and rice husk treatments up to second and third grade, respectively. Therefore, in terms of organic fertilizer quality, end-product of corn stalk outweighed rice husk, although there were no difference of fertilizer quality between various ratios within the same raw materials.

Sanitarian Indicators

As known, if thermophilic duration is long enough, pathogens and parasites are killed or partly killed. In this study, bacterial tests were performed in accordance with

Fig. 5 TP changes during composting, mean $\pm$ SD, **a** corn stalk, **b** rice husk

Fig. 6 TK changes during composting, mean $\pm$ SD, **a** corn stalk, **b** rice husk

Table 5 Grade standard of organic fertiliser quality and score grade standard

Grade	OM		TN		TP		TK		Total scores
	Content (%)	Score	Content (%)	Score	Content (%)	Score	Content (%)	Score	
1	>80	25	>3.0	40	>1.0	15	>4.0	20	86–100
2	50–80	20	1.5–3.0	32	0.5–1.0	12	2.0–4.0	16	71–85
3	30–50	15	0.5–1.5	24	0.3–0.5	9	1.0–2.0	12	56–70
4	15–30	10	0.3–0.5	16	0.1–0.3	6	0.6–1.0	8	41–55
5	≤ 15	5	≤ 0.3	8	≤ 0.1	3	≤ 0.6	4	21–40

Table 6 Organic fertiliser quality grading of treatment schemes

Treatment scheme	OM content (%)	TN content (%)	TP content (%)	TK content (%)	Total scores	Grade
C1	55.13	3.11	0.32	3.21	85	2
C1#	56.28	3.05	0.31	3.14	85	2
C2	50.52	3.31	0.38	3.28	85	2
C2#	51.76	3.09	0.35	3.13	85	2
C3	54.65	3.23	0.36	2.94	85	2
C3#	55.58	3.21	0.33	2.87	85	2
R1	47.28	1.27	0.17	1.25	57	3
R1#	48.59	1.22	0.16	1.15	57	3
R2	45.37	1.35	0.18	1.22	57	3
R2#	46.24	1.37	0.17	1.18	57	3
R3	43.45	1.42	0.19	1.29	57	3
R3#	44.32	1.36	0.18	1.22	57	3

the procedures described in Chinese sanitary standard for the non-hazardous treatment of night soil (GB7959-2012) [23]. Based on this standard, maximum composting temperature must reach at least 50 °C, the value of *E. coli* must be above 0.01MPN/ml, and mortality of ascarid egg must

be in the range of 95–100 %. The value of *E. coli* were determined by the multiple-tube, most-probable-number (MPN) technique, nine tubes were used for each dilution. The table look-up method was applied to achieve *E. coli* value using a MPN computing package based on the

Table 7 The value of *E. coli* and mortality of ascarid egg during the co-composting process

Treatment scheme	Value of <i>E. coli</i> (MPN/ml) and [mortality of ascarid egg (%)]				
	0 day	7 days	14 days	28 days	84 days
C1	0.000001 [3.89 ± 0.42]	0.0056 [31.12 ± 0.57]	0.105 [79.16 ± 0.81]	0.6 [98.12 ± 0.65]	1.1 [100]
C1#	0.000001 [4.13 ± 0.38]	0.0046 [40.04 ± 0.76]	0.053 [76.35 ± 0.67]	0.4 [96.71 ± 0.73]	1.0 [100]
C2	0.000001 [3.21 ± 0.41]	0.0036 [29.85 ± 0.38]	0.046 [81.12 ± 0.76]	1.1 [99.25 ± 0.82]	3.6 [100]
C2#	0.000001 [3.75 ± 0.52]	0.001 [39.37 ± 0.54]	0.043 [78.34 ± 0.61]	0.6 [98.35 ± 0.78]	3.6 [100]
C3	0.000001 [3.82 ± 0.46]	0.0006 [34.76 ± 0.48]	0.036 [78.12 ± 0.59]	0.1 [97.76 ± 0.61]	0.6 [100]
C3#	0.000001 [4.01 ± 0.34]	0.0001 [31.18 ± 0.051]	0.01 [76.91 ± 0.84]	0.1 [97.84 ± 0.91]	0.4 [100]
R1	0.000004 [3.91 ± 0.38]	0.000036 [11.31 ± 0.47]	N/A	N/A	N/A
R1#	0.000004 [3.24 ± 0.41]	0.000011 [11.15 ± 0.58]	N/A	N/A	N/A
R2	0.000004 [4.59 ± 0.39]	0.000053 [10.50 ± 0.34]	N/A	N/A	N/A
R2#	0.000004 [4.18 ± 0.47]	0.000046 [10.13 ± 0.46]	N/A	N/A	N/A
R3	0.000004 [3.92 ± 0.53]	0.000105 [9.76 ± 0.43]	N/A	N/A	N/A
R3#	0.000004 [4.03 ± 0.35]	0.000056 [10.07 ± 0.55]	N/A	N/A	N/A

Numbers in square brackets meant mortality of ascarid egg, mean ± SD; N/A = none available

numbers of positive fermentation tubes. Mortality of ascarid egg were counted using the saline saturated solution floating concentrated technique, and its value was calculated using the following formula: $K = 100 (N_1 - N_2) / N_1$, where K was mortality of ascarid egg(%), N_1 was the total egg numbers with microscopic examination, N_2 was the survival egg numbers with microscopic examination after germiculture.

