Soil & Tillage Research 186 (2019) 11–22

Contents lists available at ScienceDirect

Soil & Tillage Research

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

A soil texture manipulation doubled the priming effect following crop straw addition as estimated by two models

Yuzhi Xu[a,c,1], Kai Liu[a,c,1], Ya Han[b], Heng Jiang[a], Shuihong Yao[b], Bin Zhang[b,*]

[a] National Observation Station of Hailun Agroecology System, Key Laboratory of Mollisols Agroecology, Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Harbin, 150081, PR China
[b] National Engineering Laboratory for Improving Fertility of Arable Soils, Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing, 100081, PR China
[c] University of Chinese Academy of Sciences, Beijing, 100049, PR China

ARTICLE INFO

Keywords:
Priming effect
Crop straw incorporation
Soil structure
Soil organic carbon stabilization/ destabilization
Detritusphere

ABSTRACT

Crop straw is often incorporated with soil tillage to maintain soil organic carbon (SOC). Both the crop straw addition *per se* and its associated soil structure changes can stimulate SOC decomposition, known as the priming effect. Yet no attempt has been made to isolate their effects. In addition, the priming effect is usually estimated by using uniformly labeled plant litters in the laboratory, and the impacts of non-uniform labeling on the estimation of the priming are poorly understood. The objectives of this study were 1) to isolate the effects of crop straw addition and soil structure changes on SOC decomposition and microbial community composition and 2) to evaluate the effects of the addition of pulse-labeled straw on estimation of the priming effects. The labeled ^{13}C content and its $\delta^{13}C$ abundance in the labile fractions of the straw sequentially extracted by ethanol, water and 0.1 M HCl were similar, but were much larger than those in the stable fractions exacted by 0.1 M NaOH. To identify the effects of soil structure changes, the soil texture of a surface soil was manipulated by adding fine sized particles (< 53 μm from the subsoil) into the soil. After straw addition, > 74 μm macroporosity of the texture-manipulated soil (MMS_1) increased, causing strong shifts in microbial community composition characterized by phosphorus lipid fatty acid profiling compared to non manipulated soil (NMS_1) during a 56-day incubation. The dynamics and total priming effects estimated using the end mixing model (EMM) based on the $\delta^{13}C$ abundance in the labeled straw and the improved priming model (PRIM) based on first-order SOC decomposition agree well. Total straw decomposition and total priming effect in the treatment MMS_1 were larger than those in the treatment NMS_1 by 175% and 170% with the EMM model, respectively. Our findings highlight the importance of understanding abiotic and biotic interactions underlying SOC turnover in the detritusphere of arable ecosystems.

1. Introduction

Soil organic carbon (SOC) plays a key role in maintaining soil fertility, mitigating effects of climate change, and offsetting many soil degradation processes (Lal, 2003). Straw incorporation is often encouraged to maintain SOC in arable lands. An addition of fresh organic materials can stimulate mineralization of native SOC, which is referred to as the priming effect (Bingeman et al., 1953; Kuzyakov et al., 2000; Kuzyakov, 2010). The priming effect is important to the increase of the nutrient availability of soils in the short term (Kuzyakov et al., 2000; Blagodatskaya and Kuzyakov, 2008), but may cause SOC losses in the long term (Wieder et al., 2013). An increased CO_2 emission associated with crop straw incorporation is often attributed to more aerated conditions by increasing soil macropore volumes with soil tillage (Strong et al., 1998, 2004; Yao et al., 2009). However, the effects of soil structure changes on SOC decomposition have not been isolated from those induced by organic inputs. Thus, understanding the relative contribution of crop straw addition and soil structure changes to the priming of native soil organic matter is relevant to optimization of crop straw incorporation practices. Furthermore, it is vital for the balance of long-term and short-term soil functions of crop residues.

