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Changes in soil microbial community and organic carbon fractions under short-term straw return in a rice–wheat cropping system

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ABSTRACT

Straw return is an effective management practice for improving soil fertility and sustaining crop productivity in agro-ecosystems. A field experiment was conducted to investigate the effects of short-term (three-year) crop straw return on soil organic carbon fractions and microbial communities in a rice–wheat cropping system at three sites from central to eastern parts of China. Two treatments were established at each site: no straw return (N) and straw return (S). Compared to N treatment, S treatment significantly increased concentrations of total organic carbon (TOC, except for Qujialing site), dissolved organic C (DOC) and microbial biomass C (MBC), but did not significantly affect the easily oxidizable C content in the three sites. Soil light fraction, light fraction organic C and particulate organic C were higher for S than N treatment by 28–52% in both Guangde and Jiangyan, while these values were not significantly different between N and S treatment in Qujialing. Soil microbial community compositions of all three sites were changed with straw return. Crop straw return significantly increased total phospholipid fatty acid (PLFA), bacterial biomass and actinomycete biomass by 52, 75 and 56% in Jiangyan, but had no significant effects on PLFAs in both Qujialing and Guangde, compared to N treatment. MBC and TOC were the two main factors affecting microbial communities under short-term crop straw return. Our results demonstrated that DOC and MBC were the most sensitive indictors for assessing changes of SOC under short-term straw return in the rice–wheat cropping system, and soil properties in response to straw return were different at the three sites.

1. Introduction

Soil organic carbon (SOC) plays an important role in improving soil fertility and sustaining soil productivity due to its effects on soil physical, chemical and biological properties (Gong et al., 2009; He et al., 2015). Changes in SOC are influenced by many management practices, such as fertilizer application, straw return and tillage (Yan et al., 2013; Zhu et al., 2015). However, SOC is often not sensitive to short-term changes in agricultural management practices due to large background levels of SOC (Haynes, 2000; Zhao et al., 2016). Labile organic C fractions (LOCFs), including light fraction organic C (LFOC), particulate organic C (POC), easily oxidizable C (EOC), dissolved organic C (DOC) and microbial biomass C (MBC) are considered to be early and sensitive indicators of soil quality changes because of their rapid responses to changes in soil management practices (Cambardella and Elliott, 1992; Janzen et al., 1992; Haynes, 2005; Yan et al., 2007; Benbi et al., 2015).

Crop straw (i.e. wheat and rice straw) is an important source of organic C in agro-ecosystems in China (Liu et al., 2014). Returning crop straw to soil is an important practice to balance the C loss due to mineralization in agricultural soil (Li et al., 2013; Chen et al., 2014). The SOC change rate is two times higher for straw return treatments (0.29 g kg^{-1} yr^{-1}) than that for chemical fertilizer application only (0.14 g kg^{-1} yr^{-1}) in paddy soils of China (Tian et al., 2015). Zheng et al. (2015) found that returning straw could significantly increase total organic C (TOC) content in northern China. Zhu et al. (2014, 2015) also observed that short-term (two-year) crop straw return significantly increased the TOC, DOC and MBC concentrations compared to no straw return in the 0–7-cm soil layer in Jiangsu Province, China. Crop residue return also significantly affects soil microbial community composition (Govaerts et al., 2007; Zhao et al., 2016).

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Table 1
General description of geography and soil properties (0–20 cm) at the three experimental sites.

	Qujialing	Guangde	Jiangyan
Location	30°52′N, 112°50′E	31°01′N, 119°26′E	32°24′N, 120°05′E
Climate	Subtropical monsoon climate	Subtropical monsoon climate	Subtropical monsoon climate
Cropping system	Rice–wheat rotation	Rice–wheat rotation	Rice–wheat rotation
Mean annual precipitation (mm)	1140	1328	992
Mean annual temperature (°C)	16.2	15.4	14.5
Soil classification	Anthrosols	Anthrosols	Luvisols
Sand (%)	5.3	22.7	44.7
Silt (%)	59.7	64.2	46.4
Clay (%)	35.0	13.1	8.9
SOC (g kg^{-1})	18.91	15.58	13.11
TN (g kg^{-1})	1.95	1.25	1.61
pH (soil: water = 1: 2.5)	5.88	5.54	7.72
Available P (mg kg^{-1})	17.26	25.51	16.83
Available K (mg kg^{-1})	108.47	65.24	85.48

Soil microorganisms play an important role in mediating changes in soil TOC via mineralization–immobilization of soil organic matter (Breulmann et al., 2014). The process of straw decomposition is mainly mediated by soil microorganisms, and is affected by many factors including soil texture, straw quality and climate (Chen et al., 2014). Soil microbial communities respond differently to different stages of crop straw decomposition (Marschner et al., 2011): in the first stage, bacteria dominate microbial communities and fungi dominate the latter stage (Poll et al., 2008; Marschner et al., 2011). Long-term maize straw return (30 years) was shown to increase the fungal biomass, but did not affect the bacterial biomass in a summer maize–winter wheat cropping system in north-central China (Zhao et al., 2016). However, a two-year trial showed that crop residue return increased the total phospholipid fatty acid (PLFA) and bacterial and fungal biomass in central China (Guo et al., 2014).

