Initial Active Phase of In-Vessel Composting of Sewage Sludge, Leaves and Rice Straw

Xiaojie Sun*(**), Zhihan Tan*(**), Xiaosong He***, Hongxia Zhang*(**)‡, Beidou Xi*(**), Hongtao Zhou* and Hong Xiang Zhu****
*Guangxi Key Laboratory of Environmental Pollution Control Theory and Technology, Guilin University of Technology, Guilin 541004, China
**Guangxi Collaborative Innovation Center for Water Pollution Control and Water Safety in Karst Area, Guilin University of Technology, Guilin 541004, China
***State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences, Beijing 100012, China
****College of Light Industry and Food Engineering, Guangxi University, Nanning, 530004, China
‡Corresponding authors: Hongxia Zhang: zhx75@glut.edu.cn

ABSTRACT

This work studied the characteristics of leaf, rice straw, and sewage sludge (SS) co-composting with the aim of determining the best composting ratio by monitoring temperature changes, oxygen (O₂) concentration, carbon dioxide (CO₂) concentration, ammonia (NH₃) concentration, hydrogen sulfide (H₂S) concentration, pH, electrical conductivity (EC), heavy metal content, carbon-nitrogen ratio (C/N ratio), germination index (GI), moisture content (MC), and volatile solids (VS) content during the composting process. Three composting piles with the mixture ratios of 4:1:1 (Pile A), 5:1:1 (Pile B), and 6:1:1 (Pile C) (SS: leaf: rice straw) were tested. According to the temperature, C/N ratio, germination index, MC, and VS, the level of compost maturity in Pile B with a 5:1:1 mixing ratio was higher than that in Piles A and C. The contents of heavy metals in the composts were shown to meet the grade A standard in CJ/T 309-2009 (2009), except Cu and Zn, which was within the grade B standard.

INTRODUCTION

With the development of urban landscaping and agriculture, green waste (garden waste and agricultural waste) production has increased in China. The annual amount of garden waste reached approximately 2.0×10⁷ tons in China. Generally, green waste is incinerated or deposited in landfills in China (Zhang & Sun 2014). The average annual agricultural residue yield reached 5.2×10⁸ tons during 2002-2011, approximately 19% of which was burned openly (Yang et al. 2015). Given the rapid increase of urban populations, SS has also continuously increased in the past twenty years. The annual amount of SS reached approximately 30,000,000 tons (Dai 2012). SS is mainly treated for landfills (30%) and agricultural use (45%) in China (Su et al. 2010). However, these treatments of SS have caused significant environmental perturbations, such as water and air and soil pollution (Dennehy et al. 2017). Therefore, it is critical to develop strategies to effectively recycle the wastes and alleviate environmental pollution meanwhile (Lu et al. 2009).

Green waste products are rich in fiber, protein, fat, and trace elements such as calcium (Ca), iron (Fe), copper (Cu), zinc (Zn), cobalt (Co), phosphorus (P), and manganese (Mn), among others. Previous research has shown that green waste composting can improve soil fertility and soil physical properties, maintain soil moisture levels, and prevent soil erosion (Tong et al. 2018). SS contains many soil nutrients such as organic matter (OM), nitrogen (N), phosphorus (P) and other micronutrients. However, using SS without prior stabilization has potentially negative effects on the remediation of degraded soils because they may contain phytotoxic or pathogenic substances, which have a highly unstable nature. One of the efficient techniques for treating and reusing organic waste is composting (Jayanta et al. 2021). The ratio of materials in the mixture is one of the key factors during composting. However, past research hasn’t yielded a clear optimal ratio since the materials and composting circumstances differed. Banegas et al. (2007) recommended a 1:3 ratio (sludge: sawdust), based on the dilution effect caused by anaerobic sludge. Zubillaga & Lavado (2003) reported that the compost was not affected by the sawdust ratio. Lu...
et al. (2009) recommended a 3:1:1 (v:v:v) mixture ratio of municipal solid waste: SS: mature compost in an in-vessel composting.

