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Evaluation of maifanite and silage as amendments for green waste composting

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ABSTRACT

Composting is a popular method for recycling organic solid wastes including agricultural and forestry residues. However, traditional composting method is time consuming, generates foul smells, and produces an immature product. The effects of maifanite (MF; at 0%, 8.5%, and 13.5%) and/or silage (SG; at 0%, 25%, and 45%) as amendments on an innovative, two-stage method for composting green waste (GW) were investigated. The combined addition of MF and SG greatly improved composting conditions, reduced composting time, and enhanced compost quality in terms of composting temperature, bulk density, water-holding capacity, void ratio, pH, cation exchange capacity, ammonia nitrogen content, dissolved organic carbon content, crude fibre degradation, microbial numbers, enzyme activities, nutrient contents, and phytotoxicity. The two-stage composting of GW with 8.5% MF and 45% SG generated the highest quality and the most mature compost product and did so in only 21 days. With the optimized composting, the degradation rate of cellulose and hemicellulose reached 46.3 and 82.3%, respectively, and the germination index of Chinese cabbage and lucerne was 153 and 172%, respectively, which were all far higher than values obtained with the control. The combined effects of MF and SG on GW composting have not been previously explored, and this study therefore provided new and practical information. The comprehensive analyses of compost properties during and at the end of the process provided insight into underlying mechanisms. The optimized two-stage composting method may be a viable and sustainable alternative for GW management in that it converts the waste into a useful product.

1. Introduction

The eco-friendly management of forestry wastes is a major challenge for both developed and developing countries (Paradelo et al., 2013; Wei et al., 2007). Because of rapid urbanization, China currently produces about 6 million tons of green waste (GW) annually (Zhang and Sun, 2017). There is an increasing interest in the recycling of organic forestry wastes with the goals of reducing such wastes and conserving and reusing the nutrients in the residues; the recycling of these wastes by composting is therefore superior to waste deposition in landfills or waste incineration (Gabhane et al., 2012; Zhang and Sun, 2016a; Zhang et al., 2013). The final compost product can also be used as a soil conditioner or organic fertilizer (Rawoteea et al., 2017).

Researchers previously described an innovative, two-stage composting technology that includes a primary composting (PC) and a secondary composting (SC); degradation is more rapid during the PC than during the SC (Zhang et al., 2013). During the PC, the thermophilic phase (50–60 °C) can be quickly achieved and maintained for a relatively long time. When the temperature decreases below the mesophilic temperature (35–45 °C) (the microbial degradation has decreased at that time), the PC is ended and the SC begins, resulting in a second thermophilic phase, during which decomposition continues (Zhang and Sun, 2016b; Zhang et al., 2013). The thermophilic phase 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 process. This new method results in two peaks in thermophilic temperature and an extended thermophilic period. As a consequence, two-stage composting produces a more mature and stable product than traditional composting. In particular, the compost matured in only 30 days with the two-stage composting method rather than in the 90–270 days typically required for traditional composting method (Khalil et al., 2008). Zucconi et al. (1981) reported that the use of immature compost in agricultural or forestry can inhibit plant growth due to the presence of pathogenic microorganism, toxic metabolites, and heavy metals. Obtaining a mature compost pro-

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duct with GW is challenging because GW consists primarily of cellulose and hemicellulose that resist microbial attack (Zhang and Sun, 2016a). To improve the composting of organic wastes, researchers have commonly recommended various modifications of composting parameters including the use of amendments (e.g., Khan et al., 2014). The current study determined whether the addition of maifanite (MF) and/or silage (SG) improves the two-stage composting of GW.

MF is a granitoid silicate produced by the weathering and denudation of basic or acidic intrusive rocks (Chen et al., 2016). MF is used in many fields (medical care, food preparation, decontamination, etc.) because of its porous structure, high cation-exchange capacity (CEC), and large specific surface area (Wang et al., 2016). It has great potential as an amendment for composting because it maintains its porosity and thereby supports aerobic degradation of organic wastes (Zhang et al., 2013). The addition of MF, for example, supported water and gas exchange and prevented excessive compaction of the composting mass (Awasthi et al., 2018a; Chen et al., 2016). Because of its large surface area, MF also functions as an excellent absorbent and thereby reduces the loss of nitrogen (N) in the form of ammonia (NH_3) and nitrous oxide during composting (Wang et al., 2017; Wang et al., 2016). MF amendments can also increase the antioxidant and catalytic activities of some enzymes during composting (Awasthi et al., 2018b; Chen et al., 2015), and can function as a source of nutrients for microorganisms (Gao et al., 2013).