Priming effect studies have mainly focused on its size and direction following addition of simple substrates (Hamer and Marschner, 2005; Dilly and Zyakun, 2008). The priming effect is generally considered to

* Corresponding author.
E-mail address: zhangbin01@caas.cn (B. Zhang).
[1] These authors contribute equally to this study.

https://doi.org/10.1016/j.still.2018.09.011
Received 4 July 2018; Received in revised form 25 September 2018; Accepted 27 September 2018

be a microbially controlled process (Fontaine et al., 2003; Blagodatskaya et al., 2007), but can be influenced by abiotic factors, such as mineral reactivity (Rasmussen et al., 2007; Keiluweit et al., 2015), active soil pore sizes (Ruamps et al., 2011, 2013; Juarez et al., 2013) and aggregate sizes (Ohm et al., 2007; Salomé et al., 2010). These abiotic factors control the bioavailability of both SOC and added substrates (Keiluweit et al., 2015) as well as the biogeography of microbial communities in soil pores of different sizes (Ruamps et al., 2011, 2013; Juarez et al., 2013) and in aggregates (Kandeler et al., 1999). In those studies mentioned above, the additions of simple substrates have not changed soil structures dramatically. However, crop straw incorporation by soil tillage can alter soil structures and increase soil aeration, which may increase soil microbial activities to different extents for different microbial functional groups. For instance, fungi may grow faster under aerobic conditions than do anaerobic bacteria (de Boer et al., 2005). Therefore, a soil structure change associated with crop straw incorporation may influence the dynamics of the soil functional microbial groups.

The priming effect is defined as the difference of CO_2 efflux from SOC decomposition with or without straw addition. It is often quantified by using the end member mixing (EMM) model based on CO_2 efflux and its carbon (C) isotopic abundance measured during short-term incubation experiments (Kuzyakov et al., 2000; Blagodatskaya and Kuzyakov, 2008). Theoretically, the isotopic approaches for priming studies work properly only if uniformly labeled substrates or plant litters are added and not preferentially used by microbes (Blagodatskaya et al., 2011). However, $\delta^{13}C$ abundances in labeled plant litters used for priming studies vary dramatically in the literature, for example, ranging from 63‰ (Wang et al., 2015a, b) to 1854‰ (Guenet et al., 2012) because of large variations in labeling methods and durations (Fontaine et al., 2004, Fontaine et al., 2007; Rasmussen et al., 2007; Pascault et al., 2013; Creamer et al., 2015). In addition, only one available study has examined the labeling uniformity (Kuzyakov et al., 2007), whereas dominant studies have examined the effect of uniform labeling on the dynamics of the priming effect and its underlying microbial processes. Kuzyakov et al. (2007) have observed that pulse-labeling can lead to different isotope contents in the fractions extracted by different chemical agents. The differences in C isotope contents and abundances in labile and recalcitrant parts of plant litter may then influence the dynamics of priming effect induced by the decomposition of these C pools in plant litter.

Priming of SOC decomposition encompasses different processes through which the decomposition of native SOM can be amplified through the addition of new organic substrates, with the new inputs typically being more labile than the native SOM (Guenet et al., 2016). Such complex interactions have been described in a newly developed PRIM model, which can estimate the priming effect through mathematical optimization of model parameters using the measured CO_2 emissions during short-term incubation and field experiments (Guenet et al., 2016, 2018) and then significantly improve the prediction of global C stocks (Guenet et al., 2018). The model parameters include decomposition rate constants of SOC pools and priming parameters that describe the controlling effects of fresh C pools on the decomposition of SOC pools. Thus, these PRIM model parameters of different C pools in plant litter and SOC have physical meanings and can be used to assess the impacts of non-uniform labeling on the dynamics of the priming effect estimated by using the EMM model.

The objectives of this study were 1) to isolate the effects of crop straw addition and soil structure changes on SOC decomposition and microbial community composition and 2) to evaluate the effects of the addition of pulse-labeled straw on estimation of the priming effects. It was firstly hypothesized that the soil texture manipulation by increasing the fine sized fraction of the soil would change the soil pore structures and microbial communities during the decomposition of added plant litter through aggregation (Abiven et al., 2009). Secondly, non-uniform labeling would lead to isotope differences in labile and stable fractions, and then affect the estimation of the priming effect only if both the fractions were decomposed and inducing the priming effect.