The aim of the present study is to examine the effects of the ratio of feedstock (i.e., leaf, rice straw, and SS) on the characteristics of the co-composting process and to obtain an optimum composting ratio based on the changes in temperature, O₂ concentration, CO₂ concentration, NH₃ concentration, H₂S concentration, pH, EC, heavy metal content, C/N ratio, GI, MC, and VS content during the composting process.

MATERIALS AND METHODS

Composting Materials

The dewatered SS with an MC of approximately 86.3% was obtained from the Qilidian Sewage Treatment Plant in Guilin City. The leaves (approximately 3.8% in MC) were collected from the Yanshan Botanical Garden in Guilin, whereas the rice straw (approximately 0.7% in MC) was collected from a rice farm in the Guilin Suburb. We chose leaves with sizes less than 100 mm and the whole leaves were used without cutting or grinding. A 9CFZ-40 feed grinder was used to cut the rice straw into small pieces of less than 40 mm. Table 1 shows the properties of the composting raw materials.

Experimental Set-up

The control technology for a bio-composting (CTB) system with intelligent real-time monitoring was used in this study. The system included three subsystems: three composting bioreactors, a real-time monitoring system, and the intelligent control system, as shown in Fig. 1. Each reactor was 1.3 m tall with a diameter of 0.8 m, and the effective volume was 250 L. The reactors had a double-cylinder structure and a polyethylene material was wrapped in an insulating layer. The monitoring system monitored composting parameters in the reactor in real-time and provided automatic feedback for controlling during the composting process. This system had a reaction chamber, a pump, gas flow meters, temperature probes, a CO₂ monitor, an H₂S monitor, an NH₃ monitor, an O₂ monitor and a control cabinet. Two groups of temperature probes were linked to the control cabinet and placed at a distance of 0.0 and 0.2 m from the composting reactor’s cylindrical centerline. Each group of temperature probes was mounted 0.15, 0.3, 0.6, and 1.2 m above the bottom of the reactor to monitor the pile body temperatures at 1-min intervals. Each reactor installed four O₂ probes for monitoring the O₂ concentrations, which were mounted 0.2 m away from the cylindrical centerline of the composting reactor and 0.15, 0.3, 0.6, and 1.2 m above the bottom of the reactor. The CO₂, NH₃, and H₂S probes were connected to the exhaust collection tube to determine the CO₂, NH₃, H₂S concentrations. Temperature, as well as O₂, CO₂, NH₃, and H₂S concentrations, were recorded in the three reactors using the CTB automated control system and software (Compsoft 2.0; ZKBL Co., Ltd., China). The composting lasted for 300 h in this study.

Composting Methods

In this study, rice straw and leaves were cut into small pieces of less than 100 mm by a 9CFZ-40 feed grinder. The leaves and rice straw were mixed with SS by hand, using three mixing ratios, namely, Pile A, B, and C (4:1:1, 5:1:1, and 6:1:1, respectively; SS: leaf: rice straw, w:w:w). Table 2 shows the designs of the composting experiments and the main characteristics of the composting materials. The aeration rate was designed based on the pile’s temperature during different composting stages (Table 3).

Sample Analysis

The solid and gas samples were analyzed during the composting process. The heavy metal content was determined by inductively coupled plasma emission spectrometry (IRIS Intrepid II XSP, Thermo Elemental Corporation, Franklin, MA, USA). Table 1: The initial properties of raw materials.

