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Effects of rhamnolipid and initial compost particle size on the two-stage composting of green waste

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HIGHLIGHTS

- Effects of rhamnolipid (RL) and particle size (IPS) on composting were studied.
- RL at 0.15% and IPS of 15 mm reduced the two-stage composting time to 24 days.
- Physico-chemical and biological characteristics explain the rapid decomposition.
- Microbial communities, nutrient contents, and cellulose degradation are optimized.

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ABSTRACT

Composting is a potential alternative to green waste incineration or deposition in landfills. The effects of the biosurfactant rhamnolipid (RL) (at 0.0%, 0.15%, and 0.30%) and initial compost particle size (IPS) (10, 15, and 25 mm) on a new, two-stage method for composting green waste was investigated. A combination of RL addition and IPS adjustment improved the quality of the finished compost in terms of its physical characteristics, pH, C/N ratio, nutrient content, cellulose and hemicellulose contents, water-soluble carbon (WSC) content, xylanase and CMCase activities, numbers of culturable microorganisms (bacteria, actinomycetes, and fungi), and toxicity to germinating seeds. The production of a stable and mature compost required only 24 days with the optimized two-stage composting method described here rather than the 90–270 days required with traditional composting. The best quality compost was obtained with 0.15% RL and an IPS of 15 mm.

1. Introduction

Organic solid waste, which includes animal manure, agricultural and forestry residues, sewage sludge, and green waste, is an inexpensive, renewable, and abundant resource. The quantity of green waste, i.e., park and garden litter and trimmings, generated in cities has increased dramatically with the rapid development of urban green space in China; as a consequence, disposal of green waste is a major problem affecting the environment and sustainable development of cities (Zhang et al., 2013). For obvious reasons, recycling of green waste by composting is preferred to its deposition in landfills or its incineration. In composting, thermophilic, aerobic microorganisms transform organic materials into a hygienic, biostable product that can be used as a soil amendment, an organic fertilizer, or an alternative to peat in soilless culture (Gabhane et al., 2012). However, there are still some problems associated with traditional composting that must be overcome, i.e., traditional compositing is labor intensive and time consuming and produces an odorous gas and an unstable compost product. The time required is especially long for green waste because green waste generally contains up to 75% cellulose and hemicellulose (Liu et al., 2006; Shi et al., 2006).

We previously demonstrated that composting can be improved by using an innovative two-stage composting technology, which includes a primary fermentation (PF) and a secondary fermentation (SF) (Zhang et al., 2013). With this new method, the highest fermentation temperature (55–60 °C or even higher) is attained twice, and thus the thermophilic period can last for a long time. As a consequence, the production of a mature compost requires only 30 days rather than the 90–270 days required for traditional composting (Zhang et al., 2013).

Because the composting process occurs in a very thin layer of liquid on the surface of the organic particles, the physical and chemical conditions in the gaps that separate the particles greatly affect the process (Xi et al., 2005). Researchers have attempted to

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improve the composting microenvironment by adding surfactants (Shi et al., 2006). Surfactants, which include ionic and non-ionic forms, are molecules with a polar head group and a nonpolar hydrocarbon tail and are therefore amphiphilic and have the ability to reduce the surface tension between a liquid and a solid (Xi et al., 2005). Increased rates of decomposition after the addition of a surfactant have been reported for wood, bagasse, and corn stover; by modifying the surface properties of cellulose and minimizing irreversible binding, the surfactant enhanced the enzymatic hydrolysis of cellulose and promoted the production of compost (Eriksson et al., 2002).

Biosurfactants are anionic compounds that are produced as co-metabolites by particular microorganisms (Fu et al., 2007). The use of biosurfactants has recently increased because they are highly effective and, unlike synthetic surfactants, they are non-toxic to microorganisms and are biodegradable (Mulligan, 2005; Xi et al., 2005). The addition of the biosurfactant rhamnolipid (RL) enhanced the activities of microorganisms and their enzymes and thereby promoted the conversion of organic waste containing high percentages of cellulose and hemicellulose into compost (Fu et al., 2007). When RL is added to an organic waste during composting, the hydrophobic group of RL binds to the surface of the organic material while the hydrophilic group dissolves in the water, which accelerates the degradation of materials and reduces the time required to produce a mature compost (Gabhane et al., 2012). The effects of RL on the composting of green waste, however, have not been determined.

A number of factors should be considered in designing a composting process, and these include: the biodegradability of the waste; physical pretreatment to alter waste particle size and porosity; the nature of the aeration system (static, passive, or dynamic); and the frequency of turning (Barrington et al., 2002). Numerous studies have demonstrated that the biodegradability of organic waste can be increased through chemical or biochemical measures, but few have investigated the effects of initial compost particle size (IPS). Adjusting the IPS could enhance microbial activity throughout the composting period and increase the rate at which macromolecules are degraded (Manpreet et al., 2005). Adjusting the IPS could also enhance water penetration and gas exchange and prevent compaction (Zhou et al., 2014). If the IPS is too small, on the one hand, the transfer of oxygen and carbon dioxide will be inhibited, the compost process will become anaerobic, and microbial activity will be reduced. If the IPS is too large, on the other hand, the compositing materials may collapse and water-holding capacity may decline during the composting process. A large IPS can also create voids, resulting in excessive ventilation and insufficient self-heating. Adjusting the IPS and other physical parameters of the waste is important for the composting of sludge waste (Diaz, 2007). In similar studies, wood chips with IPS ranging from 5 to 25 cm were found to be optimal for composting (Barrington et al., 2003). Little information is available, however, on the effects of IPS on green waste composting.