The middle and lower Yangtze River Basin is a highly intensive agricultural region, where the dominant cropping is a rice–wheat rotation system (Shi et al., 2012). Three provinces (Hubei, Anhui and Jiangsu) account for 58% of the rice–wheat rotation area in China (Dawe et al., 2004). The rice–wheat cropping system has high straw yields of about 9.0 and 4.5 t ha^{-1} yr^{-1} of rice and wheat straw, respectively (Yang et al., 2015). Crop straw is commonly burnt directly in open fields because managing it is difficult for farmers (Zhang et al., 2014; Wang et al., 2015b). Burning straw has led to serious environmental pollution in recent decades in China (Sun et al., 2016). Many studies have shown that burning crop straw is an important source of carbon dioxide emission (Li et al., 2007; Sun et al., 2016 Sun et al., 2016). Thus, burning crop straw in open fields has been banned and the returning of crop residue to the soil encouraged in recent years. More attention should be paid to how crop straw return affects soil properties in the rice–wheat rotation system. Therefore, the objectives of this study were to: (1) examine the effects of crop straw return on SOC and soil microbial community composition; (2) investigate the sensitivity of the LOCFs under short-term crop straw return in a rice–wheat cropping system in the middle and lower Yangtze River Basin, China. We hypothesized that crop straw return could increase the SOC fractions and affect the soil microbial community in the rice–wheat cropping system.

2. Materials and methods

2.1. Study site

The three field experimental sites were selected from central to eastern parts of China: Qujialing County (QJL) of Hubei Province, Guangde County (GD) of Anhui Province and Jiangyan County (JY) of Jiangsu Province. The three regions are located in the middle and lower Yangtze River Basin. Information on geography, climate and soil basic properties of the three sites is shown in Table 1.

There is an annual rice–wheat cropping system in these three sites, with rice transplanted in late July and harvested in October and winter wheat seeded in November and harvested in early July. No irrigation was given during wheat growth season in the three sites.

2.2. Experimental design

The experiments were initiated in November 2012 in QJL and in July 2012 in GD and JY. The plot sizes were 40 m^2 (5 × 8 m), 30 m^2 (5 × 6 m) and 33.37 m^2 (4.7 × 7.1 m) at QJL, GD and JY, respectively. There were two treatments in the experiments, and four replicates per treatment. The two treatments were no crop straw return (N) and straw return (S). N1, N2 and N3 represented the no straw return treatments of QJL, GD and JY, respectively, and correspondingly S1, S2 and S3 represented the straw return treatments. In the N treatment, chemical fertilizers were applied only, and rice and wheat straws were not returned to the field. The basal fertilizers were broadcast by hand and incorporated into soil by rotary tillage (10–15 cm). In the S treatment, chemical fertilizers were applied and crop residues were air-dried, chopped to 5 cm in length after crop harvesting. Both of the basal fertilizers and crops straw were broadcast by hand and plowed into soil by rotary tillage (10–15 cm).

The chemical fertilizers and crop straw application rates are shown in Table 2. During the wheat season, nitrogen fertilizer was applied at sowing, tillering and jointing at rates of 40, 30 and 30%, respectively, for QJL and JY; and at sowing and tillering at rates of 60 and 40% at GD, respectively. During the rice season, nitrogen fertilizer was applied at sowing, tillering and jointing at 40, 30 and 30%, respectively, at the three sites. All phosphorus and potassium fertilizers and crop straw were applied before planting crops. The field management practices followed local farmers' practices. Fertilizers applied were urea (46% nitrogen), calcium superphosphate (12% P_2O_5), and potassium chloride (60% K_2O) in all sites.

2.3. Soil sampling and analysis

After rice was harvested in October 2015, five soil cores (depth 0–20 cm and diameter 5 cm) were collected in each plot and mixed as a composite sample. The fresh soil samples were sieved through a 2-mm mesh and divided into three subsamples. One subsample was freeze-dried and stored at −20 °C for microbial PLFA analysis, one was stored at 4 °C for MBC and DOC analysis, and one was air-dried for LFOC and POC analysis or passed through a 0.15-mm mesh for TOC and EOC analysis.