| Parameter          | Sewage sludge | Leaf  | Rice straw |
|--------------------|---------------|-------|------------|
| Moisture content (%)| 86.3 ± 1.7   | 7.9 ± 0.4 | 8.1 ± 0.26 |
| Organic carbon (%)   | 46.56 ± 0.20 | 39.03 ± 0.38 | 39.49 ± 0.54 |
| Total nitrogen (%)   | 4.80 ± 0.02  | 1.30 ± 0.01 | 1.06 ± 0.06 |
| C/N Ratio            | 9.7 ± 0.07   | 30.1 ± 0.13 | 37.22 ± 2.3 |
| TP (%)               | 1.09 ± 0.07  | 0.094 ± 0.018 | 0.08 ± 0.01 |
| K (%)                | 0.61 ± 0.07  | 2.42 ± 0.66 | 2.22 ± 0.11 |
| GI (%)               | 1.6 ± 0.5    | 60.1 ± 3.2 | 62.3 ± 4.7 |

Note: Reported values are mean ± STDEV of the three repeats.
The GI was determined by the germination test (Sun et al. 2012a). The MC was analyzed by the weight loss after the sample was oven-dried at 105°C for 24 h. The VS content was determined by the additional weight loss after the sample was dried at 550°C for 4 h in a muffle furnace based on previously oven-dried weight. Other analytical methods involved in the protocol are shown in Table 4. The data was analyzed using SPSS 14.0 software. The differential analysis was used with the paired-sample t-test, and the bivariate correlation analysis was performed to analyze the relationship between the indexes.

RESULTS AND DISCUSSION

Changes in Temperature

The temperatures of the three composting piles of leaves, rice straw, and SS are shown in Fig. 2. The time-temperature curves at the central axis and edge of the bottom, lower-middle, middle, and surface layers in each reactor were different. The temperatures at the central axis of the reactor were higher than those at the edge. The temperatures at the lower-middle and bottom layers were higher than those at the middle and surface layers. The peak temperature reached 64.2, 62.2, and 65.9°C after 79, 78, and 46 h at the lower-middle layer in Piles A, B, and C respectively, while the peak temperature reached 59.2, 62.2, and 57.8°C after 71, 77, and 98 h at the bottom layer in Piles A, B, and C, respectively.

To meet the relevant composting requirements, the temperature needs to be maintained at above 55°C for at least 72 h or above 50-55°C for at least 120-168 h to kill pathogens (Chang et al. 2017, GB7959-2012 2012). Table 5 gives the highest temperature and the length of time each pile was over 50°C in both horizontal and vertical directions. In Pile A, the temperature at the central axis of the lower middle layer met the regulatory requirement for composting temperature, whereas, in Pile B and C, the temperatures at the center axis of the lower middle and bottom layers met the regulatory requirement. For Piles A, B, and C, the total time when the temperature was over 50°C was 240, 421, and 314 h, respectively. The temperature variations during the composting process indicated that the 5:1:1 ratio (SS: leaf: rice straw) gave the best performance in terms of maintaining a high temperature.

Changes in O₂ and CO₂ Concentrations

The changes in the O₂ consumption and CO₂ concentration are shown in Fig. 3. The O₂ consumption and CO₂ concentration increased as the temperature increased and they decreased as the temperature decreased. The lowest O₂ concentration was recorded at 72, 73, and 43 h in Piles A, B, and C respectively, which was consistent with the appearance of the temperature peak (Fig. 2). The O₂ concentration was significantly different at the surface, middle, lower-middle, and bottom layers of the three piles. For the lower-middle layer, the O₂ concentration was not significantly different in Piles A and B (P=0.562q) but was significantly higher than that in Pile C (P<0.01). At the middle and surface layers, the O₂ concentration in Pile B was apparently lower than that...
in Piles A and C ($P<0.01$). The trend indicates that the $O_2$ utilization in Pile B was higher than that in other piles. Based on the examination of testing data for each pile, a substantial negative correlation ($r^2>0.83$, $P<0.01$) was discovered between $CO_2$ and $O_2$ concentrations.

