ISSN: 2790-5209 Vol 2, No.1, 2024

# Aerobic composting effect of crop straw with biogas residue

Xiaohong Huang [1,2], Jiacong Lin[3], Jing Jiao[1,4,5,a,*], Songbiao Wang[1], Jihua Du[1,3,5], Zunxiang Li[1,5], Xinpeng Liu[1,5]

[1] South Subtropical Crops Research Institute, Chinese Academy of Tropical Agricultural Sciences, Guangdong Zhanjiang 524091, China;

[2]Institute of Agricultural Machinery, Chinese Academic of Tropical Agricultural Sciences, Guangdong Zhanjiang 524091,China;

[3]Environmental and Plant Protetion Institute, Chinese Academy of Tropical Agricultural Sciences,Haikou 571101, China;

[4]Agricultural Products Processing Research Institute, Chinese Academy of Tropical Agricultural Sciences, Guangdong Zhanjiang 572829, China;

[5]Zhanjiang Tropical Crop Straw Efficient Recycling Engineering and Technology Research Center, Guangdong Zhanjiang 524091, China.

[*,a] eddweiss@163.com

## Abstract

*This study aims to improve the aerobic composting efficiency and quality of biogas residue. The residue of biogas production from pig manure was mixed with coconut leaves, sugarcane leaves, and sawdust, respectively, for the aerobic composting experiments. The pile temperature, pH, organic matter content, seed germination index, total nitrogen, total phosphorus, and total potassium were measured to evaluate the composting performance of different treatments. The results showed that the aerobic composting treatment of biogas residue mixed with sugarcane leaves had a seed germination index of 107.71%, the highest maturity, and the highest total phosphorus and total potassium. The aerobic composting treatment of biogas residue mixed with coconut leaves maintained high temperatures above 55 °C for the longest time (23 days) and demonstrated the most thorough harmless treatment, with the total nitrogen increase being the highest (75.63%), which indicated the strongest nitrogen retention capacity. Overall, the supplementation of coconut leaves and sugarcane leaves can improve the maturity and nutrient content, thus improving the aerobic composting quality of biogas residue. The findings provide a scientific basis for the harmless treatment and reuse of manure biogas residue and crop straw.*

## Keywords

*biogas residue, crop straw, aerobic composting.*

## 1. Introduction

Anaerobic fermentation, one of the commonly used methods for the harmless treatment of manure, can realize the reduction and reuse of wastes. As animal farming is becoming increasingly intensified, industrial, and professional, a large amount of manure is generated from the farms and mainly treated by anaerobic fermentation, from which a large amount of biogas residue is generated. The treatment of the by-product has become a bottleneck that restricts the large-scale promotion of biogas engineering [1]. Although the biogas residue from anaerobic fermentation can be directly used as organic fertilizer[2], it has poor biological stability since anaerobic fermentation pursuing high methane production usually has short fermentation time and mild fermentation conditions. Therefore, the improper application of biogas residue can easily cause acidification or secondary salinization of the farmland soil[3].

Aerobic composting is the process of converting active organic matter into stable humus by microorganisms under aerobic conditions, generating a large amount of heat, stabilizing organic matter, and inhibiting and killing potential pathogens. It serves as an effective approach to reuse biogas residue. However, the high moisture content makes it difficult to conduct aerobic fermentation with biogas residue alone. Moreover, the properties of biogas residue vary significantly due to different raw materials and processes of anaerobic fermentation[4]. Supplementing crop straw for the aerobic fermentation composting of biogas residue can adjust the moisture content, porosity, and C/N ratio to achieve a better initial fermentation state, thereby improving the fermentation efficiency and the quality of fermentation products. Returning high-quality fermentation products to the soil can improve the quality of cultivated land and achieve green circulation. Studies have been carried out regarding the aerobic composting of manure biogas residue mixed with crop straw to prepare organic fertilizer[5–6]. However, the production still face problems such as the lack of theoretical information on raw material ratio, low composting efficiency, and even substandard products. How to improve composting efficiency and product quality is a practical problem to be addressed for the recycling of biogas residue resources and the reduction of environmental hazards.