The second amendment considered in the current research, SG, is a product of the anaerobic fermentation of forage crops, grasses, and other raw agricultural materials (Rajabi et al., 2017). After ensiling, SG has high porosity (Sun et al., 2017; Wustholz et al., 2017), which enhances the aeration and water permeability of the composting mass (Ahn et al., 2009). SG contains substantial quantities of easily degradable carbohydrates, lysine, and methionine, and N (Migliorati et al., 2017; Wustholz et al., 2017), which can support microbial activity and thereby accelerate the breakdown of organic waste (Restrepo et al., 2013). SG can also help lower the pH of compost. The pH tends to increase during composting because of the microbial decomposition of organic acids and the subsequent release of ammonium following mineralization of organic N sources (Zhang and Sun, 2016b). High pH, however, can limit microbial activity and thereby reduce the decomposition of organic waste (Zhang and Sun, 2017). Because SG has a relatively low pH due to the high concentration of organic acids produced during ensiling (Danner et al., 2003), it can help neutralize or lower the pH during composting and therefore provide an environment that supports high microbial activity. In addition, SG contains aerobic microorganisms and enzymes (Machado et al., 2013) that can accelerate the composting process (Ahn et al., 2009). The micro- and macro-elements in SG (Benito and Greger, 2017) can also enhance the quality of the final compost product (Restrepo et al., 2013).

Although MF or SG have been previously studied as amendments for the composting of organic wastes (Ahn et al., 2009; Awasthi et al., 2018a, 2018b; Restrepo et al., 2013; Wang et al., 2017, 2016), they have not been studied in combination as amendments for the composting of GW. In addition, these previous studies have usually focused on a few properties of the compost and have not comprehensively described properties during composting and in the final product. Therefore, the specific objectives of this study were to (1) evaluate the effects of MF and SG on the physical, chemical, and microbiological properties of GW during the two-stage composting; (2) evaluate the effects of MF and SG on the quality of the final compost; and (3) identify the optimal combination of MF and SG for the two-stage composting of GW. In addition to providing new and practical information, this study provides a detailed analysis of compost properties and insight into the mechanisms of how those properties were altered by the amendments during the two-stage composting of GW.

2. Materials and methods

2.1. Selection and preparation of raw materials

The GW, which was collected during urban landscape maintenance in Beijing in the spring of 2017, consisted of grass, fallen leaves, and branch cuttings. It was shredded into 1.0-cm-long fragments before it was used (Zhang et al., 2013). MF was purchased from the Lingshou Yaoxin Minerals Processing Co. (Hebei, China). The particle size of MF ranged from 2.0 to 4.0 mm, which was reported to be optimal for composting (Wang et al., 2016). SG with particle size <6.0 mm was produced from the ensiling of sugar beet and was purchased from the Shandong Zunkai Agricultural Development Co. Ltd. (Shandong, China). Urea, which was used to adjust the initial carbon-to-nitrogen (C/N) ratio of the composting mass, was purchased from the Beijing Kaiyin Organic Fertilizer Production Co. (Beijing, China). Microbial inoculum was purchased from the Beijing Jingpuyuan Biological Engineering Co. Ltd. (Beijing, China) and was used to accelerate the initial composting. The inoculum consisted of *Trichoderma* spp. and *Phanerochaete chrysosporium Burdsall* at a ratio of 3:2, v/v, with a total population density of 1×10^7 colony forming units per ml. The basic physical and chemical properties of the raw materials are listed in Table 1.

2.2. Composting procedure

A two-stage composting experiment with nine treatments was conducted. The initial quantity of GW was the same in all treatments, and the quantities of MF and/or SG added in the nine treatments were calculated according to the percentages indicated by an orthogonal design (Table 2). The treatment T1 with 0% MF and 0% SG served as the control. The two-stage composting was performed as described by Zhang and Sun (2016a) with some modifications. Before the start of the composting and based on Zhang and Sun (2016a), the initial C/N ratio was adjusted to 25–30 by application of urea (2.4 kg per 100 kg of dry weight GW). The composting mixtures were mixed with water, and the moisture content was adjusted to 60% of water-holding capacity (WHC). This moisture content was maintained at about 60% throughout the composting process, because 60% was considered optimal for microbial activity; the moisture content was determined daily with an SK-100 moisture meter (Tokyo, Japan). After the initial C/N ratio and moisture were adjusted, an equal amount of microbial inoculum (5 ml of inoculum kg^{-1} dry GW) was added to each composting mixture, and the mass was well mixed.

As indicated earlier, the two-stage composting method includes a PC and SC. At the beginning of the PC (on day 0), the nine mixtures were added to composting reactors, which were the non-covered cement containers (6 m long, 2 m wide, and 1.5 m high) with an automatic compost-turning and -watering system. Each of the nine treatments was represented by three replicate composting reactors. The automatic system turned the mixture in each reactor for 40 min every day during the PC. Turning was done to aerate the mass and to thereby enhance chemical and biological activities. When the composting temperature dropped to 35–45 °C (on day 6 for all reactors), the PC was considered complete. The SC of all treatments was begun on day 6 by creating three windrows from the mixture in each composting reactor; the windrows were formed with a mini-excavator (model DLS830-9B; Shandong, China). Each windrow had a trapezoidal cross-section and was 2 m long, 1.5 m wide, and 1 m high. Windrows were turned with the mini-excavator for 40 min every 3 days to ensure

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