**Changes in $NH_3$ Concentration**

The changes in $NH_3$ concentration over time are shown in Fig. 4. The $NH_3$ concentration in Pile C was higher than that in Piles A and B ($P<0.01$). $NH_3$ was detected at approximately 90, 40, and 20 h in Piles A, B, and C, respectively. Then the $NH_3$ concentration increased and reached the peak values of 19, 66, and 84 ppm in Piles A, B, and C at 164, 190, and 186 h, respectively. Therefore, controlling $NH_3$ emission at 160-190 h was important for odor minimization.

After 190 h, the $NH_3$ emissions decreased quickly in all the piles and reached almost 0 ppm in Pile A at the end of composting. In Pile B, the $NH_3$ emissions fluctuated between 20-30 ppm after 220 h until the end of composting. However, the $NH_3$ concentration in Pile C continued to increase after 225 h and reached 60 ppm at the end of composting. This trend may be due to localized anaerobic conditions caused by the higher SS ratio in Pile C. The anaerobic bacteria might use $CO_2$ as a carbon source and produce more $NH_3$. This hypothesis could be confirmed by the changes in $CO_2$ concentration (Fig. 3). The $CO_2$ concentration of the exhaust gas in Pile C was lower than that in Piles A and B. As a result, effective measures to avoid and regulate $NH_3$ contamination during composting with a high sludge ratio should be adopted. Some additives including exogenous microbes such as

![Fig. 2: Changes of temperature in vertical and horizontal gradient in the piles.](image-url)
cellulose-degrading bacteria, Azotobacter, the absorbent such as clay and zeolite, and metallic salt such as calcium salt and magnesium salts, could be used to reduce nitrogen loss during the composting.

**Changes in H$_2$S Concentration**

A similar H$_2$S emission profile was found in the three piles (Fig. 5). H$_2$S emissions were first discovered 10 h after the commencement of composting and quickly rose to 45 ppm at 18 h for Pile A, 63 ppm at 15 h for Pile B, and 63 ppm at 20 h for Pile C. The H$_2$S emission decreased quickly afterward and approached zero after 80 h in the three piles. Within this, the H$_2$S emission in the three piles decreased fast and reached zero after 80 h. As a result, H$_2$S emissions were concentrated between 10 and 20 h following the start of composting, with the highest levels of H$_2$S emissions occurring between 15 and 20 h. The findings showed that controlling H$_2$S emissions before 80 h was critical for odor reduction. Li et al. (2008) reported that H$_2$S maintained a high level in the first 4 days, especially after 1 and 2 days of the experiment.

The results of the H$_2$S emission showed no significant difference between Piles A and B ($P = 0.402$), and between Piles B and C ($P = 0.086$). However, a significant difference was observed between Piles A and C ($P = 0.042$). The results also suggest a good correlation between H$_2$S production and the amount of SS in three piles. The H$_2$S emissions increased as the sludge content increased in the three piles.

**Changes in pH and EC Values**

The pH and EC values are presented in Table 6. Overall, the final pH values of compost products of the three piles were higher than the initial pH values, which might be due to the ammonization of organic nitrogen by microbes. The pH values in the surface and middle layers were higher than those in the bottom layer. The difference in pH value in different layers might be caused by the volatilization of ammonium in the nitrification process. The pH values of compost products met the allowed range of 6.5-8.5 for land use (GB8172-87 1987).
The changes in EC values indicated the possible phyto-toxicity or phyto-inhibitory effects (Zhang & He 2006). As shown in Table 6, the compost products at the middle and bottom layers recorded higher EC values than other layers. At the middle and bottom layers, microorganisms were more intensely activated so that more biodegradable organics were decomposed into inorganic salt, which might explain the difference in different layers. The EC values of the compost samples in this study were notably within the Greek standard (e.g., the upper limit is 4.0 mS.cm\(^{-1}\)) (Lasaridi et al. 2006). Therefore, the compost products were possibly suitable for land application with proper usage provisions.