In this study, the residue of biogas production from pig manure was mixed with coconut leaves, sugarcane leaves, sawdust (from mango branches pruned off), and montmorillonite (control), respectively, for aerobic composting. By studying the impacts of different crop straw samples on the aerobic composting performance, we aim to provide a scientific basis for the harmless treatment and reuse of manure biogas residue and crop straw.

## 2. Materials and methods

### 2.1. Materials

The biogas residue used in this study was collected from a pig farm of CP Group in Zhanjiang, Guangdong, China. Coconut leaves, sugarcane leaves, and sawdust (from mango branches pruned off) were collected from the surrounding areas of Zhanjiang. Before aerobic composting, sugarcane leaves and coconut leaves were cut into pieces within 5 cm, and mango branches pruned off were shredded into sawdust with the size smaller than 1 mm. The properties of the raw materials for composting are shown in Table 1. Montmorillonite was produced under the supervision of Beijing Zhongnong Animal Feed Research Institute, with the purity over 95%.

**Table 1:** Material properties

| Material | Moisture (%) | Total nitrogen (%) | Total carbon (%) |
|---|---|---|---|
| Biogas residue | 94.24 | 0.43 | 2.3 |
| Sugarcane leaves | 7.24 | 0.67 | 67.25 |
| Coconut leaves | 11.96 | 0.4 | 61.22 |
| Sawdust | 19.24 | 0.72 | 42.3 |

## 2.2. Aerobic composting device

The thick woven bags (100cm × 100cm × 100cm) with small holes for sampling and temperature measurement on the upper, middle, and lower parts were used for aerobic composting experiments.

## 2.3. Aerobic composting treatments

Four treatments were designed in this study. Treatment 1 (T1): sugarcane leaves:biogas residue at a dry mass ratio of 10:1; treatment 2 (T2): coconut leaves:biogas residue at a dry mass ratio of 10:1; treatment 3 (T3): sawdust:biogas residue at a dry mass ratio of 10:1; treatment 4 (T4, control): montmorillonite:biogas residue at a dry mass ratio of 10:1. After mixing, the initial moisture content and C/N ratio of materials in each treatment were adjusted to 70% and 25:1, respectively. The mixed materials were put into the bags for aerobic composting, and the compost in each treatment was turned once every 7 days. After 25 days, the compost was not further turned, and the ventilation and uniform fermentation were ensured. The aerobic composting lasted for a total of 40 days.

## 2.4. Measurement methods

### 2.4.1 Sample collection and preservation

On days 1 and 35 of composting, equal amounts of samples were collected from the upper (20 cm from the opening), middle, and lower parts (20 cm from the bottom) of each bag and fully mixed. Each mixed sample was divided into two parts, with one preserved at 4 °C and the other dried in the air for later use.

### 2.4.2 Measurement of pile temperature

An intelligent temperature monitoring method was adopted. Specifically, a temperature probe was buried 25 cm from the pile surface, and the computer recorded the temperature data regularly each day.

### 2.4.3 Determination of organic matter, total nitrogen, total phosphorus, and total potassium

According to the industrial standard Organic Fertilizer (NY 525) [7], the potassium dichromate oxidation-volumetric method was employed to measure the organic carbon content of the composting samples. After digestion of compost samples with sulfuric acid and hydrogen peroxide, dilution, standing, and filtration, the Kjeldahl method, vanadium-ammonium molybdate colorimetric method, and flame photometry were employed to determine the content of total nitrogen, total phosphorus, and total potassium, respectively.

2.4.4 Determination of pH value

Each fresh sample was mixed with deionized water at a ratio of 1:10 (W/V) on a shaker for 2 h. The liquid was then let stand for 30 min, and a pH meter was used to measure the pH value.

2.4.5 Determination of seed germination index

Each the fresh sample after composting was mixed with deionized water at a ratio of 1:10 (W/V) and extracted with shaking for 1 h. After filtration, 10 mL of filtrate was transferred into a petri dish covered with filter paper. Ten sterilized cucumber seeds were then put in each petri dish and incubated at (25±2) °C in the dark for 48 h. Deionized water was taken as the blank control. The germinated seeds were counted and the main root length was measured by a vernier caliper. The germination index (GI) was calculated according to the following equation:

$$GI = \frac{A_1 \times A_2}{B_1 \times B_2} \times 100 \tag{1}$$

where A1 is the proportion (%) of germinated seeds cultured with the sample extract; A2 is the average root length (mm) of all seeds cultured with the sample extract; B1 is the proportion (%) of germinated seeds cultured with deionized water; B2 is the average root length (mm) of all seeds cultured with deionized water.

