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# Influence of bulking agents on physical, chemical, and microbiological properties during the two-stage composting of green waste

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ABSTRACT

A recyclable organic bulking agent (BA) that can be screened and was developed to optimize green waste (GW) composting. This study investigated the use of wood chips (WC) (at 0%, 15%, and 25%) and/or composted green waste (CGW) (at 0%, 25%, and 35%) as the BAs in the two-stage composting of GW. The combined addition of WC and CGW improved the conditions of composting process and the quality of compost product in terms of composting temperature, porosity, water retention, particle-size distribution, pH, electrical conductivity (EC), cation exchange capacity (CEC), nitrogen losses, humification indices, microbial numbers, enzyme activities, macro- and micro-nutrient contents, and toxicity to germinating seeds. The compost matured in only 22 days with the optimized two-stage composting method rather than in the 90–270 days typically required for traditional composting. The optimal two-stage composting process and the best quality of compost product were obtained with the combined addition of 15% WC and 35% CGW.

## 1. Introduction

Composting is an effective and environmental friendly method to stabilize organic wastes, inactivate pathogens, and recycle nutrients (Zhang and Sun, 2015). The final product, compost, is rich in stable humus-like substances and can be used as a soil amendment or organic fertilizer (Zhang et al., 2013). The composting process is greatly affected by environmental conditions (i.e., temperature, moisture content, pH, and aeration) and organic waste properties (i.e., C/N ratio, particle size, and nutrient content) (Iqbal et al., 2010; Silva et al., 2014). If composting conditions are not appropriate, the efficiency of the process is compromised. Furthermore, application of the immature compost may inhibit seed germination and reduce plant growth because the immature compost may deprive roots of oxygen or be directly phytotoxic (Zorpas and Loizidou, 2008).

One kind of organic material that can be composted is green waste (GW). GW is the biodegradable organic fraction of municipal solid waste and generally consists of grass, leaves, tree trimmings, and other similar constituents. However, the composting of lignocellulosic GW is challenging because it usually decomposes very slowly (Fernandez-Hernandez et al., 2014). Previous research has demonstrated that the composting of GW can be improved by adding a bulking agent (BA), such as sawdust, rice husks, cotton waste, or peanut shells (Zhou et al., 2014). BAs are commonly used to ensure efficient composting, in part because they adjust the porosity of the material to be composted and thereby improve ventilation and water penetration and enhance microbial growth and activity (Blazy et al., 2014; Shao et al., 2014). In addition, BAs can be used to adjust carbon availability, C/N ratio, and the pH during composting so as to increase the rate of decomposition (Jolanun and Towprayoon, 2010). BAs can also enhance the stability of organic matter and suppress pathogens and parasites (Shao et al., 2014).Therefore, selecting an appropriate BA is critical for large-scale, long-running composting operations.

The term “two-stage composting” refers to a process that includes primary composting (PC) and secondary composting (SC) (Zhang et al., 2013). During the PC, the thermophilic period (55–60 °C) can be quickly achieved and maintained for a relatively long time. Once the composting temperature in the PC decreases below the middle composting temperature (35–45 °C) (the microbial degradation has decreased at that time), the PC has essentially ended, and the SC is started in order to quickly increase the temperature to a second thermophilic period, during which decomposition continues (Zhang et al., 2013). The thermophilic period is generally longer in the SC than in the PC. Therefore, neither PC nor SC represents a complete composting process; when combined, the PC and SC together represent a complete composting

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process. Two-stage composting can generate a better product and in a shorter time than traditional composting. Because the highest composting temperature is attained twice and because the thermophilic period lasts for a relatively long time, two-stage composting generates stabilized, high value compost products in only 30 days rather than the 90–270 days typically required for traditional composting (Khalil et al., 2008; Zhang et al., 2013).

The current study concerned the two-stage composting of GW with the addition of wood chips (WC) and/or composted green waste (CGW) as the BAs. Lignocellulosic by-products such as WC are commonly used as BAs to enhance the degradation rate during composting (Blazy et al., 2014; Koivula et al., 2004; Vandecasteele et al., 2013). By providing structural support, WC may ensure adequate gas exchange and prevent excessive compaction of the composting materials (Koivula et al., 2004). WC addition can also increase the concentrations of macro- and micro-nutrients and reduce the volatilization and leaching of nutrients during composting. For instance, the use of WC greatly reduced nutrient losses in the composting of cattle manure (Kato and Miura, 2008). In particular, WC may serve as the carbon and nitrogen sources that support the activity and reproduction of microorganisms (Jolanun and Towprayoon, 2010). As a consequence, the addition of woody materials can improve the quality of the compost product (Vandecasteele et al., 2013).

