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Responses of manure decomposition to nitrogen addition: Role of chemical composition

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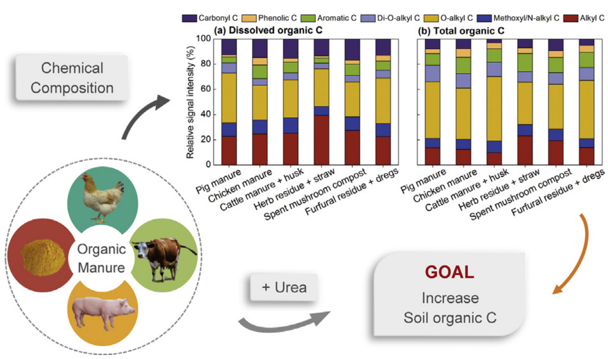
HIGHLIGHTS

- Chemical composition and decomposition dynamics of organic manures were studied.
- Manure quality indicators were measured by ^{13}C NMR, colorimetry and CuO oxidation.
- N effect on C decomposition shifted from initial stimulation to inhibition.
- Stimulation and inhibition were related to high and low C quality, respectively.
- Organic manure combined with N fertilizer could effectively increase soil C storage.

GRAPHICAL ABSTRACT



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ABSTRACT

Understanding the interactions among organic manure chemical composition, decomposition and nitrogen (N) fertilization is critical for sustainable agriculture management. Six organic manures were incubated in a cultivated black soil with or without N addition for one year, and carbon dioxide (CO_2) emissions from these organic manures were monitored. Chemical compositions of the organic manures were determined by elemental analysis, proximate chemical analysis, and carbon (C)-13 nuclear magnetic resonance spectroscopy, and evaluated after cupric-oxide oxidation for lignin biomarkers. During the experimental period, 19–44% of manure C was decomposed without N addition, which decreased to 17–35% with N addition, except for the composted furfural residue with rice dregs. However, during different decomposition stages, N effect changed from stimulation to inhibition, or behaved as increasing inhibition. During stage 1 (days 0–100) when N stimulation effect reached a maximum, CO_2 emissions from manure had positive relationships with labile C fraction indicators, including total sugars, soluble polyphenols, and lignin cinnamyl/vanillyl ratio regardless of N addition. N effect on manure decomposition was related to the C/N ratio and labile organic C content. During stage 2 (days 101–267), N effect shifted to inhibition, with CO_2 emissions from manure negatively related to lignin vanillyl-units content. The magnitude of N inhibition increased linearly with the aromaticity of dissolved organic C, and was strengthened by nitrate in manure. Finally, N inhibition effect reached a maximum during stage 3 (days 268–365), increasing with higher aromatic C in manure. Critical factors for manure decomposition shifted from total sugars, soluble polyphenols, and lignin cinnamyl-units to recalcitrant lignin vanillyl-units and aromatic C fraction, which mediated the type and magnitude of N effect on decomposition. Our results suggested that the potential for enhancing

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soil C sequestration with organic manures would magnify under combined application with N fertilizer in the long term.

1. Introduction

Soil organic carbon (SOC) is a critical attribute of soil quality and plays an important role in soil fertility (Lehmann and Kleber, 2015). Enhancing the SOC content in croplands is beneficial to maintaining agronomic yields, purifying surface and ground water, and offsetting carbon dioxide (CO_2) emissions from fossil fuel combustion (Reeves, 1997; Lal, 2004). Every year, billions of tons of crop residue and animal waste are produced globally (Thangarajan et al., 2013), which could be used as a substitute for high-energy cost and limited-resource inorganic fertilizers to increase SOC storage (Otinga et al., 2013). For example, the application of organic manure composted with wheat straw, oil cake, and cotton cake to intensively cultivated fluvo-aquic soil for 13 years increased the SOC content two-fold (Ding et al., 2007). Based on long-term field trials, SOC sequestration potential in northern China was predicted to increase more than five-fold by 2100 using organic manure (Jiang et al., 2014). Shindo et al. (2006) noted that rice straw-cow dung compost increased the humification degree of soil humic acids, which facilitated SOC stabilization. However, SOC loss was merely slowed by 40 years of farmyard manure fertilization in a double-cropping field with rice and barley (Nardi et al., 2004), while slurry was observed to have no significant effect on SOC in Mediterranean cropping systems (Aguilera et al., 2013). Hence, more research is needed to clarify the influences of organic amendments on SOC build-up.

