Geoderma 333 (2019) 35–42

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Dynamic contribution of microbial residues to soil organic matter accumulation influenced by maize straw mulching

Xiao Liu[a,b,1], Feng Zhou[a,d,1], Guoqing Hu[c], Shuai Shao[a,d], Hongbo He[a,e,*], Wei Zhang[a,**], Xudong Zhang[a], Lijun Li[f]

[a] Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, China
[b] Shandong Agriculture and Engineering University, Jinan 250100, China
[c] National Engineering Laboratory for Efficient Utilization of Soil and Fertilizer Resources, College of Resources and Environment, Shandong Agricultural University, Taian 271018, China
[d] University of Chinese Academy of Science, Beijing 100049, China
[e] National Field Observation and Research Station of Shenyang Agro-ecosystems, Shenyang 110016, China
[f] Shenyang Center, China Geological Survey, Shenyang 110032, China

ARTICLE INFO

Keywords:
Maize straw mulching
Microbial residue
Amino sugar
Soil organic matter

ABSTRACT

Soil degradation is a serious problem in northeast China due to the routine removal of aboveground crop residues under conventional tillage systems; thus, crop residue retention becomes an essential approach for maintaining and improving soil organic matter (SOM) in this area. However, the impact of returning crop residue on microbial-driven SOM accumulation remains unclear. In this context, an 8-year field experiment with maize straw mulching (SM) was conducted in northeast China to evaluate how maize straw return may influence the dynamic contribution of microbial residues to SOM accumulation. Conventional cultivation was used as a control (CR), in which only 10 cm of aboveground maize biomass remained after the annual harvest. Soil samples (0–10 cm) were collected after the annual harvest for the measurement of soil organic carbon (SOC) and amino sugars (AS). Based on a first-order model, we found that soil microbial residue accumulation in this temperate arable soil might reach a steady state within decades under a specific agricultural management practice. Maize straw mulching both strengthened the retention ability of soil microbial residues and expanded their accumulation capacity. According to the glucosamine to muramic acid ratio, maize straw mulching facilitated the accumulation of fungal residues more than bacterial ones. Compared to maize residue removal, maize straw mulching accelerated the accumulation of microbial residues in SOM and enhanced the contribution of microbial residues to SOM sequestration in the surface soil, likely elucidating the pivotal mechanisms by which the "4/1000" initiative goal for agricultural soil will be met, at least for the first 10 years. Because bacterial residues are actively involved in SOM turnover while fungal residues dominantly contribute to SOM accrual enhanced by maize straw return compared to maize residue removal, we conclude that SOM in this arable field might be stabilized at a higher sequestration capacity under management with maize straw mulching.

1. Introduction

Soil degradation is a serious problem for arable land under intensive cultivation in northeast China. Soil organic matter (SOM) is important in maintaining crop productivity and soil quality (Lal, 2009; Powlson et al., 2012), but in northeast China, SOM in arable land is declining because all aboveground plant biomass is removed from the land after the annual harvest (Xie et al., 2014). To address this problem, crop residue retention practices, such as crop straw mulching, are being considered (Jacobs et al., 2009; Scopel et al., 2013), but the mechanisms underlying the control of long-term SOM accumulation are still debated.

Biochemical processes are critical for regulating the accumulation and depletion of SOM, and as feedback, changes in SOM might

* Correspondence to: H. He, Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, China.
** Corresponding author.
E-mail addresses: hehongbo@iae.ac.cn (H. He), zhangw@iae.ac.cn (W. Zhang).
[1] These authors contributed equally and they share the first authorship.

https://doi.org/10.1016/j.geoderma.2018.07.017
Received 30 January 2018; Received in revised form 3 July 2018; Accepted 10 July 2018

Table 1
Characteristics of the soil before the trial (2006).

pH	Particle size distribution ($g\,kg^{-1}$)			Bulk density ($g\,cm^{-3}$)	Soil organic C ($g\,kg^{-1}$)	Total amino sugar ($mg\,kg^{-1}$)
	Clay	Silt	Sand			
5.38 ± 0.02	206.7 ± 7.5	663.7 ± 10.2	130.0 ± 13.0	1.17 ± 0.1	10.5 ± 0.08	824 ± 11.9

Mean ± standard error.

modulate microbial activity and growth, community structure and biomass accumulation (Kong et al., 2011; Ludwig et al., 2015). Microbial-derived organic matter, including both microbial biomass and microbial residues resulting from microbial regeneration and metabolism (Blagodatskaya and Kuzyakov, 2013), are effective indicators for evaluating the contribution of microbial processes to SOM accumulation (Liang et al., 2017). Although microbial biomass responds rapidly to changing nutrient statuses and plays important roles in driving SOM turnover, the accumulation of microbial residues is ultimately associated with long-term SOM accumulation (van Groenigen et al., 2010; Khan et al., 2016). Therefore, investigations of the production and accumulation patterns of microbial residues can be used to assess how crop residue additions contribute to SOM accumulation.

