Aerosol and Air Quality Research, 16: 3358–3363, 2016
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ISSN: 1680-8584 print / 2071-1409 online
doi: 10.4209/aaqr.2016.10.0431

Technical Note

Short-Term Effects of Straw Application on Carbon Recycle in a Rice-Rapeseed Rotation System

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ABSTRACT

Efficient and fast methods for disposing rapeseed straw are badly needed in the rice-rapeseed rotation system, where rice is planted immediately after the rapeseed harvest. In this research, the effects of rapeseed straw returning (6 g kg^{-1}) on rice cultivation soil organic carbon accumulation, CH_4 and CO_2 emissions, and total organic carbon (TOC) contents of the aqueous layer in the flooded condition within the 60 days of incubation experiment were studied. The experimental results showed that the straw addition increased the peak of CH_4 and CO_2 emission flux by 32.9% and 6.3%, respectively, compared to that of without straw. The CO_2 emissions were mainly concentrated during the first 1–10 days, while CH_4 emissions were concentrated during the latter 30–60 days. The organic carbon contents in soil of straw addition varied from 21.5 to 23.1 g kg^{-1} compared with that in the range of 20.7–22.3 g kg^{-1} without straw. With straw addition, the TOC contents in aqueous layer were increased continuously from 55.1 to 68.1 mg L^{-1} during the late periods (30–60 days). The experimental results of this study indicated that an increase of external carbon addition by using rapeseed straw in the soil will have a better cultivation environment for rice crops and very possibly result in a higher amount of harvest. Therefore, the straw addition in the soil will be more environmental friendly and have economic benefit in the rice-rapeseed rotation system.

Keywords: Rapeseed straw addition; CO_2 emissions; CH_4 emissions; Soil organic carbon.

INTRODUCTION

The rice-rapeseed rotation is a pervasive farming system in Yangtze River basin of China, where rice is planted immediately after the rapeseed harvest. Traditionally, farmers burn rapeseed straw in this farming system to reduce time and labor, thereby causing soil erosion and atmospheric pollution (Duan *et al.*, 2004; Montgomery, 2007). In situ combustion of rice straw forms a major part of annual biomass burning incidents in Asia has been shown to be a major source of emissions, which due to their photochemical and radiative potentials are capable of influencing both local and global climate (Chang *et al.*, 2013; Jain *et al.*, 2014; Yaman *et al.*, 2015), in addition to affecting the air quality and visibility (Popovicheva *et al.*, 2015). These emissions include CO_2, N_2O, CH_4 including trace chemicals like CO, NH_3, NO_x, SO_2, NMHC, volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) and particulate matter or aerosols especially the organic type (Alonso-Blanco *et al.*, 2014; Wang *et al.*, 2014; Tian *et al.*, 2015). With the implementation of prohibition of straw burning policy by many local governments in China in recent years (http://news.xinhuanet.com/2015-02/02/c_111415458.htm), efficient and fast methods of disposing previous rapeseed straw prior to rice cultivation are badly needed.

Crop straw is an important organic fertility resource for the soil (Zhao *et al.*, 2014), and the crop straw production of china was 8.1 × 10^8 t in 2008 (Li and Jin, 2011). Recycling crop straw is thus considered an efficient method for sustaining soil fertility and improving crop productivity (Singh *et al.*, 2008; Sommer *et al.*, 2011). Numerous studies have demonstrated the significant effects of returning straw in rice-wheat cropping systems on greenhouse gases fluxes (Yao *et al.*, 2010; Shan *et al.*, 2013; Zhang *et al.*, 2015), soil nutrients recycling (Lal, 2004), erosion control (Peng *et al.*, 2016), organic matter fractions (Zhao *et al.*, 2016a), soil organic carbon and crop yields (Hang *et al.*, 2014;

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Wang *et al.*, 2015). However, comparative researches about the short-term effects of rapeseed straw returning on the rice-rapeseed cropping systems have been rarely reported.

In this research, short-term incubation experiments of rapeseed straw mixed with rice cultivation soil were conducted and effects of straw application on soil organic carbon accumulation, CH_4 and CO_2 emissions were studied. The objective of this study was to determine the combined effects of rapeseed straw returning on carbon cycle of rice-rapeseed rotation fields prior to rice cultivation, and hence present an attractive option for disposing rapeseed straw in an eco-friendly way.