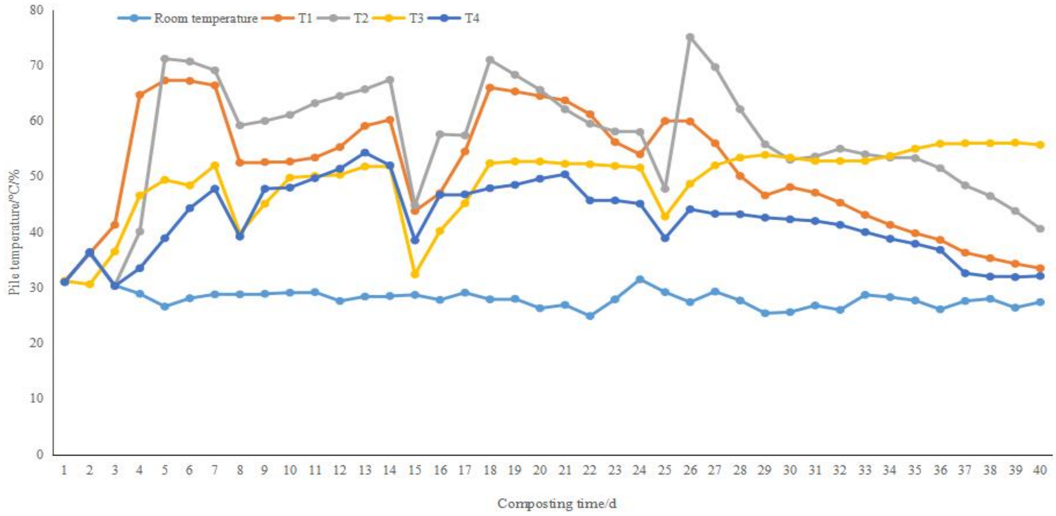
2.4.6 Data analysis

Excel 2016 was used to organize and process the data and establish the graphs.

## 3. Results

### 3.1. Pile temperature

The pile temperature variations during the aerobic composting process are associated with microbial metabolism and serve as a key indicator of composting maturity. The pile temperature variations in different treatments in this study are illustrated in Fig. 1. The pile temperatures in all the four treatments increased over time. However, the temperature increases varied due to the different raw materials. T1 entered the high-temperature (≥ 55 °C) stage on day 4 and T2 on day 5 [5]. However, T3 took 35 days to enter this stage and T4 did not reach 55 °C throughout the entire composting period, with a maximum pile temperature of only 54.3 °C. It is generally believed that the pile temperature should be maintained above 55 °C for no less than 15 days [8] to kill pathogens, so as to achieve harmless treatment and stabilize the pile. In this study, the high-temperature (≥ 55 °C) stage in T1, T2, and T3 lasted for 16, 23, and 5 days, respectively. T1 and T2 met the requirements for harmless treatment, with the high temperature stage during days 5–25, followed by a gradual decrease in the pile temperature. The pile temperature of T3 gradually increased over time, indicating that the composting did not finish. The small particles (less than 1 mm) and high initial moisture content (around 70%) in T3 limited the oxygen, which was not conducive to microbial growth, resulting in low heat generation. As the composting progressed, the gradually decreasing moisture and increasing oxygen resulted in the slow rise in pile temperature.