Amino sugars (AS) are important components of microbial cell walls and are composed of 2–7% carbon (Stevenson, 1982; Amelung et al., 2002). Amino sugars in SOM are the result of microbial biomass production and microorganism death, but the latter is dominant. Amino sugars can serve as time-integrated biomarkers of long-term microbial residue accumulation in soil (Liang and Balser, 2008; Ding et al., 2013). Among the various AS, glucosamine (GluN) is the most abundant (47–68%) (Joergensen, 2018). GluN is derived mainly from the chitins of fungal cell walls, though a small amount originates from bacterial peptidoglycan (Joergensen, 2018). Galactosamine (GalN) is the second-most abundant amino sugar (17–42%), but the use of GalN as a biomarker is limited due to its debatable origin (Engelking et al., 2007; Joergensen, 2018). Although the abundance of muramic acid (MurN) is lowest (4–6%) among these three AS, MurN is a unique bacterial residue biomarker because it originates exclusively from the peptidoglycans of bacterial cell walls (Parsons, 1981; Engelking et al., 2007). Due to the different origins of GluN and MurN, their ratio (GluN/MurN) can be used to evaluate the relative accumulation of fungal- and bacterial-derived residues in soils (van Groenigen et al., 2010).

Ding et al. (2013) reported that a 21-year mulching management scheme with crop straw (such as the residues of maize, soybean and wheat) stimulated the accumulation of microbial residues compared with no straw addition. However, less information is available on the temporal accumulation patterns of soil microbial residues as influenced by annual maize straw mulching. These dynamics are important because they may help explain the regulatory mechanisms of microbial-mediated SOM retention on different time scales. Considering the rapid response of microorganisms to the initial addition of substrate and the gradual adaptation of soil microbes after the long-term supply of specific substrates (de Nobili et al., 2001; Shimizu, 2013), we hypothesized that mulching with maize straw would enhance the production of AS rapidly but that the rate of increase would slow down gradually as the levels of AS approach a new steady state.

Different microbial groups possess different strategies for substrate utilization (Blagodatskaya et al., 2009). Fungi are considered to be more efficient at decomposing recalcitrant constituents, while bacteria favor more bioavailable substrates (Schneider et al., 2012); thus, fungi are believed to be more effective for crop straw decomposition. The cell walls of fungal residues have a higher stability and serve as major carbon and nitrogen sinks, whereas bacterial residues are more likely to progress through rapid cycles of formation and decomposition (Fontaine et al., 2011; He et al., 2011). As a consequence, we hypothesized that fungal residues will accumulate to a greater extent than bacterial residues as the result of periodic crop straw applications. Therefore, in this field experiment conducted with maize straw mulching over 8 years, amino sugar dynamics were assessed to investigate the contribution of fungal- and bacterial-derived residues to long-term SOM accumulation and stabilization.

2. Materials and methods

2.1. Study site

A long-term field experiment with maize straw mulching was initiated in the spring of 2007 at the National Field Observation and Research Station of Shenyang Agro-ecosystems (N 41°31′, E 123°24′) in northeast China (Liu et al., 2016). The weather at the site is typical of a temperate, humid, continental monsoon climate. The mean annual temperature is 7–8 °C, and the mean annual precipitation is approximately 700 mm. The soil type in the experimental field is classified as Alfisols (Soil Taxonomy) or Luvisols (Word Reference Base). The basic soil properties are listed in Table 1. Maize (*Zea mays* L.) was planted annually at a mean density of 57,700 plants ha^{-1} and harvested in late September. Before 2007, conventional tillage was practiced for over 30 years, and after the annual harvest, all aboveground maize biomass was removed above 10 cm.

2.2. Experimental design

The experiment was conducted in a randomized design with three replicates. The micro-plots (1.6 m × 1.3 m) were surrounded by polyvinylchloride (PVC) boards and randomly arranged in the field at approximately 2.5 m apart. The PVC boards were pressed into the soil to a depth of 35 cm at an aboveground height of 15 cm. For all plots, maize was sown at a density of 12 plants per plot.

Two treatments were included in this experiment. In the control treatment (CR), only 10 cm of aboveground maize biomass remained after the annual harvest under conventional cultivation. In the straw mulching treatment (SM), maize straw was mulched on the surface of the soil in addition to the 10 cm of aboveground maize biomass retained. The air-dried maize straw (with an average C/N of 51.9), which was collected from the previous harvest, was chopped into 10-cm-long pieces and evenly placed on the soil surface in spring for long-term decomposition. The total aboveground biomass left on the surface of the soil in the CR treatment was approximately 0.5 Mg $ha^{-1}\,yr^{-1}$, while in the SM treatment, the additional application of maize straw of approximately 5.8 Mg $ha^{-1}\,yr^{-1}$ (equivalent to approximately 50% of the annual average yield) was covered on the surface of the soil.

As recommended locally, 200 kg N $ha^{-1}\,yr^{-1}$ (in the form of $(NH_4)_2SO_4$) was annually applied at three different times throughout the crop growing season. The first 50 kg N $ha^{-1}\,yr^{-1}$ was banded as the basal fertilizer and applied at a depth of 5–10 cm just before seeding. The second 100 kg N $ha^{-1}\,yr^{-1}$ was applied at the jointing stage as the first topdressing, and the last 50 kg N $ha^{-1}\,yr^{-1}$ was again applied at the silking stage as the second topdressing. Phosphorus (P) and potassium (K) fertilizers, as granulated KH_2PO_4 and K_2SO_4, were applied annually at rates of 30 kg P $ha^{-1}\,yr^{-1}$ and 58 kg K $ha^{-1}\,yr^{-1}$ as basal