In this study, after 14 days composting, the value of *E. coli* met the standard and the ascarid egg were destroyed after 28 days composting (Table 7). The durations of the thermophilic phase of corn stalk treatments met the national standard of GB 7959-2012. However, all of the rice husk treatments did not reach the set temperature, so sanitarian indicators for them could not be determined after 7 days composting.

Discussion

As carbonous materials, corn stalk and rice husk are characterized by high cellulose and lignin concentration, and very low nutrient concentrations, neither corn stalk nor rice husk can be composted alone. Thus, they must be composted in mixtures with materials rich in nutrients, especially nitrogen and easily biodegradable carbon [37, 38]. For example, it is common to co-compost corn stalk or rice husk with animal manures [39, 40].

Some researches focused on the automotive composting technologies for mechanical aeration and forced ventilation [41]. However, that technology is still immature and expensive for promotion. By contrast, for the advantages of low investment, simple performance and cheap operation cost, static aerobic composting process mentioned in this

study is more acceptable to Chinese farmer. Waste management are waste-specific and local-specific, compost raw materials in this study are typical agricultural residues in China, corn stalk and rice husk have obviously regional and seasonal characteristics, the conclusions and method of this study can offer a base for future systematic research about spatial-temporal allocation and co-processing of agriculture waste in China.

The carbonous materials determined the length of the thermophilic phase regardless of the mixing ratio, being longer in piles containing corn stalk than in piles with rice husk. Results suggest that corn stalk enhanced microbial activity possibly due to higher organic matter amount, water retention capacity, and accessibility to microbial attack. At the beginning of the composting process, the composting body contained easily decomposed organic matter that decomposed rapidly with the effect of aerobic microorganisms, these actions emitted a great deal of heat, which caused the temperature to rise. During composting all piles of rice husk didn't reached temperatures required to meet guidelines for pathogen reduction. There were two reasons leading to this situation. One reason was that the rice husk contained a high content of lignin and lower water-soluble carbon, which could not be utilised effectively as energy by the aerobic microorganisms; the other reason was that rice husk's worse hygroscopicity caused ventilator inadequacy in the internal body, which affected the growth of the aerobic microorganisms.

High losses of nitrogen as ammonia volatilization were a commonplace in the literature on composting [42, 43]. In the present work, however, nitrogen losses were limited in the piles of corn stalk, moreover, nitrogen content increased throughout the process. This was mainly associated to the decrease of dry mass resulting from

mineralisation of organic matter, releasing loss of carbon dioxide and evaporation of water, higher increase of nitrogen than rice husk piles. Though loss of nitrogen during composting is a major concern in most works, some authors also found nitrogen conservation [44, 45]. The decrease of nitrogen content in rice husk was caused by less biodegradable dissolved organic carbon in rice husk, and carbon loss as gas was limited. The decrease of the dry mass was not obvious, but nitrogen was constantly being released with volatilisation losses as pH rise.

From a composting time point of view, some previous literatures [46, 47] also demonstrated mixing rice husk with livestock manure directly to be inefficient just like the result of this study. This phenomena was determined by the characteristics of rice husk, and rice husk were characterized by a waxed surface and high silica contents which reduced water-holding capacity and could limit microbial attack [40, 48], it was hard for microbes to absorb and utilise the cellulose and lignin components. A few of researchers proposed improved methods, for instance, Zhang et al. [49] and Soda et al. [50] found that rice husk ash had an obvious effect on co-composting with livestock manure and remediation of acidic polluted soil. Isoda et al. [51] prepared activated carbon from rice husk, Conrado et al. [52] introduced rice husk ash as a supplementary raw material in cement-based products. These study works provided a new approach for rice husk utilisation as a resource in China.

Conclusions

This study showed that after an 84d composting process, from a maturity properties perspective, the treatment of corn stalk and swine waste at 1:1.5 ratio with biological agent addition had the fastest temperature rise, its C/N ratio and GI reached mature level early in 56 days, and the treatment of 1:1 ratio without biological agent addition had the worst maturity among corn stalk treatments. For rice husk, none of the treatments reached the ideal high temperature. Only the treatment of rice husk and swine waste at 1:2 ratio with biological agent addition reached barely mature, the rest were in immature status. From an organic nutrient standpoint, the organic nutrient grade of corn stalk treatments achieved the 2nd level, and rice husk treatments had error levels than corn stalk, which were the 3rd level. Meanwhile, TN content decreased throughout the rice husk composting process, indicating the unfavourable position of nitrogen maintenance. In terms of hygienic indicators, the compost products of corn stalk satisfied the relevant standards regarding harm. The study also proved that a biological agent played roles in corn stalk composting, but no positive effect was observed in the rice husk composting. Thus, research results showed that corn stalk should be

favoured over rice husk for use as attendant agents in co-composting with swine manure and that the suitable ratio of corn stalk to swine manure was 1:1.5, and positive effect of biological bacterium agent on corn stalk composting was proved in this study as well.

The corn stalk is produced in large quantities in China and showed excellent effects on co-composting in this study. Use of corn stalk could reduce composting costs and produce better organic fertiliser. Therefore, corn stalk can be selected as a promising candidate for co-composting. Because of the high content of cellulose, hemicellulose and lignin in crop straw, efficient cellulose-decomposing microorganisms are suggested to separate and purify these materials. If measures are taken to reduce the production and sale costs of the biological agent and to attract more farmers to composting agriculture wastes on-site, China's organic deficiency in arable land may be improved.

Acknowledgments This work was supported by the National Natural Science Foundation of China (No. 71273254) and Beijing Science and Technology Plan Projects.

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