The temperature decreases on days 8, 15, and 25 were caused by the pile turning on the previous days

**Figure 1:** Variations in pile temperature during the aerobic composting processes in different treatments

## 3.2. pH

During the composting process, pH changes due to the production of microbial metabolites. Therefore, pH is an indicator directly reflecting the aerobic fermentation process [9]. Too high or too low pH affects the decomposition of organic matter and the reproduction of microorganisms, thereby influencing the composting process. As shown in Fig. 2, other treatments except T4 showed pH > 8 before composting. As the composting progressed, lignocellulose degradation produced small-molecule organic acids [10], resulting in a decrease in pH. After the composting was completed, all the treatments showed pH < 7.5. Particularly, T3 experienced the largest decrease, possibly due to the fact that the pile had high moisture content and poor ventilation on day 40 when the pile temperature was rising, which promoted the activities of anaerobic microorganisms and the production of organic acids. At the late stage, stable humus and other macromolecular complexes were formed in T1 and T2, which cushioned the pH variations, and thus the pH decreases in the two treatments were relatively mild. T4 had little change in pH before and after composting.

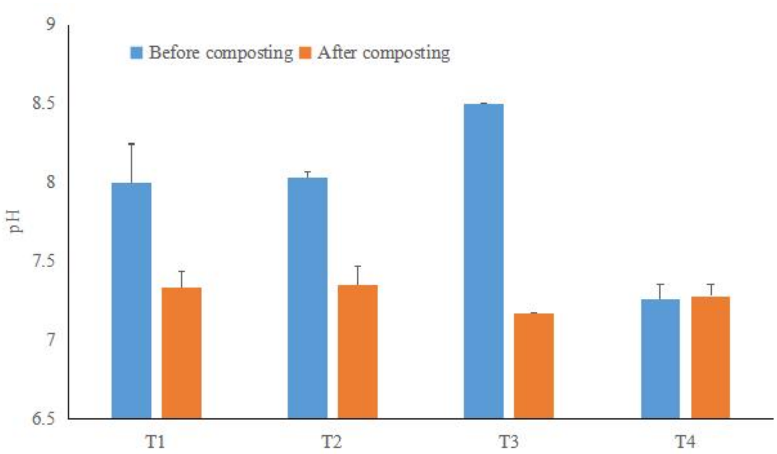


**Figure 2:** Variations in pH before and after composing in different treatments

## 3.3. Total nitrogen, total phosphorus, and total potassium

As shown in Fig. 3, the addition of different straw materials increased the total nitrogen, total phosphorus, and total potassium in the pile compared with the addition of montmorillonite (or before composting). Specifically, the addition of sawdust was conducive to the increase in total nitrogen, while that of sugarcane leaves contributed to the increases in total phosphorus and total potassium. Due to the concentration effect caused by organic matter decomposition and reduced water content, the total nitrogen, total phosphorus, and total potassium of all the treatments increased to different degrees after composting.

The aerobic composting process experiences nitrogen loss, nitrogen fixation, and nitrogen release [11]. As shown in Fig. 3A, the total nitrogen content after composting in TI, T2, T3, and T4 was 2.64%, 1.47%, 2.69%, and 0.41%, respectively, which increased by 25.78%, 75.63%, 15.23%, and 72.34%, respectively, compared with that before composting. Such increases were attributed to the greater nitrogen concentration of the pile than the loss of nitrogen from ammonia volatilization. The increase was the largest in T2, indicating that the composing of biogas residue mixed with coconut leaves had the strongest nitrogen retention ability.

The total phosphorus content in T1, T2, T3, and T4 was 2.99%, 0.30%, 1.26%, and 0.31%, respectively, before composting and 4.01%, 0.478%, 2.23%, and 0.50%, respectively, after composting, both following the trend of T1>T3>T4>T2. Before composting, the total potassium content in T1, T2, T3, and T4 was 1.17%, 0.40%, 0.52%, and 0.02%, respectively, following the trend of T1>T3>T2>T4. After composting, the total potassium in the four treatments was 1.7%, 0.56%, 1.11%, and 0.075%, respectively, in an order of T1>T3>T2>T4. The results indicated that phosphorus and potassium were stable elements in the composting process, and their absolute content was related to the type of straw added. Generally, the absolute content of phosphorus and potassium content did no change significantly during the fermentation process, while the relative content increases due to the concentration effect [12–13]. The aerobic composting of biogas residue supplemented with sugarcane leaves had the highest total phosphorus and total potassium.