Successful composting often involves microbial inoculation. The most convenient way to add microorganisms is to use mature compost as the BA, because mature compost often contains large numbers of microorganisms. Kato and Miura (2008) reported that the addition of mature compost accelerated the succession of microbial communities and maintained the microbial diversity in the composting of cattle manure. The addition of mature compost is also expected to shorten the composting period and reduce offensive odors produced during composting (Makan et al., 2012). Moreover, mature compost can provide microorganisms with abundant macro- and micro-elements (Kulikowska and Gusiatin, 2015; Zhang and Sun, 2015). Finally, addition of compost product could increase aeration and water penetration during composting and thereby optimize the process and increase compost stability and quality (Eyheraguibel et al., 2008).

The use of WC and mature CGW as the BAs in GW composting has not been previously evaluated. Therefore, the objectives of this research were to determine: (1) how addition of various quantities and combinations of WC and CGW affects the physical, chemical, and microbiological properties during the two-stage composting of GW; (2) how these additions affect the quality of the final compost; and (3) the optimal combination of WC and CGW for the two-stage composting of GW.

## 2. Materials and methods

### 2.1. Composting materials and bulking agents

In this study, GW was composted after WC and/or CGW were added as BAs. The GW consisted of various biodegradable organic materials (i.e., grass, fallen leaves, and branch cuttings) generated by urban landscape maintenance in Beijing, China; the materials were cut to a length of 10 mm before the composting began (Zhang and Sun, 2015). WC and CGW were purchased from the Beijing Jingpuyuan Biological Engineering Co., Ltd., China. The WC consisted of a mixture of pine and alamo wood, which was cut with a shredder to a length of 15 mm, a length that was reported to optimize composting performance (Raichura and McCartney, 2006). The particle size of CGW used in the study was <8 mm. Bamboo vinegar, a light-yellow and transparent acidic liquid with a slightly smoky smell, was used in the composting because it can neutralize ammonia gas and reduce N volatilization and therefore increase the retention of N in the compost (Zhang et al., 2013). The bamboo vinegar, which was obtained from the Beijing Kaiyin Organic Fertilizer Production Co., China, had a pH of 3.10 and an electrical conductivity (EC) of 1.30 mS/cm. Urea, which was obtained from the Beijing Jingpuyuan Biological Engineering Co., Ltd., was used to adjust the initial C/N ratio of the composting materials. The main properties of the initial GW, WC, CGW, and nine composting mixtures are presented in Tables 1–3. The determination methods are described in section 2.4.

### 2.2. Experimental set-up and procedure

The initial quantity of GW (dry weight) was the same in all treatments, and the quantities of WC and/or CGW added in the nine treatments were calculated according to percentages (based on dry weight) indicated by an orthogonal design (Table 3). Before the composting was initiated, water was added to the GW to obtain a moisture content of 60–65% (w/w). Then, the C/N ratio was adjusted to 25–30 by application of urea (2.4 kg per 100 kg of dry weight GW) (Zhang et al., 2013). Finally, different quantities of WC and CGW were evenly mixed into the GW according to Table 3. During the whole two-stage composting process, the composting materials were watered regularly to maintain the moisture content at 60–65%; the moisture content of composting mixture was determined daily with an SK-100 moisture meter (Tokyo, Japan); the oxygen-supplying method of composting (the details were specified on the next paragraph) could provide appropriate oxygen condition, and thus, ensure the successful completion of the two-stage aerobic composting (Zhang et al., 2014, 2013).

This study used a two-stage composting method that includes PC and SC (Zhang et al., 2013). On day 0 (the beginning of the PC), the nine mixtures were added to composting reactors, which were non-covered cement containers (6 m long, 2 m wide, and 1.5 m high) with an automatic compost-turning and -watering system. Each treatment was represented by three replicate composting reactors, and thus there were 27 composting reactors. The automatic system turned the mixture in each composting reactors for 40 min every day during the PC to ensure oxygen supply, to homogenize the materials, and to stimulate microbial activity (Zhang et al., 2014, 2013). When the temperature of the mixture increased to 50–60 °C, 2 ml of bamboo vinegar (diluted in 2 L of water) was added per 100 kg of mixture (dry weight). The vinegar solution was sprinkled onto the mixtures as they were being turned. When the temperature dropped to 35–45 °C, the PC was considered complete. The temperatures in all treatments decreased to 35–45 °C by day 6. At that time, the mixtures were once again treated with the vinegar solution (Zhang et al., 2013). On day 6, the mixture was removed from each composting reactor with an excavator and was placed in open windrows (three windrows per reactor). The SC of all treatments began on day 6. Each windrow had a trapezoidal cross-section and was 2 m long, 1.5 m wide, and 1 m high. For sufficient aeration, each windrow was manually turned with a mini-excavator for 40 min every 3 days (Zhang et al., 2014, 2013). Diluted bamboo vinegar was added during the SC as described for the PC. When the temperature of a windrow decreased to the ambient temperature, the whole composting process was considered complete.

### 2.3. Sampling and monitoring

Samples were collected as the composting mixtures were being turned on day 0, 1, 4, 6, 10, 16, 22, 25, 27, and 30. On these days, three subsamples (200 g per subsample) were collected from the top, middle, and bottom of each reactor or windrow and were combined to form one composite sample per composting reactor or

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