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Dynamics of labile and stable carbon and priming effects during composting of sludge and lop mixtures amended with low and high amounts of biochar

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ABSTRACT

This study was performed to investigate the effects of biochar amendment on the dynamics of labile and stable carbon (C) fractions and associated priming effects during composting of sludge and lop mixtures. Furthermore, the effect of aerobic composting on biochar stable C composition was analyzed.

Low amounts of activated carbon [dosage 0–1.7% w/w] and higher amounts of charcoal [dosage 0–38% w/w] were applied to the organic feedstock mixture in two separated full-scale composting trials under practical field conditions. The results demonstrated that biochar-C was substantially more stable during the composting process than compost-derived organic C resulting in a significant enrichment of the stable black C fraction in the final product. Furthermore, stability of final products were significantly increased, if more biochar has been initially added prior to composting. However, labile organic C losses were increased (positive priming) if low amounts of activated carbon have been applied, while no short-term priming effects could be observed after adding charcoal over a wider application range. Moreover, biochar stable C composition was positively affected during the composting process. Based on our results, a biochar amendment ≥10% (w/w) seems generally favorable for an accelerated composting process, while stability characteristics of the final products were improved. However, some caution seems to be required concerning the usability of activated carbon due to positive priming.

1. Introduction

In view of the serious impacts and challenges caused by global warming, soil C sequestration is more and more considered as an essential and feasible strategy for climate change mitigation with an additional benefit of improving soil structure and soil conditions (Lal, 2016). For this reason, the '4 per mille Soils for Food Security and Climate' was launched at the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in Paris in 2015 aiming at an increase of global soil organic matter (SOM) stocks by 4 permil (or 0.4%) per year as a compensation for the global emissions of greenhouse gases by anthropogenic sources (Minasny et al., 2017).

In general, terrestrial C pools store two to three times more C than the atmosphere. Therefore, soils play a key role in the global C dynamics (Lal, 2010). This dynamics can be significantly influenced by implementing farming practices that promote SOM reproduction in agricultural soils (Lal, 2016). In this respect, the ecoregion Kaindorf in Austria represents an excellent example of how this can be effectively achieved via different sustainable farming practices, decentralized organic residue management and compost application (Dunst, 2012).

Composting represents a widely used and rapid technology for the biological transformation of organic residues into more stabilized products under aerobic conditions that can be used as organic fertilizer or soil amendment (Amlinger et al., 2007; Smith & Collins, 2007). To ensure an efficient process and aerobic composting conditions, aeration is normally provided by mechanical turning or via forced aeration systems (Haug, 1993). Even though there is no doubt about the manifold beneficial effects of compost application such as organic matter addition and soil amelioration (Amlinger et al., 2007), there are also some major environmental drawbacks

Abbreviations: BC, black carbon; BPCA, benzene polycarboxylic acid; OC, labile organic carbon; SOM, soil organic matter; TOC, total organic carbon.

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caused by composting. For instance, composting has been regarded as a source of anthropogenic greenhouse gases (Wu et al., 2017) associated with high C losses (Barrington et al., 2002), especially under unfavorable conditions. Furthermore, economic pressure has resulted in shorter processing times on some composting operation facilities resulting in the production and spreading of younger and less mature composts (Dimambro et al., 2015). However, a high degree of stabilization and maturity seems crucial to ensure a high compost product quality influencing the agronomic value and environmental benefit of compost application.

One promising approach to diminish these problems could be the use of biochar as an effective bulking agent in composting (Steiner et al., 2010; Fischer & Glaser, 2012) with several synergistic and advantageous effects for organic residue management and sustainable land use (Fischer & Glaser, 2012; Kammann et al., 2016; Wu et al., 2017). Generally, the use of co-substrates and bulking agents is an established and already well-known option to optimize the composting process, improve the physical, chemical and biological characteristics of the feedstock mixture while minimizing the potential environmental risks during composting (Haug, 1993; Sánchez-García et al., 2015).