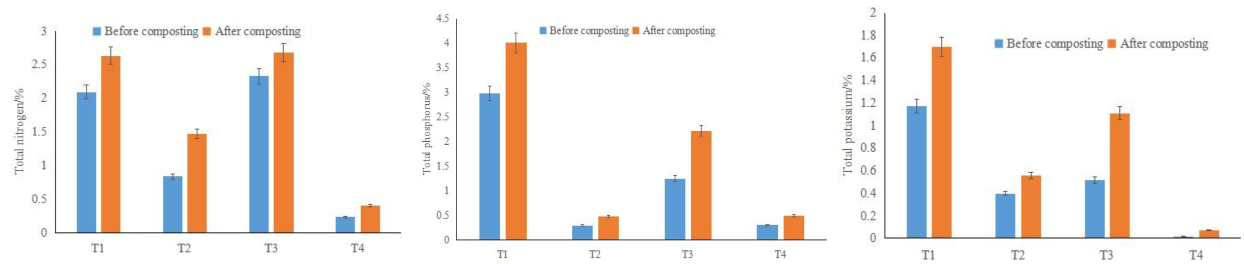



**Figure 3:** Total nitrogen, total phosphorus, and total potassium before and after composting in different treatments

## 3.4. Organic matter content

Carbon is the basic energy source for microorganisms in aerobic composting. During the composting process, microorganisms decompose organic matter into carbon dioxide, which is then released, resulting in the decreasing organic matter content. As shown in Fig. 4, the organic matter content of each treatment decreased after composting for 40 days. Specifically, the organic matter content of T1, T2, T3, and T4 after composting was 58.41%, 66.32%, 76.03%, and 0.21%, decreasing by 14.60%, 4.51%, 1.399%, and 61.46%, respectively. The decreases followed the trend of T4>T1>T2>T3. The content of organic matter in compost depends on the decomposition and synthesis of organic matter [14]. T4 was a mixture of montmorillonite and biogas residue, with biogas residue as the only carbon source, which was mainly used to maintain the metabolism of microorganisms and rapidly degraded by microorganisms to generate carbon dioxide, water, and heat. T1, T2, and T3 with the supplementation of crop straw had high carbon content. Crop straw, together with biogas residue, provided sufficient carbon source for microbial activities. In addition to maintaining microbial life, the small-molecule substances decomposed in the early stage were gradually synthesized into large-molecule humic acids, which reduced the loss of organic matter.

