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Reduced turning frequency and delayed poultry manure addition reduces N loss from sugarcane compost

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ABSTRACT

Composting is an effective method to recycle biodegradable waste as soil amendment in smallholder farming systems. Although all essential plant nutrients are found in compost, a substantial amount of nitrogen is lost during composting. This study therefore investigated the potential of reducing N losses by (i) delaying the addition of nitrogen-rich substrates (i.e. poultry manure), and (ii) reducing the turning frequency during composting. Furthermore, we tested the effect of compost application method on nitrogen mineralization. Sugarcane-waste was composted for 54 days with addition of poultry manure at the beginning (i.e. early addition) or after 21 days of composting (delayed addition). The compost pile was then turned either every three or nine days. Composts were subsequently applied to soil as (i) homogeneously mixed, or (ii) stratified, and incubated for 28 days to test the effect of compost application on nitrogen mineralization. The results showed that delayed addition of poultry manure reduced total nitrogen loss by 33% and increased mineral nitrogen content by >200% compared with early addition. Similarly, less frequent turning reduced total N loss by 12% compared with frequent turning. Stratified placement of compost did not enhance N mineralization compared to a homogeneous mixing. Our results suggested that simple modifications of the composting process (i.e. delayed addition and/or turning frequency) could significantly reduce N losses and improve the plant-nutritional value of compost.

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1. Introduction

Sugarcane is cultivated commercially in >109 countries (Dotaniya et al., 2016), and its production is expected to expand in the future due to the increase in demand for ethanol. Currently, sugarcane processing generates a large amount of biomass by-products. About 23% and 3% sugarcane harvest ended as bagasse and filter cake respectively (George et al., 2010). In 2012 alone, for example, >4 million metric tons of sugarcane were produced (FAOSTAT, 2014) in Costa Rica (where this study was conducted) which is estimated to generate about 1.3 million metric tons of bagasse, and 0.2 million metric tons of filter cake. In many countries, the major part of bagasse is commonly combusted for power generation to run the sugar mills (Dotaniya et al., 2016). Filter cake, on the other hand, has no direct use and is mostly piled out in the open-air. In most cases, filter cake is applied as soil amendment with little or without processing. Globally, the management of sugarcane by products is very limited, leading to widespread environmental concerns and suboptimal resource utilization (Chandel et al., 2012; Pandey et al., 2000). Hence composting could be one solution to alleviate the environmental problems caused by sugarcane by-products as well as to enhance crop production.

Composting is a well-known processing method for the bioconversion of organic waste into soil amendments. Composting is effective in decreasing the volume of organic waste and thereby eases transportation of waste (Cook et al., 2015). Application of compost on cropland increases or maintains soil organic matter content and thereby contributes to long-term agricultural sustainability. Studies have shown that sugarcane-waste compost has a potential to be used as organic amendment (Franca et al., 2016; Prado et al., 2013; Stoffella and Graetz, 2000). However, it is still necessary to optimize the sugarcane-waste compost for rapid and efficient release of nutrients. It is also essential to reduce nutrient losses and thereby produce composts with higher agronomic value.

Nutrient content of compost depends mainly on the quality of feedstock materials. In addition to this, proper compost management is required to reduce nutrient losses. This includes: (i) adjusting the initial compost properties such as the C:N ratio, structure and moisture of the feedstock, and (ii) maintaining optimal composting conditions such as oxygen, temperature, and moisture con-

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tent (Bernal et al., 2009). Uncontrolled composting processes result in nutrient losses *via* leaching and gaseous emissions. Nitrogen (N) loss, in particular, is extensive in poorly managed composting piles (Chowdhury et al., 2014a; Vu et al., 2015). The total N losses during composting can account for 40–70% of initial N (Nigussie et al., 2017). The major N loss is ammonia (NH_3), which contributes over 70% of the total N losses (Chowdhury et al., 2014a). High N loss reduces the agronomic value of compost and contributes to greenhouse gas emissions.

Many efforts have been made to reduce N losses mainly by manipulating various physical and chemical parameters (Chowdhury et al., 2014a,b). Addition of carbon-rich materials (bulking agents) is a well-established approach to reduce N losses because these materials increase the C:N ratio of the composting mixtures (Chowdhury et al., 2014a; Khan et al., 2014). For example, the addition of bagasse to filter cake compost increased the C:N ratio from 14 to 22, consequently the total N loss decreased from 14% to 10% (Meunchang et al., 2005). Similarly, N-rich substrates (i.e. poultry manure) are commonly added to lignocellulosic materials (i.e. sugarcane by-products) in order to optimize the initial C:N ratio and/or increase the fertilizing-value (i.e. N content) of the final product (Adamtey et al., 2009). However, this practice increases N losses during composting because the co-existence of high concentrations of NH_4^+, easily mineralizable compounds and high temperatures (>45 °C) which favor ammonia volatilization during the initial phases of composting (Eklind et al., 2007). Delayed addition of N-rich material (i.e. addition of N-rich substrates after the thermophilic phase) is therefore suggested to reduce N losses during composting. To our knowledge, very few studies have been conducted on the effect delayed addition of N-rich substrate on N loss during composting (Dresboll and Thorup-Kristensen, 2005; Nigussie et al., 2017). Moreover, the existing literature is contradictory and hence further studies are required to elucidate the relationship between the timing of the addition of the N-rich substrate and N loss during composting.

