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Changes in physical, chemical, and microbiological properties during the two-stage co-composting of green waste with spent mushroom compost and biochar

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HIGHLIGHTS

- Spent mushroom compost (SMC) and/or biochar (BC) were added to green waste composting.
- Physico-chemical and microbiological properties explained the rapid decomposition.
- Particle sizes, microorganisms, enzymes, nitrification, and nutrients were optimized.
- Combination of 35% SMC and 20% BC reduced two-stage co-composting time to 24 days.
- Two-stage co-composting enhanced the humification and decomposition of organic wastes.

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ABSTRACT

This research determined whether the two-stage co-composting can be used to convert green waste (GW) into a useful compost. The GW was co-composted with spent mushroom compost (SMC) (at 0%, 35%, and 55%) and biochar (BC) (at 0%, 20%, and 30%). The combined addition of SMC and BC greatly increased the nutrient contents of the compost product and also improved the compost quality in terms of composting temperature, particle-size distribution, free air space, cation exchange capacity, nitrogen transformation, organic matter degradation, humification, element contents, abundance of aerobic heterotrophs, dehydrogenase activity, and toxicity to germinating seeds. The addition of 35% SMC and 20% BC to GW (dry weight % of initial GW) and the two-stage co-composting technology resulted in the production of the highest quality compost product in only 24 days rather than the 90–270 days required with traditional composting.

1. Introduction

Organic solid wastes, such as agricultural and forest residues and municipal solid wastes, have become major environmental and social problems in both developed and developing countries throughout the world (Rashad et al., 2010). In China, green waste (GW) is considered a municipal solid waste and mainly includes park and garden litter and trimmings. GW has traditionally been incinerated or deposited in landfills, which are undesirable practices because they produce large amounts of greenhouse gases and occupy valuable agricultural land (Zhang et al., 2013). In contrast to traditional disposal methods, composting has received increasing attention as an environmentally acceptable way to dispose of and utilize organic wastes. Composting, which can be defined as a process of biological decomposition and stabilization of wastes under aerobic conditions (Paredes et al., 2002), can transform organic wastes into a stable final product that is not phytotoxic, that is free of pathogens, and that can be used as a substrate and nutrient source for plant growth or as a conditioner to improve soil properties (Huang et al., 2006).

The term co-composting refers to the simultaneous composting of several types of residual materials such as physic nut deoiled cake, rice straw, and animal dung (Das et al., 2011); olive mill wastewater sludge and agricultural wastes (Paredes et al., 2002); municipal solid waste and poultry manure (Petric et al., 2012); and soybean residues and leaves (Wong et al., 2001). Co-composting not only simultaneously disposes of different organic wastes but can also enhance compost quality by the comprehensive use of diversified waste properties (Paredes et al., 2002). In addition,

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the fermentation period can be shorter when two or more organic wastes are composted together rather than separately (Das et al., 2011).

The current study concerns the co-composting of GW with spent mushroom compost (SMC) and biochar (BC). SMC, a waste product of the mushroom industry, contains mushroom mycelium and high levels of residual nutrients such as organic substances, nitrogen (N), phosphorus (P), and potassium (K). As a compost component, SMC also has many other desirable characteristics including a high moisture content, a low bulk density, and an absence of plant pathogens (Curtin and Mullen, 2007). Furthermore, SMC contains many residual enzymes such as protease, cellulase, hemicellulase, LiP, MnP, and laccase (Zhu et al., 2012). Although high amounts SMC are produced in China, they have not been disposed of efficiently (Qiao et al., 2011). Most SMC is either spread on land or dumped in landfills, and only a small proportion is used as a soil amendment or as a potting material (Ko et al., 2005). SMC could be especially effective when composted with GW because GW contains a significant amount of lignin. Lignin is a recalcitrant organic polymer that can inhibit microbial access to cellulose and hemi-cellulose and thereby slow the composting process (Zhang and Sun, 2014). SMC can enhance the degradation of lignin because it contains ligninolytic enzymes and a large and active microbial community (Sánchez, 2004). The effects of SMC on the composting of GW, however, have not been determined.

Composting can also be enhanced by the addition of a bulking agent like BC, which is the carbon-rich material produced by the slow pyrolysis of biomass under low oxygen conditions (Dias et al., 2010). As a byproduct of renewable energy production, BC is an inexpensive and renewable resource that can improve soil structure and enhance plant growth (Ngo et al., 2013). As a bulking agent in the composting of organic waste, BC can decrease bulk density (and thereby moderate aeration and increase water retention) and increase cation exchange capacity (CEC), resulting in an improved final compost (Steiner et al., 2010). Moreover, BC can enhance the absorption of gaseous NH_3 and water-soluble NH_4^+, and thereby reduce N loss (Thies and Rillig, 2009). The high surface area and porosity of BC can also help bind nutrients and prevent loss by leaching, provide a habitat for beneficial microorganisms, and improve oxygen and water availability (Meng et al., 2013); these effects can stimulate microbial activity and reproduction and thus accelerate the degradation of organic waste. Dias et al. (2010) reported an organic matter degradation of 73.2% when poultry manure was mixed with BC at a 1:1 (w/w) ratio. Little information is available, however, on the effects of BC on the GW composting.