2. Materials and methods

2.1. Soil preparation

To create contrasting soil structures, we manipulated the soil texture by mixing soil samples taken from the surface layer (0–10 cm) with those from the subsoil taken from > 2 m depth in a soil profile, as described in the following. The soil profile was located at the State Key Experimental Station of Agroecology, Chinese Academy of Sciences, Hailun, Heilongjiang Province (47°26′N, 126°38′E). The field has been cropped for more than a century and specifically for soybean (*Glycine max* L.) over 10 years. The soil was classified as a Pachic Haploboroll according to the USDA Taxonomy (Soil Survey Staff, 2010).

The subsoil was dispersed by shaking in 50 g L^{-1} sodium metaphosphate (1:3 w/v ratio) for 30 min and passed through a 53-μm aperture sieve. The < 53-μm fraction was then heated at 500 °C for 4 h in muffle (SX-8-10, Taisi, China) to oxidize the soil C and kill the soil microbes. Thereafter, the soil materials were repeatedly washed with deionized water to remove sodium metaphosphate. After the pretreatment, the < 53-μm fraction was mixed with the surface soil at a ratio of 15:85, and then passed through a 0.25-mm sieve. It was expected that such a manipulation would increase soil macroporosity due to an increased content of the fine sized fraction and straw compared to the original surface soil. Other methods of soil structural manipulations have been reported in the literature, e.g. mechanical compression (Sleutel et al., 2012) and mixing different sized aggregates (Mangalassery et al., 2013). However, those methods were reported to change soil moisture conditions very significantly, which may influence microbial growth and the priming effect. In this study, the soil texture manipulation by mixing a surface soil with the fine sized fraction of its subsoil at a low rate was expected to have little effects on soil moisture.

Soil physical, chemical and mineral properties were analyzed using routine methods. Briefly, the soil particle size distribution was determined by the pipette method (Lu, 2000). The soil pH was measured at 1:2.5 (soil:deionized water) by using a pH electrode (Lu, 2000). As indicated by a hydrochloric acid reaction, there was no inorganic C in this soil and thus the total SOC and total N were analyzed with a VarioEL CHN elemental analyzer (Heraeus Elementar VarioEL, Hanau, Germany). The soil ^{13}C abundance was measured using the isotopic ratio mass spectrometry (Isoprime-100, trace Gas-IRMS). Non-crystaline iron (Fe_o) was extracted by using acid ammonium oxalate, while crystallized iron (Fe_d) was extracted by using dithionite-citrate-bicarbonate (Parfitt and Childs, 1988; Dahlgren, 1994). The microbial biomass in the soil (SMB-C) was determined by using the fumigation extraction technique, whereby the k_{EC} value was 0.45 (Brookes et al., 1985; Vance et al., 1987). The mineral compositions in the < 2- and 2-5-μm clay fractions were determined by using a classical X-ray diffraction method of oriented clay preparations (Moore and Reynolds, 1997) and numerical decomposition methods (Lanson, 1997).

2.2. Crop straw labeling

To obtain labeled crop straw, one maize (*Zea mays* L.) seed was sown on May 1st in a pot and grew till the end of June in 2016. The plot was moved to a Plexiglas chamber for $^{13}CO_2$ labeling every day from July 1st to 8th. The labeling was performed by the injection of 1 L of $^{13}CO_2$ (98 atom%) to the chamber through a rubber gasket from 7:30 am to 15:00 pm under a sunlight condition, following the method by Sauer et al. (2006). The gas flow was controlled with a CO_2 analyzer (LI-820 LI-COR, America) to maintain a concentration of CO_2 at 350–400 ppm and mixed by two small ventilators (165 mm in diameter) equipped overhead of each chamber. After each labeling, the pot was