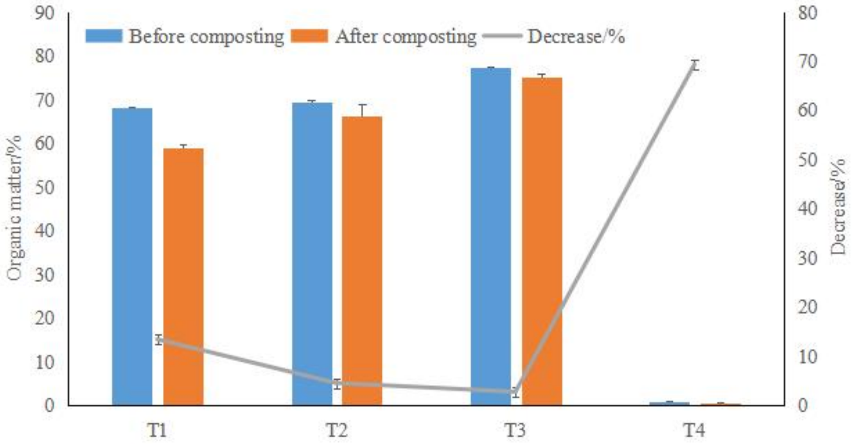



**Figure 4:** Variations in organic matter content before and after composting in different treatments

## 3.5. Seed germination index

The seed germination index calculated from the seed germination test in which seeds are incubated with the compost sample extract is an indicator for evaluating the biotoxicity and harmless of compost products. The extracts of immature compost samples contain high concentrations of toxic substances such as NH4+, small-molecule organic acids, and heavy metals, which have strong inhibitory effects on the growth of crop seeds. The germination index >50% and >80% indicates that the compost sample is basically harmless and completely mature [15–16], respectively. The germination index >110% generally indicates the compost sample has the characteristics of plant nutrients and plant growth-promoting agent and can be used as fertilizer in agricultural production [17]. However, Ko et al. [18] believe that the germination index above 110% is more suitable to be taken as the standard for compost maturity. The seed germination indexes of T1, T2, T3, and T4 before composting were 37.68%, 43.86%, 43.63%, and 50.30%, respectively (Fig. 5). After 40 days of aerobic composting, the seed germination index increased, being 107.71% (the highest), 101.22%, 72.77%, and 81.42% in T1, T2, T3, and T4, respectively. The results indicated that the mixed composting of biogas residue with sugarcane leaves or coconut leaves had the best decomposition effect on plant toxic substances such as NH3 and organic acids in the pile. T3 did not reach complete maturity at the end of the experiment, indicating that the organic acids (causing plant toxicity) generated in the composting process had not been effectively degraded, which was highly correlated with the pile temperature and pH. On day 40 of composting when the pile temperature was rising, the rapid fermentation of soluble organic matter produced a large amount of harmful substances such as small-molecule organic acids, resulting in the lowest pH and seed germination index.

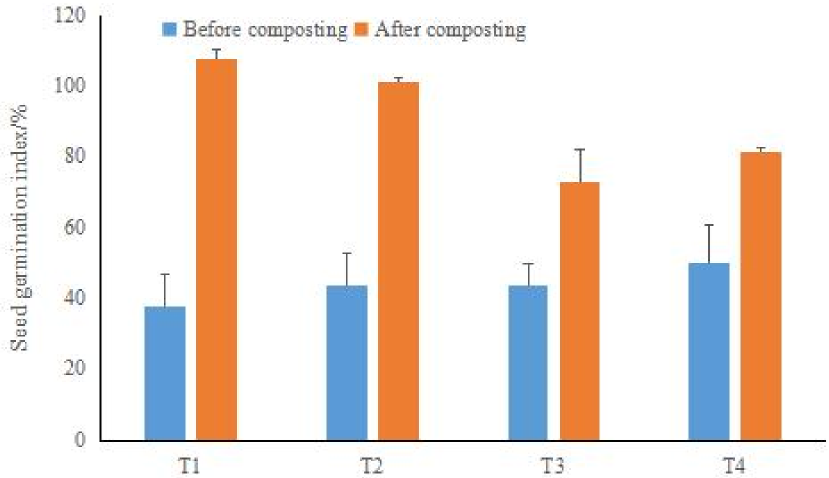



**Figure 5:** Seed germination indexes before and after composting in different treatments

## 4. Conclusions

We studied the effects of different crop straw samples such as coconut leaves, sugarcane leaves, and sawdust on the aerobic composting performance of biogas residue and obtained the following results. (1) The aerobic composting of biogas residue mixed with sugarcane leaves showed a period of 16 days with pile temperature >55 °C, the highest content of total phosphorus and total potassium, the highest seed germination index (107.71%), and the best compost maturity. (2) The aerobic composting of biogas residue mixed with coconut leaves showed a period of 23days with pile temperature >55°C, which indicated the complete harmless treatment. This treatment had the largest increase in total nitrogen, demonstrating the strongest nitrogen retention ability. In addition, the seed germination index in this treatment was 101.22%, which meant the compost reached complete maturity. (3) The aerobic composting of biogas residue mixed with sawdust experienced slow rise in pile temperature and entered the maturity stage late. This treatment was still in the temperature rising stage on day 40, with a seed germination index of 72.77% and poor maturity, which remained to be studied.

In conclusion, sugarcane leaves and coconut leaves serve as the ideal materials to be supplemented in the aerobic composting of biogas residue. They can be selected based on the comprehensive consideration of material production season and production costs.

## Acknowledgements

This work was financially supported by Hainan Province Science and Technology Special Fund(ZDYF2021XDNY301), Hainan Provincial Natural Science Foundation of China (420QN329), Hainan Provincial Natural Science Foundation of China(520MS093), Central

Public-interest Scientific Institution Basal Research Fund for Chinese Academy of Tropical Agricultural Sciences(1630042022002)and Project on Key Technology for Ecological Restoration and Green Development in Tropical Dry-Hot Valley(202302AE090023).