Controlling aeration rate is another important parameter to minimize N losses during composting (Chowdhury et al., 2014a; Jiang et al., 2011). In developing countries (such as Costa Rica), most composting operations are carried out using low-tech technologies. Hence aeration is performed manually by turning compost piles (Getahun et al., 2012). Turning increases aeration; however, frequent turning could also result in high N losses via ammonia volatilization (Kalamdhad and Kazmi, 2009; Tirado and Michel, 2010). For example, Cook et al. (2015) observed that frequent turning of compost piles (i.e. three times per week) increased total N losses by >200% compared with less frequent turning (i.e. once a week) during composting of slurry-woodchip mixtures. In contrast, Ogunwande et al. (2008) observed that total N loss was not affected by turning frequency during composting of poultry manure and sawdust. Likely, differences in NH_4^+ concentration, temperature and scale of the experiment could explain this variation. These studies imply that the effect of turning frequency may depend on the characteristics of the composting material.

While a limited number of studies have been conducted to optimize the fertilizing-value of compost via delayed addition of poultry manure (Nigussie et al., 2017) and turning frequency (Cook et al., 2015; Getahun et al., 2012; Jiang-Ming, 2016), the combination of turning frequency and delayed addition of poultry manure has received even less attention. In this study, we examined the effect of the combination of turning frequency and delayed addition of poultry manure on N loss, N-mineralization and the composting process. Furthermore, we tested whether the distribution of compost in soil influences nitrogen mineralization. Concentrated placement in compost pockets rather than homogenously mixed compost may accelerate nitrogen mineralization because the soil microbial biomass will be less protected from predation in small soil pores, thus enhancing the rapid transformation and release of N (Breland, 1994). On the other hand, Magid et al. (2006) found that the accelerating effect of concentrated placement was dependent on the C:N ratio of materials, indicating that *high* C:N ratio materials would be less prone to immobilizing N from soil when concentrated, whereas *low* C:N materials would be less affected by concentrated placement. Therefore, the general objective of this study was to quantify processes which can increase the N fertilizer value of sugar cane waste compost. This was approached by investigating: (i) the effects of the time of poultry manure addition to compost, testing if late application could reduce N losses, (ii) the effects of compost-turning frequency on N losses and N availability in mature compost, and (iii) the effect of localized versus mixed placement of compost in soil on N release, testing if localized placement would lead to faster increase in soil mineral N.

2. Materials & methods

Two independent experiments were carried out in this study. The first experiment was conducted to investigate the effect of delayed addition of N-rich substrate (poultry manure) and turning frequency on total N loss and composting process. To achieve this objective, a meso-scale composting experiment was conducted at CATIE (Centro Agronómico Tropical de Investigación y Enseñanza), Costa Rica. The second experiment was conducted to assess the effect of compost application method on N mineralization, and consisted of a soil incubation study conducted at University of Copenhagen, Denmark. Details of both experiments are presented in Sections 2.1 and 2.2.

2.1. Composting experiment (Experiment 1)

2.1.1. Raw materials for the composts

Compost was made from sugarcane bagasse, filter cake and poultry manure in 1 m^3 piles. The physical and chemical characteristics of the composting materials are presented in Table 1. Bagasse and filter cake were provided fresh from two local sugar mills (Ingenio Attiro and Ingenio Juan Viñas, both in the region of Turrialba, CR). Poultry manure was provided by a regional processor (Rolando Guzman Villega in Grecia, CR). The poultry manure had been pre-composted for 22 months with sawdust and $CaCO_3$ before being used in this experiment, and had a higher total N and mineral N content, than the sugarcane materials. The experiment ran for 54 days in a mesh greenhouse with concrete floor.

2.1.2. Compost set-up

Filter cake and bagasse were mixed on wet basis ratio of 9:1 (filter cake: bagasse) to obtain a mixture (400 kg fresh weight) with a moisture content of 60–65% and C:N ratio of 20:1, considered suitable for composting. Moreover, the addition of bagasse (i.e. porous and fibrous material) increases the porosity of the mixture and facilitates airflow. In order to increase the nitrogen content of the bagasse and filter cake, poultry manure (40 kg fresh weight) was added to the mixture in two different manners: (i) at the beginning of composting, hereafter referred to as *early addition*, and (ii) after 27 days of composting, hereafter referred to as *late addition*. The manure mixing rate (10% on fresh weight basis) was chosen in order to mainly influence total and mineral N in the compost, but with limited impact on compost structure and porosity, to ensure comparability between treatments. In addition to differences in time of manure application, the compost piles were turned at two different intervals: (i) every three days, hereafter referred to as *frequent turning*, and (ii) every nine days, hereafter referred to as *less frequent* turning. Details of the treatments are presented in Table 2. The experimental design was therefore a

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