**Changes in Heavy Metal Concentrations**

The heavy metals contents are inclined to increase in the compost product; thus, evaluation of heavy metal content is essential. Table 7 shows the control standards about heavy metals (GB4284-84 1984, CJ/T 309-2009 2009). The contents of heavy metals As, Cd, Cr, Cu, Ni, Pb, and Zn in the end products are listed in Table 8. The heavy metals Zn and Cu exceeded the limits in GB4284-84 (1984), but they were within the B grade standard in CJ/T 309-2009 (2009). Other heavy metal contents in the end products were under the A grade standard in CJ/T 309-2009 (2009). However, metal accumulation should be given sufficient attention when the compost products are repeatedly applied to the soil (Ko et al. 2008).

**Changes in Other Chemical and Maturity Parameters**

The chemical and maturity parameters before and after composting are shown in Table 9. The C/N ratio of the composting raw materials was approximately 6-8, which declined to 3-5 in the end products (Table 9). Generally, a final C/N ratio of 20 or below indicates the maturity of the compost with an initial C/N ratio of 25-30. However, the C/N ratio observed in this study did not sufficiently indicate the maturity of the compost because the initial C/N ratio (6 - 8) was not in the range of the initial C/N ratio in the general rule. Another maturity parameter \( T = (C/N)_{\text{final}}/(C/N)_{\text{initial}} \) was proposed by Morel et al. (1985), and compost products were considered as mature when the parameter \( T \leq 0.6 \). Similarly, Sun et al. (2012b) stated that the compost became mature when \( T \) was approximately 0.7. In the present study, \( T \) was approximately 0.63, 0.51, and 0.57 in Piles A, B, and C, respectively. Therefore, the compost products reached complete maturity. The compost of Pile B was more mature than that of Piles A and C.

The GI can assess the toxicity and maturity level of compost products. A GI of 50% was used to indicate that the
Table 6: Changes of pH and EC during composting.

| Raw material       | pH  | EC[mS.cm⁻¹] |
|--------------------|-----|-------------|
| Pile A             | 7.91| 1.69        |
| Pile B             | 7.53| 1.15        |
| Pile C             | 8.21| 1.71        |
| Product surface    |     |             |
| layer              | 8.21| 1.37        |
| Product middle     | 8.3 | 2.44        |
| layer              | 8.17| 2.41        |
| Product bottom     | 8.17| 2.56        |
| layer              |     |             |

Table 7: Control standards for heavy metal content for agricultural use [mg.kg⁻¹].

| Control standards | pH<6.5 | pH≥6.5 | As  | Cd  | Cr  | Cu  | Ni  | Pb  | Zn  |
|-------------------|--------|--------|-----|-----|-----|-----|-----|-----|-----|
| GB4284-84         | 75     | 75     | 5   | 20  | 600 | 250 | 100 | 300 | 500 |
| pH≥6.5            | 75     | 75     | 600 | 1000| 500 | 500 | 100 | 500 | 1000|
| CJ/T309-2009      | A Grade| 30     | 3   | 500 | 1500| 100 | 500 | 300 | 1500|
|                   | B Grade| 75     | 15  | 1000| 200 | 100 | 300 | 1000| 3000|

The compost was phytotoxin-free (Wong et al. 2001). The GI values of end products in three piles increased significantly and reached 47.5%-70.1%. Therefore, the compost in Piles A and B were sufficiently stable at 300 h.

The MC of compost significantly decreased in the three piles. The MC of end products in piles A and B was within the acceptable limit of 20-35% (CJJT52-93 1993). The largest decrease in MC was found in Pile B, which was 36.7%.

The VS decreased during the composting process for all the piles. Similar results were observed in Wong (2001) and Zhou et al. (2014). Among the three piles, Pile B with a 5:1:1 mixture ratio had the highest loss of VS content (14.37%).