## References

[1] G.W. Li, N. Li, J.X. Li, et al. Application of cultivation of Sedum lineare Thunb with biogas residue resources under low temperature condition in North China. Journal of Environmental Engineering Technology, vol.9(2019), 103–110. (in Chinese)

[2] C.H. Song, M.X. Li, B.D. Xi, et al. Characterisation of dissolved organic matter extracted from the bio-oxidative phase of co-compositing of biogas residues and livestock manure using spectroscopic techniques. International Biodeterioration & Biodegradation, vol.103(2015), 38–35.

[3] Editorial Committee of Flora Reipublicae Popularis Sinicae, Chinese Academy of Sciences. Flora Reipublicae Popularis Sinicae(Beijing: Science Press, China 1977). (in Chinese)

[4] W. Zheng, B. Gao, H.M. Ma, B. Li, et al. Analysis on parameters of organic waste anaerobic biogas residue compost. Sichuan Environment,vol.41(2022), 324–332. (in Chinese)

[5] R.Q. Lei, W.J. Qin, J. Liu, et al. Research on composting of swine manure biogas residue and sawdust with different C/N and effects of the products on germination characteristics of rice seed. Soil and Fertilizer Sciences in China, vol.8(2022), 205–211. (in Chinese)

[6] F.C. Guan, H.R. Yu, W. Yan, et al. Key points of simplified secondary fermentation technology for animal manure biogas residue. Special Economic Animals and Plants, vol.4(2022), 109–110. (in Chinese)

[7] Ministry of Agriculture and Rural Affairs of the People's Republic of China. Organic fertilizer (NY525) [S]. 2021; 7–10. (in Chinese)

[8] L.T. Li, C.H. Dong, Z.X. Rao, et al.Effects of biogas residue addition on humification of kitchen waste compost. Journal of Agro-Environment Science, vol.42 (2022), 1148–1155. (in Chinese)

[9] C.L. Gou, Y.H. Gao, S.X. Liu, et al. Investigation and application progress of inoculating microbes on aerobic composting of manure. Hubei Agricultural Sciences, vol.52(2022), 1244–1247. (in Chinese)

[10] J.L. Ji, Y.Z. Wang. Enhancement of aerobic composting performance of biogas residue through inoculation of Bacillus subtilis Z2. Highlights of Sciencepaper Online, vol.15 (2022), 303–310. (in Chinese)

[11] R. Cáceresa, K. Malińska, O. Marfà. Nitrification within composting: A review. Waste Management, vol.72 (2022), 119–137. (in Chinese)

[12] Y. Liu, X.W. Ruan, T.C. Xu. Prospect of composting technology for treating rural domestic organic wastes. Chemical Engineering Design Communications, vol.44 (2018), 136. (in Chinese)

[13] W.D. Xu, J.N. Zhang, J.M. Wang, et al. Dynamics of nutrient indexes and maturity changes of chicken manure composting. Journal of Anhui Agricultural Sciences, vol.49 (2021), 153–156. (in Chinese)

[14] M.P. Bernal, J.A. Alburquerque, R. Moral, et al. Composting of animal manures and chemical criteria for compost maturity assessment. A review. Bioresource technology, vol.100(2019), 5444–5453.

[15] X.Y. Qian, G.X. Shen, Z.Q,. Wang, et al. Co-composting of livestock manure with rice straw: Characterization and establishment of maturity evaluation system. Waste Management, vol.34 (2014), 530–535. (in Chinese)

[16] A.C. Cunha-Queda, H.M. Ribeiro, A. Ramos, et al. Study of biochemical and microbiological parameters during composting of pine and eucalyptus bark. Bioresource Technology, vol.98(2007), 3213–3220. (in Chinese)

[17] G. Aggelis, C. Ehaliotis, F. Nerud, et al. Evaluation of white-rot fungi for detoxification and decolorization of effluents from the green olive debittering process. Applied Microbiology and Biotechnology, vol.59(2002), 353–360.

[18] H.J. Ko, K.Y. Kim, H.T. Kim, et al. Evaluation of maturity parameters and heavy metal contents in composts made from animal manure. Waste Manage, vol.28(2008), 813–820.