METHODS

Experimental Soil

Soil samples (0–20 cm soil layer) were collected from the paddy field of experimental research station of the Academy of Agricultural Sciences of Anhui, Hefei, Anhui Province, China. The soil was then air dried naturally in the laboratory and passed through 5-mesh (1 mm) sieves. The properties of initial soil (0–20 cm) were as follows: the content of organic carbon, total nitrogen and total phosphorus were 18.4, 1.70 and 0.41 g kg^{-1}, respectively.

Experimental Design

According to Anhui statistical yearbook (http://www.ahtjj.gov.cn/tjj/web/tjnj_view.jsp?strColId=13787135717978521&_index=1#), the average yield of rapeseed was 2319 kg ha^{-1} in the year of 2014 in Anhui Province, China, hence the whole yield of rapeseed straw could be worked out and was 6957 kg ha^{-1} assuming a mass ratio of 3:1 between straw and rapeseed. Therefore, the application of rapeseed straw was 0.3% of the air-dried soil weight (6 g kg^{-1}). The rapeseed straw was sun-dried in fields and cut into 8–10 cm pieces, transferred into nylon net bags (200-mesh) and incorporated into 2 kg of soil in series response boxes (5 L). The surfaces of soil in boxes were flooded with distilled water at the depth of 5 cm. The experiment was conducted at a constant temperature of 25°C within the 60 days of experiment, the humidity was regulated using distilled water every 3rd day in the first month of cultivation, and later every 7th day. Soil and water samples were obtained to analyze the organic carbon in the 3rd, 6th, 9th, 15th, 30th and 60th days, respectively. Besides, CH_4 and CO_2 emissions were collected in the 1st, 2nd, 3rd, 4th, 5th, 7th, 9th, 15th, 30th and 60th days, respectively.

Soil Sampling and Analysis

During the period of soil incubation experiment, soil samples were collected from box at a pre-determined time interval (from 0 to 60 day), air-dried, and then passed through 5-mesh sieves for organic carbon content determination. At the same time, water samples were also withdrawn from floodwater layer of boxes and passed through 0.45-mm nylon film for total organic carbon (TOC) analysis. Gas samples were withdrawn twice each week using 50 mL plastic syringe for CH_4 and CO_2 flux analysis. Soil organic carbon content was determined by the $K_2Cr_2O_7$-$FeSO_4$ oxidation wet digestion method. The CH_4 and CO_2 flux was determined using chromatography (GC) equipped with a flame ionization detector (FID) (Wang and Wang, 2003), the column temperature was 550°C, and the analysis temperature for CH_4 and CO_2 was 380°C and 200°C, respectively. TOC in water samples was determined by TOC-TN analysis meter (IL500, HACH, U.S. A).

RESULTS

Soil Organic Carbon Contents

Fig. 1 shows the effects of rapeseed straw addition on soil organic carbon contents within the 60 days of incubation experiment. It is evident from Fig. 1 that during the whole experiment period, the soil organic carbon contents of straw application were higher than that of no straw addition, the soil organic carbon contents with straw application at different days (3, 6, 9, 15, 30 and 60) were increased by 5.14%, 3.86%, 1.79%, 3.83%, 1.89% and 4.52%, respectively, compared

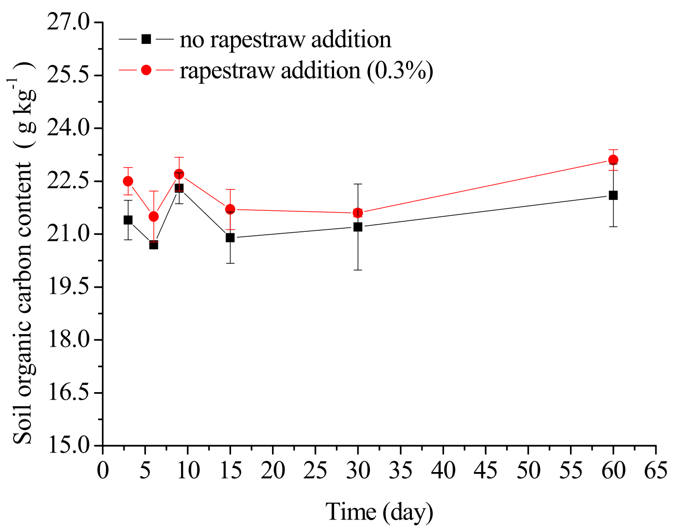

Fig. 1. The effects of straw addition on soil organic carbon contents.

to without straw. The soil organic carbon contents increased with the straw addition were also found in an earlier study by Zhao *et al.* (2016a).