CONCLUSION

The co-composting of SS with leaves and rice straw was realized at the mixture ratios of 4:1:1 (Pile A), 5:1:1 (Pile B), and 6:1:1 (Pile C). A ratio of 5:1:1 was found to be the optimum ratio for maintaining the highest temperature. A significant negative correlation was observed between CO₂ and O₂ concentrations. The O₂ utilization in Pile B was higher than that in other piles. The NH₃ and H₂S emissions significantly increased as the ratio of sludge increased. Therefore, special attention should be given to controlling NH₃ pollution caused by composts with a high sludge ratio. Higher EC values were observed in the middle and bottom layers than the top layers in the composting products, but
Table 8: Changes in the amount of heavy metals before and after composting [mg.kg⁻¹].

| Piles  | Time(h) | As  | Cd  | Cr  | Cu  | Ni  | Pb  | Zn  |
|--------|---------|-----|-----|-----|-----|-----|-----|-----|
| Pile A | 0       | 15.8 | 0.7 | 85.8 | 560.2 | 45.2 | 22.5 | 472.5 |
|        | 300     | 15.2 | 0.9 | 102.7 | 653.4 | 47.5 | 27.4 | 523.7 |
| Pile B | 0       | 16.2 | 0.5 | 91.0 | 584.7 | 43.7 | 25.6 | 511.4 |
|        | 300     | 18.4 | 0.8 | 112.5 | 705.3 | 47.8 | 21.9 | 463.2 |
| Pile C | 0       | 17.5 | 0.7 | 110.4 | 642.5 | 55.4 | 24.3 | 526.1 |
|        | 300     | 20.1 | 1.1 | 93.6  | 589.6 | 44.6 | 22.7 | 447.3 |

Table 9: The changes of other chemical and maturity parameters before and after composting.

| Parameter | Time [h] | Pile A | Pile B | Pile C |
|-----------|----------|--------|--------|--------|
| C/N       |          | 7.67   | 7.31   | 5.94   |
| GI [%]    | 300      | 4.86   | 3.73   | 3.38   |
| GI [%]    | 300      | 63.8   | 69.5   | 73.1   |
| GI [%]    | 300      | 28.7   | 32.8   | 41.7   |
| GI [%]    | 300      | 70.9   | 66.8   | 74.3   |

they did not exceed the tolerance level for plants of medium sensitivity according to the Greek standard. The pH values in the surface and middle layer were higher than those in the bottom layer, and the pH of the composting products was within the accepted range of 6.5-8.5 for land use. While the Cu and Zn concentrations were within the grade B standard, other heavy metal contents in all the compost products were shown to meet the grade A standard in CJ/T 309-2009 (2009). According to the C/N ratio, GI, MC, and VS, Pile B with a 5:1:1 mixing ratio were more mature than Piles A and C.

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REFERENCES

Banegas, V., Moreno, J.L., Moreno, J.I., García, C., León, G. and Hernández, T. 2007. Composting anaerobic and aerobic sewage sludges using two proportions of sawdust. Waste Manag., 27: 1317-1327.

Chang, H.Q., Zheng C.J., Zhang, J.Y. and Deng Q. 2017. Effects of different environmental temperatures on dewatered sludge composting. J. Ecol. Environ., 26(10): 1755-1760.

CJJT 309-2009. 2009. Disposal of Sludge from Municipal Wastewater Treatment Plant - Control Standards for Agricultural Use. Ministry of Housing and Urban-Rural Development of the People’s Republic of China.

CJJT52-93. 1993. Technical Regulations for the Aerobic Static Composting of Municipal Solid Waste. Industry-Standard of the People’s Republic of China.

Dai X. 2012. Comparison of Sludge disposal techniques at home and abroad. Water Ind. Mkt., 4: 15-17.

Dennenhy, C., Lawlor, P.G., Jiang, Y., Gardiner, G.E., Xie, S., Ngkiem, L.D. and Zhan, X. 2017. Greenhouse gas emissions from different pig manure management techniques: A critical analysis. Front. Environ. Sci. Eng., 11: 11-16.

GB4284-84. 1984. Control Standards for Pollutants in Sludge from Agricultural Use. Ministry Of Urban and Rural Construction and Environmental Protection, Beijing, China.