The overall goal of the present study was to optimize the two-stage composting of green waste. The specific objective was to measure the effects of RL and IPS on the two-stage composting of green waste in terms of the time required to produce compost and the quality of the compost. The changes in the physical, chemical, biochemical, and microbial properties of the compost were measured and analyzed during the two-stage composting process.

2. Methods

2.1. Preparation of compost materials

The green waste that was used as the raw material for composting consisted mainly of fallen leaves and branch cuttings produced by urban landscape maintenance in Beijing in the spring of 2012. Tables 1 and 2 list the main physico-chemical characteristics of the initial material. RL in the form of a brown, water-soluble paste was purchased from Zijin Biological Technology Co. (Huzhou, China) and the critical micelle concentration of RL used in the current study was 0.10%. Bamboo vinegar, which can reduce nitrogen volatilization during composting, was purchased from the Beijing Kaiyin Organic Fertilizer Production Co. (China). The microbial inoculum, which was a mixture of *Trichoderma* spp. inoculum (60%, v/v) and *Phanerochaete chrysosporium Burdsall* inoculum (40%, v/v), was prepared as described by Wei et al. (2007).

Table 1
Physico-chemical characteristics of initial material (IM) and finished composts (means ± SD; *n* = 3). Treatments T1–T9 are described in Table 3.

Treatment	BD (g/cm^3)	WHC (%)	TPS (%)	AP (%)	WHP (%)
IM	0.8759(0.023)	–	–	–	–
T1	0.3156(0.039)f	1.19(0.10)g	47.24(0.34)f	14.92(0.11)f	32.32(0.49)e
T2	0.3290(0.017)e	1.26(0.07)f	45.17(0.22)g	13.11(0.23)g	32.06(0.52)ef
T3	0.3022(0.024)g	1.02(0.02)h	42.35(0.47)h	11.05(0.19)h	31.30(0.33)f
T4	0.3493(0.056)d	1.57(0.04)e	52.67(0.89)e	16.86(0.35)e	35.81(0.50)d
T5	0.4021(0.019)b	1.94(0.12)a	64.02(0.31)a	20.69(0.16)a	43.33(0.23)a
T6	0.4217(0.047)a	1.66(0.09)d	55.06(0.40)d	18.41(0.30)c	36.65(0.37)d
T7	0.3954(0.038)b	1.81(0.03)b	59.49(0.63)b	19.37(0.27)b	40.12(0.15)b
T8	0.3735(0.040)c	1.63(0.06)d	56.31(0.26)cd	17.56(0.48)d	38.75(0.26)c
T9	0.3828(0.016)c	1.75(0.08)c	57.44(0.55)c	18.14(0.21)c	39.30(0.12)bc
	pH	EC (mS/cm)	HA (%)	TOC (%)	C/N ratio
IM	7.33(0.18)	1.71(0.06)	14.59(0.64)	40.41(1.55)	43.45(0.86)
T1	7.00(0.21)d	0.77(0.03)ab	11.98(0.78)de	31.70(1.09)a	10.27(0.54)ab
T2	6.99(0.75)d	0.74(0.02)b	11.62(0.43)ef	30.20(1.23)b	9.93(0.29)b
T3	6.86(0.33)e	0.80(0.05)a	11.39(0.65)f	32.49(1.87)a	10.44(0.62)a
T4	7.42(0.54)c	0.67(0.01)cd	12.70(0.81)c	27.58(1.20)c	8.41(0.23)c
T5	7.61(0.77)a	0.49(0.07)g	14.06(0.52)a	22.06(1.58)f	6.16(0.43)f
T6	7.43(0.63)c	0.58(0.04)f	13.04(0.97)bc	25.26(1.11)e	8.08(0.51)c
T7	7.54(0.39)b	0.62(0.02)e	13.22(0.59)b	24.31(1.64)e	7.58(0.37)de
T8	7.40(0.40)c	0.65(0.05)de	12.82(0.20)bc	26.04(1.32)cd	8.03(0.16)cd
T9	7.52(0.82)b	0.69(0.01)c	12.91(0.36)bc	24.87(1.30)e	7.39(0.68)e

BD = bulk density; WHC = water-holding capacity; TPS = total porosity; AP = aeration porosity; WHP = water-holding porosity; EC = electrical conductivity (25 °C); HA = humic acid; TOC = total organic carbon.
Means in a column followed by the same letter are not significantly different at $p \leqslant 0.05$ by LSD.
All percentages are based on air-dry weight.