CH_4 and CO_2 Emission

Figs. 2(a) and 2(b) shows the effects of rapeseed straw return to soil on the CH_4 and CO_2 emission within the 60 days of incubation experiment. As shown in Fig. 2(a) that straw addition significantly increased CO_2 emission flux. Without straw addition, the maximum CO_2 emission flux (1540 mg m^{-2} h^{-1}) was at the 9th day, while the highest CO_2 emission flux of straw addition of 1637 mg m^{-2} h^{-1} appeared on the 2nd day and which was 6.3% higher compared to that was without straw. Fig. 2(b) shows that straw addition increased CH_4 emission. The maximum CH_4 emission flux without straw addition was 7.35 mg m^{-2} h^{-1} on the 60th day, while that with straw addition was 9.77 mg m^{-2} h^{-1} on the 30th day, the latter was 32.9% higher than the former. Figs. 2(a) and 2(b) also shows the CO_2 emission flux dramatically decreased after 9 days, while CH_4 emission flux remained at a higher level during following 30–60 days, this trend was probably caused by the flooded condition (Hou *et al.*, 2013).

TOC in the Aqueous Layer

The effects of rapeseed straw addition on TOC contents in the aqueous layer within the 60 days of incubation experiment are shown in Fig. 3. With straw addition, the increase amount of TOC contents in aqueous layer at different days (3, 6, 9, 15, 30 and 60) were 20.3, 5.1, 4.8, 9.4, 9.8, and 23.4 mg L^{-1}, respectively, more than that was no straw addition. It was also noticed that, without straw addition, the peak value of TOC content in aqueous layer, was 45.3 mg L^{-1} and appeared on the 30th day, and the remained stable till the end of experiment. However, with straw addition, the TOC contents in aqueous layer were increased continuously from 55.1 to 68.1 mg L^{-1} during the late periods (30–60 days).

Redox Potential (Eh) in the Aqueous Layer

Fig. 4 shows the effects of returning straw to the soil, on redox potential (Eh) in the aqueous layer within the 60 days of incubation experiment. It was noticed that the Eh in aqueous layer of where straw was added had similar trends to the one where no straw was added. The difference between the two treatments was not significant during the first 1–15 days, however, the Eh in aqueous layer of straw addition (–78,