The current study evaluated whether the two-stage co-composting of GW with SMC and BC shortened the composing period and produced a high quality compost. The changes in the physical, chemical, and microbiological properties of the compost were measured during and at the end of the co-composting process in order to determine the optimal proportions of SMC and BC.

2. Methods

2.1. Raw composting materials

The GW consisted mainly of fallen leaves and branch cuttings generated by urban landscape maintenance in Beijing, China. The SMC, which was obtained from the Beijing Jingpuyuan Biological Engineering Co., Ltd. (China), consisted mainly of mushroom-degraded paddy straw generated by mushroom cultivation. BC was made from coir (coconut husk fiber) and was produced at approximately 450 °C in a low-temperature pyrolysis facility. Bamboo vinegar was used during the composting because it reduces N volatilization; the bamboo vinegar was purchased from the Beijing Kaiyin Organic Fertilizer Production Co. (China). To accelerate the initial composting process, the raw materials were inoculated with the microbial inoculum, which was a mixture of *Trichoderma* spp. (60%, v/v) and *Phanerochaete chrysosporium Burdsall* (40%, v/v). Selected physicochemical properties of the raw composting materials were measured before the start of the composting experiment (Table 1). The determination methods are described in Section 2.4.

2.2. Composting set-up and design

The raw materials were subjected to a two-stage co-composting process, which includes a primary fermentation (PF) and a secondary fermentation (SF) (Zhang et al., 2013). With this new method, a thermophilic phase (50–60 °C) can be attained twice (once during PF and once during SF). This increases microbial activity and reduces the time required to obtain a mature compost (Zhang et al., 2013).

Before the start of the co-composting process, the GW was chopped into 1-cm pieces, the SMC was chopped into 0.5-cm pieces, and the BC was passed through a 0.2-cm sieve. SMC and/or BC were mixed with GW at nine different rates as indicated in Table 2. Then, the C/N ratio of each mixture was adjusted to 25–30 by application of urea, and the moisture content was adjusted to 60–70% by addition of water; this moisture content was maintained throughout the composting. The moisture content of the composting mixture was determined daily with an SK-100 moisture meter (Tokyo, Japan). Finally, according to the initial dry weight of the GW, the dosage of microbial inoculum (5 ml kg^{-1} dry GW) was calculated (Zhang et al., 2013). The microbial inoculum was then sprayed on the composting mixture, and the mixture was mixed evenly.

On day 0 (the start of the co-composting and the start of the PF), the composting mixtures were added to digester cells, which were non-covered cement containers. Each digester cell was 6 m long, 2 m wide, and 1.5 m high, and had an automatic compost-turning and -watering system. Each of the nine treatments was represented by three replicate digester cells. The mixtures were turned for 40 min every day during the PF. When the temperature of the mixture had increased to 60–70 °C, bamboo vinegar (2 ml diluted in 2 L of water) was added per 100 kg of GW (dry weight) (Zhang et al., 2013). The vinegar solution was sprinkled onto the mixture as it was being turned. When all temperatures had dropped to 45–55 °C on day 6, the PF was considered complete.

For the SF, the mixture in each digester cell was once again treated with diluted bamboo vinegar and then formed into three windrows on day 6. Each windrow was 2 m long, 1.5 m wide, and 1 m high. Windrows were turned with a mini-excavator for 40 min every 3 days to ensure oxygen supply. Diluted bamboo vinegar was added every 6 days during the SF as the windrows were being turned. Finally, when the temperature of a windrow decreased to the ambient temperature, the compost was considered mature.

2.3. On-site sampling and monitoring

The top, middle, and bottom of each digester cell or windrow were sampled while the mixtures were being turned on day 0, 2, 4, 6, 12, 18, 21, 24, 28, and 30. The three subsamples (200 g per subsample) were mixed to make one composite sample per digester cell or windrow. Each composite sample was divided into three parts. The first part was air-dried (3–5% moisture content), and the second was oven-dried at 65 °C. All dried samples were crushed in a small grinder, passed through soil sieves (0.25 and 0.1 mm), and used for analysis. Air-dried samples were used for determination of