Based on a meta-analysis of 49 sites in the world, the characteristics of organic materials were suggested to influence the response of SOC stock (Maillard and Angers, 2014). To effectively offset CO_2 emissions after manure application, selecting organic manure with a stable fraction is important (Cotrufo et al., 2013). The initial ratio of carbon (C) to nitrogen (N) has been a well-established indicator of organic matter biodegradability since the 1920s (Bertrand et al., 2006). Theoretically, organic materials with low C/N ratios are directly decomposed by microorganisms, but those with high C/N ratios require extra N from the environment before decay can occur (Parton et al., 2007). Nonetheless, this ratio sometimes fails to predict decomposition patterns, because it includes total organic C without taking the C chemical composition into account (Powers et al., 2009; Lashermes et al., 2010; Bonanomi et al., 2013). A previous study suggested that after incubating plant materials for 90 days, the initial C/N ratio no longer correlated with decomposition, while the (aromatic C + phenolic C)/carbonyl C ratio remained correlated throughout (Wang et al., 2004). Talbot et al. (2012) also found that plant residue decomposition was primarily driven by lignin chemistry rather than the C/N ratio. In plant cell walls, lignin aromatic C is linked to carbohydrates through ether bonds, forming a lignin-hemicellulose matrix that encrusts the cellulose and protects it from microbial attack (Webster et al., 2005). Therefore, when predicting the potential effects of organic manures on increasing SOC sequestration in a specific soil, more attention should be paid to their chemical compositions.

Organic manures usually contain relatively low nutrients in comparison with inorganic fertilizers. Therefore, the combined application of organic manure and inorganic N fertilizers is strongly recommended in agriculture (Yang et al., 2015). External N addition can have a profound but disputed impact on the decomposition of organic materials, with increases, decreases and no effects having been reported (Liu et al., 2016). For example, externally supplied N was observed to enhance the mass loss of grass and shrub leaves, accompanied by increased activities of cellulose-degrading enzymes (Allison et al., 2010). However, added N also decreased the decomposition of switchgrass root, which was attributed to the formation of recalcitrant organic matter (Jung et al., 2011). These seemingly inconsistent findings were in accordance with the meta-analysis results of Knorr et al. (2005), which proposed that N addition enhanced initial labile C decomposition, but slowed decomposition in the lignin-dominant stage. Nonetheless, Vivanco and Austin (2011) demonstrated another possibility that N addition stimulated lignin degradation in *Nothofagus* residues. The contrasting effects of N addition on lignin degradation are due to, at least in part, differences in lignin chemistry (Carreiro et al., 2000). For example, the cinnamyl units in lignin are more accessible to microorganisms and preferentially decomposed with N addition (Bahri et al., 2006; Feng et al., 2010; Bonanomi et al., 2017). However, few studies have focused on the effects of N addition on the decomposition of organic manure and controlling chemical components therein, which would undoubtedly influence their effectiveness in SOC sequestration.

Northeast China is a vital national grain production base. However, the cultivated black soil in this region has suffered from SOC loss in the last three decades, mainly due to the low input of organic materials (Yu et al., 2009). Therefore, clarification of the organic materials that are beneficial to increasing SOC storage, especially under combined applications with inorganic N fertilizers, is urgently needed. Laboratory experiments can be used effectively to assist in designing large-scale field experiments (Mondini et al., 2007). In this study, six organic manures, composted from crop residues or animal wastes, with different chemical compositions were employed with or without N addition in a year-long incubation experiment. The objectives of this study were to: investigate the decomposition of organic manures with or without N addition and the type and magnitude of N effect, and identify potential components that regulate the decomposition of organic manures and relevant N effects.

2. Material and methods

2.1. Soil and organic manure

Soil was sampled from maize-cultivated cropland located in the Hailun National Agro-ecological Experimental Station, Heilongjiang Province, China (47°26′N, 126°38′E). The region is characterized by a temperate continental monsoon climate, with mean annual air temperature of 1.5 °C and mean annual precipitation of 550 mm. The soil is derived from loamy loess and classified as Typic Hapludolls according to the US soil taxonomy. Surface soil (0–20 cm) was sampled randomly from 10 positions in a 20 m × 100 m area, passed through a 2-mm sieve after root removal, homogenized, and stored at 4 °C until use. The soil had a clay loam texture, comprising 8% sand, 72% silt, and 20% clay. The soil pH was 6.0 and the bulk density was 1.0 g cm^{-3}. The soil contained 26.3 g kg^{-1} total organic C (TOC), 2.2 g kg^{-1} total N (TN), 0.8 mg N kg^{-1} ammonium (NH_4^+), and 16.1 mg N kg^{-1} nitrate (NO_3^-).

Six types of organic manure were selected for the incubation experiment: pig manure (PGM), chicken manure (CKM), composted cattle manure combined with rice husk (CMH), composted herb residue combined with *Artemisia selengensis* straw (HRS), spent mushroom compost (SMC), and composted furfural residue combined with rice dregs (CFR). All these manures were commercially available. The main characteristics of these manures are presented in Table 1. The manures were ground and sieved (<0.15 mm) before incubation with soil to avoid particle size effects.

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