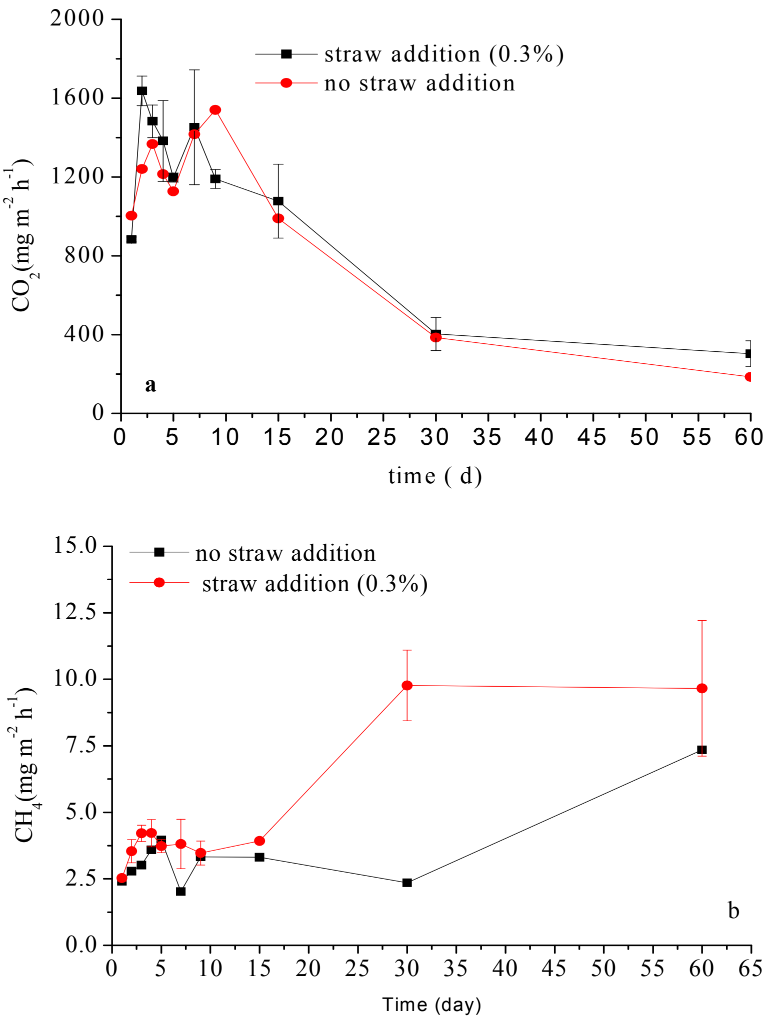

Fig. 2. The effects of straw addition on CO_2 emission flux (a) and CH_4 emission flux (b).

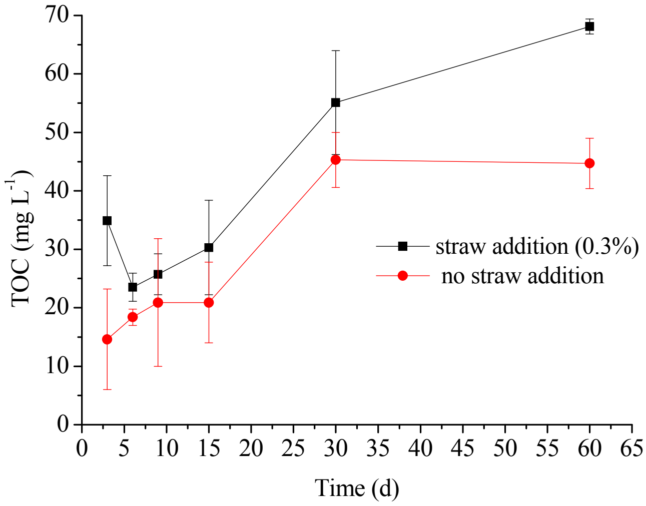

Fig. 3. The effects of straw addition on TOC contents in the aqueous layer.

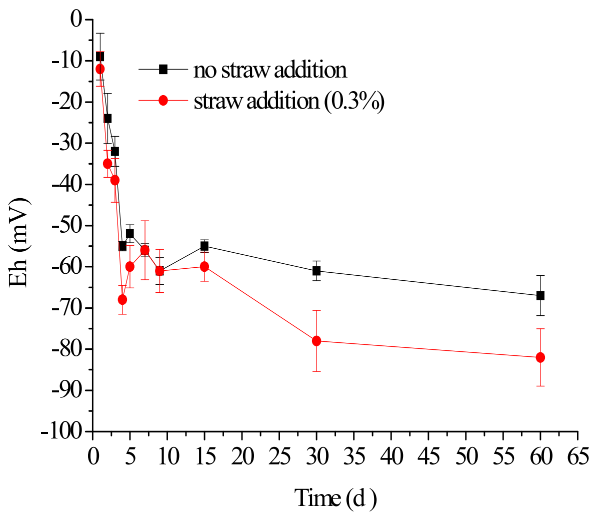

Fig. 4. The effects of straw addition on redox potential in the aqueous layer.

