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Effect of different components of single superphosphate on organic matter degradation and maturity during pig manure composting

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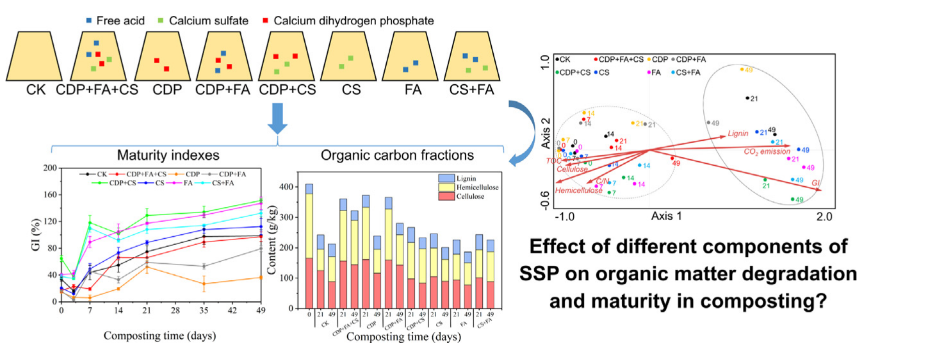
HIGHLIGHTS

- Different components of SSP were added to compost individually or in combination.
- CDP reduced the duration of thermophilic phase and organic matter degradation.
- Combined CDP with FA could postpone the biodegradation process of composting.
- CS buffered the inhibiting effect of CDP leading to a neutral or weakly alkaline pH.
- High salinity and phosphate from CDP should be regulated for better SSP application.

GRAPHICAL ABSTRACT



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ABSTRACT

Single superphosphate (SSP) as an additive could improve phosphorus availability and reduce nitrogen loss for composts, but few studies have explored the influence of SSP on the transformation of carbon fractions in composting. The aim of this work was to assess the effect of different components of SSP, including calcium dihydrogen phosphate (CDP), calcium sulfate (CS) and free acid (FA) on organic matter degradation and maturity during pig manure composting. The results showed that CDP had significantly negative effects on the duration of thermophilic phase and organic matter degradation, but lengthened the curing phase for the transformation of organic matter. FA could intensify the inhibiting effect of CDP and postpone the biodegradation process of composting, but CS could buffer the effect of CDP on the degradation of organic carbon fractions by controlling pH. The study reveals the roles of different components of SSP to the transformation of organic carbon fractions, which lays a foundation for regulating the effects of chemical additives during composting. Regulating the content of CDP in SSP or applying SSP with other chemical additives to control the biotoxicity of excess phosphate on microbial activity should be concerned for complete and efficient composting in further study.

1. Introduction

Single superphosphate (SSP) is a commonly used inorganic phosphorus fertilizer for agricultural application. However, direct application

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of the inorganic phosphorus fertilizers usually has relatively low efficiency for plants due to the immobilization by metal ion (e.g., Ca^{2+}, Fe^{3+} and Al^{3+}) in the soil and may result in an increased potential risk for phosphorus loss in runoff and leachate (Wei et al., 2015; Yang et al., 2015). Hence, it is crucial to improve the effectiveness of SSP fertilizer for resource management and environmental pollution control. Several studies have pointed out that adding a certain amount of SSP additives in agricultural waste composting could significantly increase the percentages of available phosphorus fractions in the composting products, and further improve the absorption and utilization of phosphorus by plants in soils (Jiang et al., 2014; Requejo and Eichler-Lobermann, 2014). Therefore, more attention was paid to the effect of SSP on composting to prepare phosphate fertilizer more effectively.

Composting is a controlled biological decomposition process of organic matter, which can reduce the volume of organic waste and produce a safe, stable and nutrient-enriched soil amendment (Zhang et al., 2017; Zhao et al., 2016). However, the gaseous emission mainly including greenhouse gas and ammonia is a major challenge of manure composting, which are detrimental to the environment and can cause secondary environmental pollution (Chowdhury et al., 2014; Zang et al., 2017). Luckily, many studies have shown that phosphate fertilizer as an additive might be effective in reducing NH_3, N_2O and CH_4 emissions during manure composting (Luo et al., 2013; Predotova et al., 2010). The study by Predotova et al. (2010) showed that SSP was effective in reducing NH_3 emissions from animal manure composting systems, and did not have any negative effects on compost maturity. Luo et al. (2013) indicated that there were 30%–48% NH_3, 32%–38% CO_2 and 31%–37% greenhouse gas emission reduction in the application of SSP with high addition (10%–30% of dry weight of compost raw material). Moreover, Wu et al. (2017) suggested that adding SSP into composting was effective in controlling nitrogen loss during composting, which was beneficial for enhancing the nutrient value of compost product including the contents of carbon, nitrogen and phosphorus. Therefore, composting with SSP addition can not only decrease the harmful gas emission and mitigate the environmental risk of phosphorus leaching after application, but also increase the organic component content in compost product due to the less organic carbon fractions degradation and CO_2 emission. However, there is little information on which is the main factor for the restriction of organic matter decomposition due to the added high levels of SSP during composting.