GB7959-2012. 2012. Sanitary Standard of No-Hazardous Treatment of Night Soil. Ministry of Health, Beijing, China.

GB8172-87. 1987. Control Standards for Urban Wastes for Agricultural Use. State Bureau of Environmental Protection, The People’s Republic of China, Beijing, China.

Jayanta, A., Shailendra, Y. and Atiya, K. 2021. Challenges and control strategies of odor emission from composting operation. Appl Biochem. Biotechnol., 12: 490-499. https://doi.org/10.1007/s11440-013-2640-x.

Ko, H.J., Kim, K.Y., Kim, H.T., Kim, C.N. and Umeha, M. 2008. Evaluation of maturity parameters and heavy metal contents in composts made from animal manure. Waste Manag., 28: 813-820.

Lasaridi, K., Protopapa, I., Kotsou, M., Pilidis, G., Manios, T. and Kyriacou, A. 2006. Quality assessment of composts in the Greek market: the need for standards and quality assurance. J. Environ. Manag., 80: 58-65.

Li X.J., Zhang R.H. and Pang Y.Z. 2008. Characteristics of dairy manure composting with rice straw. Bioresearch. Technol., 99: 359-367.

Lu, Y., Wu, X. and Guo, J. 2009. Characteristics of municipal solid waste and sewage sludge co-composting. Waste Manag., 29: 1152-1157.

Morel, J.L., Colin, F., Germon, J.C., Godin, P. and Juste, C. 1985. Methods for the evaluation of the maturity of municipal refuse compost. In: Gasser, J.K.R. (ed.), Composting of Agricultural and Other Wastes, Elsevier, London, pp. 56-72.

Su, C.X., Wang, L.B., Li, L.X. and Cao, J. 2010. Sludge handling and reuse into resources in a sewage treatment plant. China Resourc. Compre. Util., 28(5): 50-52.

Sun, X.J., Wang, D.Q., Lu, W.J. and Wang, H.T. 2012a. Characteristics of night soil and leaf co-composting using an aerobic static method. Front. Environ. Sci. Eng., 6(3): 421-427.

Sun, X.J., Wang, S.M. and Wang, J.J. 2012b. Composting of night soil and green wastes. Compost Sci. Util., 20: 254-259.

Tong, J., Sun, X., Li, S., Qu, B. and Wan, L. Reutilization of green waste as compost for soil improvement in the afforested land of the Beijing Plain. Sustainability, 10(7): 2376.

Wong, J.W.C., Mak, K.F., Chan, N.W., Lam, A., Fang, M., Zhou, L.X., Wu, Q.T. and Liao, X. 2001. Co-composting of soybean residues and leaves in Hong Kong. Bioresearch. Technol., 76: 99-106.

Yang, X.L., Jiang, Q., Song, H.L., Gu, T.T. and Xia, M.Q. 2015. Selection and application of agricultural wastes as solid carbon sources and biofilm carriers in MBR. J. Hazard. Mater., 283: 186-192.

Zhang, L. and Sun, X. 2014. Changes in physical, chemical, and microbiological properties during the two-stage co-composting of green waste with spent mushroom compost and biochar. Bioresearch. Technol., 171: 274-284.

Zhang, Y. and He, Y. 2006. Co-composting solid swine manure with pine sawdust as organic substrate. Bioresearch. Technol., 97: 2024-2031.

Zhou, H.B., Chen, T.B., Gao, D., Zheng, G.D., Chen, J., Pan, T.H., Liu, H.T. and Gu, R.Y. 2014. Simulation of water removal process and optimization of aeration strategy in sewage sludge composting. Bioresearch. Technol., 171: 452-460.

Zubillaga, M.S. and Lavado, R.S. 2003. Stability indexes of sewage sludge compost were obtained with different proportions of the bulking agent. Commun. Soil Sci. Plant Anal., 34: 581-591.