However, the utilization of biochar, a carbonaceous, recalcitrant and highly porous material generated via pyrolizing biogenic materials under low oxygen conditions (Schmidt & Noack, 2000), which can be used as an advantageous tool for amelioration and C sequestration in agricultural systems (Glaser, 2007; Spokas 2010), was just recently suggested as an effective composting additive due to following co-benefits: (1) enhanced aeration (Steiner et al., 2010), (2) reduced odor and greenhouse gas emissions (Steiner et al., 2010; Sánchez-García et al., 2015; Kammann et al., 2016), (3) reduced non-pyrogenic organic C (OC) losses (Fischer & Glaser, 2012), (4) accelerated decomposing (Dias et al., 2010; Steiner et al., 2010; Sánchez-García et al., 2015; Kammann et al., 2016) and improved quality of compost products (Jindo et al., 2012; Zhang et al., 2014). But most importantly, by co-application of biochar during composting, a nutrient-rich organic substratum with terra preta-like properties could be potentially generated with superior characteristics for C sequestration, soil amelioration and enhanced plant growth compared to ordinary composting (Fischer & Glaser, 2012; Liu et al., 2012; Schulz et al., 2013; Kammann et al., 2016). Thus, biochar application could become a key factor in organic residue management with valuable co-benefits for climate change mitigation and C sequestration in soils facilitating the achievement of the Paris treaty goal.

Recent research indicates that biochar interacts positively with various organic materials and minerals in the composting matrix (Sánchez-García et al., 2015; Darby et al., 2016; Kammann et al., 2016; Wu et al., 2017). However, the interactions between labile organic matter and biochar during composting remain largely unknown (Sánchez-García et al., 2015; Vandecasteele et al., 2016; Awasthi et al., 2017). In particular, few information has been published yet how (i) non-pyrogenic labile organic C (OC) fractions mainly originated from composting feedstocks and (ii) the much more stable pyrogenic black C (BC) fractions derived from biochar, sometimes also termed as biochar-C, will change over time if they are co-applied during composting. There might be a risk that biochar addition could change or even accelerate organic matter degradation, also known as "priming effect" (Kuzyakov, 2010), while at the same time biochar-C mineralization could be stimulated under the rapid decomposing conditions of aerobic composting. Therefore, a quantification of both labile and stable C fractions seems crucial to gain a deeper understanding about their dynamics under these conditions.

However, contradictory priming effects of biochar on SOM have been reported (Zimmerman et al., 2011; Maestrini et al., 2015; Wang et al., 2016) indicated by an organic matter decomposition which is either accelerated (positive priming), reduced (negative priming) or showing no effect (no priming). Similarly, this might be also the case if biochar is used as a bulking agent for composting but specific effects remain unclear due to missing research data.

Therefore, we conducted two independent composting experiments with sludge, lop and biochar additions at different rates for testing the following hypotheses:

(H1) Biochar exhibits a substantially higher recalcitrance to decomposition during composting compared to other organic residues. Therefore, a relative enrichment of biochar during the composting process is expected.

(H2) Biochar addition reduces labile OC losses that occur during the rotting process (negative priming).

(H3) According to our previous assumptions, we suppose that the final products are more stable, the more biochar has been initially added before composting.

2. Material and methods

2.1. Experimental design

The experiments were carried out at the professional composting facility 'Sonnenerde' in the Ecoregion Kaindorf in Riedlingsdorf, Austria (382 m above sea level, mean annual precipitation 700 mm, mean annual temperature 9 °C; Elpons, 2011). Both trials were performed outdoors in open windrows.

Table 1 provides basic information on both trials (A and B). Organic feedstock sources were municipal sewage sludge and lop. Lop designates cuttings from shrubby vegetation, trees and lawns. Both feedstock components as well as their initial mixture, defined by a volume ratio of 1:1, can be characterized as follows: dry matter content for sludge, lop and the initial feedstock mixture was ~20%, ~60% and 51–57%, respectively. Mass density was 1 g/cm^3 for sludge and 0.3 g/cm^3 for lop. Furthermore, loss of ignition was 26–27% and TOC 15–16% for the initial compost feedstock mixture.

Table 1
Basic information about important characteristics of both composting experiments.

Series	A	B
Number of treatments (including control)	4	6
Biochar application rate (% w/w dry matter)	0, 0.6, 1 and 1.7	0, 4, 7.3, 13.5, 25 and 38
Composition of compost feedstock	Sludge (50%) Shredded lop (35%) Screenings (15%)	Sludge (50%) Shredded lop (25%) Screenings (25%)
Type of biochar	Activated Carbon	Charcoal
Biochar particle size	Fine (pulverized)	Coarse, up to 3 cm
Composting duration (weeks)	10	8
Pile turnovers	6	8
Screening after composting	yes (15 mm)	yes (15 mm)