There are many different factors affect composting, such as raw materials, environmental conditions including pH, the concentration of ions and so on, which play very important roles during the transformation of organic matter. It is generally believed that low pH can limit the microbial activity, and SSP as an acidic fertilizer could lower the pH of compost material, which further lead to the less degradation of organic matter (Fang et al., 2012; Jiang et al., 2014; Tang et al., 2015). However, the raw materials of compost, such as pig manure, rice straw, corn stalks and so on, usually have strong buffer capacity against acid and alkali in fact (Luo et al., 2013). In the previous researches, the pH ranged from 6.2–9.0 with high amounts of SSP addition during composting from pig manure and corn stalks (Jiang et al., 2014; Luo et al., 2012). Considering that the pH ranging from 6.7 to 9.0 was beneficial for bacterial growth and pH of 5.5–8.0 was more suitable for fungal activity during composting (Bernal et al., 2009; Miller and Metting Jr., 1993), the ranges of pH with SSP addition in these cases may be still appropriate for the microbial activity. Therefore, it need further study on whether a large amount of H^+ from SSP addition is an important factor for reducing organic matter degradation. On the other hand, it was reported that phosphate might be the major cause of inhibiting organic matter degradation by microbial activity (Hu et al., 2007; Lee et al., 2009). Jeong and Hwang (2005) found that excess addition of potassium dihydrogen phosphate led to a notable decrease in organic matter degradation during composting. The study by Ren et al. (2010), who tried to eliminate the influence of salinity, found that the reduction of organic matter decomposition still existed when phosphoric acid was used to replace phosphate. Up to now, it is still hard to explain whether the high salt concentration or different components of saline ions in SSP, such as phosphate, calcium ions, etc., could limit microbial activity for organic matter degradation. Therefore, we hypothesized that: (1) different components of SSP may cause different biological microenvironment and further affect in the organic matter degradation and maturity during composting in diverse degree; and (2) the components changing pH and salinity may mainly lead to organic carbon retention.

In the present work, the main components of SSP including calcium dihydrogen phosphate (CDP), calcium sulfate (CS) and free acid (FA) were added in the initial of composting individually or in combination to investigate which component in SSP is the main factor in affecting the degradation of organic matter in compost with high amount of SSP addition. The important factors such as pH, electrical conductivity, PO_4^{3-} and SO_4^{2-} that may be affected by SSP addition were analyzed according to the relationships of them with the degradation process of organic carbon fractions in composting. The aim of this study was to evaluate the differential effect of SSP components addition on organic carbon fractions degradation and to lay down a foundation to reveal the further mechanism involved in carbon transformation with SSP application during composting, which is important for the application of SSP in both compost and soil.

2. Materials and methods

2.1. Composting experiment design and sample collection

Composting materials comprised a mixture of pig manure and corn stalk. Fresh pig manure was taken from a large-scale pig farm located in Beijing suburb, and corn stalk was obtained near Shangzhuang research station of China Agricultural University. Corn stalk chopped into small pieces (30–50 mm) was used to adjust the initial C/N ratio of composting materials. Pig manure and corn stalk were mixed with a ratio of 6.5:1 of wet weight. The characteristics of the raw materials are presented in Table 1.

The main ingredients of SSP fertilizer used in agricultural production include CDP ($Ca(H_2PO_4)_2$), CS ($CaSO_4$) and FA (H_3PO_4 and H_2SO_4). Here, SSP was calculated as 12% P_2O_5, 5% FA and 40% CS. Therefore, CDP, CS and FA (pure materials) were added in the beginning of composting individually or in combination according to the SSP addition of 18% (dry weight) of initial raw materials referenced to Hu et al. (2007) and Luo et al. (2013) in this study, which allowed the effects of different components of SSP on composting to be readily observed. Eight groups of composting experiments were carried out in total as shown in Table 2. The group without any additives was used as control (CK). In case of being affected by H^+, CDP that contained 7.8% FA was washed with ethanol three times and then dried in the oven at 40 °C before being added.

The trial was operated for 49 days in Shangzhuang research station of China Agriculture University from October to November in 2015. Composting materials were put in a series of laboratory-scale composting reactors (60 L in volume) with forced aeration systems, which referenced to Wu et al. (2017). Both turning and forced aeration were used for oxygen supplement during composting. The aeration rates were set to 0.2 $m^3 \cdot h^{-1}$, and the piles were turned manually on day 3, 7, 14, 21, 28, 35 and 42. All the samples were homogenized using the methods of coning and quartering. The triplicate samples were employed for analyzing physical and chemical parameters.

Table 1
Physical and chemical properties of the composting raw materials.

Materials	Moisture content (%)	TOC[a] ($g \cdot kg^{-1}$)	TN[a] ($g \cdot kg^{-1}$)	C/N[b]
Pig manure	66.3 ± 2.66	361.3 ± 2.46	29.3 ± 0.69	14.4
Corn stalk	5.1 ± 0.25	426.3 ± 1.52	10.6 ± 0.22	46.8

[a] Dry weight basis.
[b] C/N was calculated as atomic ratios.