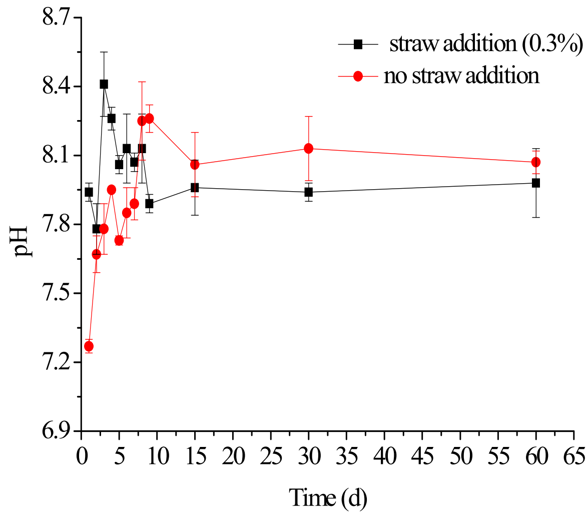

Fig. 5. The effects of straw addition on pH in the aqueous layer.

–82 mv) at 30th and 60th day decreased by 27.9% and 22.3% compared to that where no straw was added.

pH in the Aqueous Layer

The effects of straw addition on pH in the aqueous layer within the 60 days of incubation experiment are shown in Fig. 5. It was observed that a rapid increase in pH of the aqueous layer of straw addition occurred within the first 3 days, followed by a slow decrease until the relatively stable state was attained after the 15th day. Similar trend was noticed in the case without straw, where the pH increased greatly with the incubation time up to day 9 and then decreased slightly until a stable state was attained after the 15th day.

DISCUSSION

In this study, straw addition increased the CO_2 emission, which was mainly concentrated during the first incubation experiment period (Fig. 2(a)), similar results have been reported by many previous studies (Zhao *et al.*, 2016b). The peak value of CO_2 emission flux where straw was added appeared on the 2nd day, while the peak value of no straw was added appeared on the 9th day, 7 days later than former. The peak value of CH_4 emission flux where straw was added appeared on the 30th day, and the peak value where no straw was added appeared on the 60th day, 30 days later than the former. In addition, addition of straw increased the maximum CO_2 and CH_4 emission flux by 6.3% and 32.9%, respectively, compared to the emission flux where no straw was added. These were possibly caused by the decomposition of the carbon-containing compounds in the straw, which provided available carbon substrates (Li *et al.*, 2011; Wang *et al.*, 2015), Straw decomposition also enhances a reduction environment (Bayer *et al.*, 2014) and could result in a drastic decrease in the Eh (Fig. 4).

It was also observed that during the first 9 days, the pH in aqueous layer without straw was lower than that where straw was added 10–60 days (Fig. 5), The potential mechanisms of the volatile acids consumed by methane-forming bacteria could be used to explain the increase in CO_2 emissions with decreasing pH values, as stated previously (Gerardi, 2003). However, we also found during 3–9 days, the pH in aqueous layer where straw was added was higher than that of later 10–60 days (Fig. 5), which were inconsistent with the CO_2 emission flux of straw addition. The reason for this may be the acid production from straw decomposition which were mainly concentrated during the later incubation experiment period, which decreased the pH in aqueous layer, which will be advantageous to increase in rice production.

We observed straw addition had a slight effect on soil organic carbon contents, which were in the range of 21.5 to 23.1 g kg^{-1} compared to that without straw was in the range from 20.7 to 22.3 g kg^{-1}, Moreover, the soil organic carbon contents variances of both treatments had similar trends during the whole experiment period (Fig. 1). On the contrary, the straw addition significantly increased the TOC contents of the aqueous layer, which were increased continuously during the whole period of 30–60 days (Fig. 3). The reason for this may be the continuously flooded condition in our study, most of organic matter from straw decomposition floated into the aqueous layer, while a part accumulated in the soil and increased soil organic carbon contents (Stockmann *et al.*, 2013).

CONCLUSIONS

This study showed that the straw addition could increase the CH_4 and CO_2 emission in the continuously flooded condition during the first incubation experiment period, and the CO_2 emission dramatically decreased, while CH_4 emissions remained at a higher level during the later experiment period. The straw addition had a slight increase effect on soil organic carbon contents, However, with straw addition, the TOC contents in aqueous layer were increased greatly. The increments of external carbon addition for rice crops cultivation means rapeseed straw returning is a feasible method for disposing rapeseed straw prior to rice cultivation.

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Received for review, October 3, 2016
Revised, October 21, 2016
Accepted, October 21, 2016