Agriculture, Ecosystems and Environment 232 (2016) 302–311

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Response of paddy soil organic carbon accumulation to changes in long-term yield-driven carbon inputs in subtropical China

Anlei Chen[a], Xiaoli Xie[a,*], Maxim Dorodnikov[b], Wei Wang[a], Tida Ge[a], Olga Shibistova[c,d], Wenxue Wei[a], Georg Guggenberger[a,c]

[a] Key Laboratory of Agro-ecological Processes in Subtropical Region, Institute of Subtropical Agriculture, Chinese Academy of Sciences, Hunan, 410125, China
[b] Department of Soil Science of Temperate Ecosystems, Department of Agricultural Soil Science, University of Göttingen, 37077 Göttingen, Germany
[c] Institute of Soil Science, Leibniz Universität Hannover, 30419 Hannover, Germany
[d] VN Sukachev Institute of Forest, SB-RAS, 660036 Krasnoyarsk, Russian Federation

ARTICLE INFO

Article history:
Received 17 February 2016
Received in revised form 25 June 2016
Accepted 11 August 2016
Available online xxx

Keywords:
Soil organic carbon
Carbon sequestration
Carbon inputs
Yield decline
Paddy field
Long-term experiment

ABSTRACT

A decrease in C inputs from the return of crop residues to soil has occurred in many regions worldwide in recent years. The effects of this decline in C inputs could provide valuable information for assessing the long-term impact of litter C inputs on soil organic C (SOC) in rice paddy soils. The present study aimed to evaluate the response of rice paddy SOC accumulation to changes in actual C inputs in subtropical China, with emphasis on the response of C accumulation to declining C inputs. For this, we used a long-term field experiment on paddy soil in a rice-rice (*Oryza sativa* L.) cropping system running from 1990 to 2014. The four treatments were CK (control, no fertilizer), OM (organic matter application), NPK (N, P, and K fertilizer application), and NPKOM (NPK and organic matter application). Organic matter application for the OM and NPKOM treatments included rice straw and green manure that were left in the field after harvest and chopped, along with rice residues with stubbles and roots. In all treatments, C sequestration showed an increasing trend (from 0.207 to 0.880 $g\,kg^{-1}\,yr^{-1}$) in the early and middle stages of the experiment (1990–2006) followed by a decreasing trend (from −0.429 to −0.064 $g\,kg^{-1}\,yr^{-1}$) in the late stage (2007–2014). The trends were more pronounced for the OM and NPKOM treatments than for their CK and NPK counterparts. The changes in SOC stocks were consistent with changes in C inputs ($p < 0.01$). During the late stage, yield and litter inputs from crop residues and green manure decreased, quickly affecting SOC stock in paddy soils. This declining trend in annual rice yields was mainly caused by the decline in first rice yields, accounting for 42.3–91.5% of the decrease in annual C inputs. Insufficient P or N and K supply and unfavorable climatic factors (decreases in sunshine duration and both maximum and minimum temperatures) are possible reasons for the decline in first rice yields and green manure biomass in the late stage. Collectively, the results suggest that C stocks in high-productivity paddy soils respond very sensitively to a decline in C inputs. This raises the risk of loss of C stock in paddy soil if, in the long run, a large return of C to soil with crop residues or by other sources, e.g., green manure, cannot be achieved.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

Mitigation of the continuously increasing greenhouse gas emissions to the atmosphere has become an important global issue (Paustian et al., 2000). Agricultural soils attract great attention as a potential sink for atmospheric CO_2, the main greenhouse gas, by sequestrating soil organic C (SOC) (Smith et al., 2000; Pan et al., 2003). Owing to its high rate of SOC accumulation, rice cultivation may play an important role in mitigation of atmospheric CO_2 (Lal, 2004; Wu, 2011).

Rice (*Oryza sativa* L.) is the most important cereal crop in China, accounting for 32.5% of the total area harvested of cereals in 2014 (FAOSTAT, 2015), mostly in tropical and subtropical regions (Li, 1992). On the regional scale, substantial accumulations of SOC in paddy soils in subtropical China have been reported (Pan et al., 2003; Sun et al., 2009; Wu, 2011). SOC accumulation has been largely attributed to the increased use of chemical fertilizers that promote increased rice yields, higher biomass production, and more crop residues to return to soil, over the last several decades (Huang and Sun, 2006; Sun et al., 2009; Wu, 2011). A meta-analysis

* Corresponding author.
E-mail address: xlx@isa.ac.cn (X. Xie).

http://dx.doi.org/10.1016/j.agee.2016.08.018
0167-8809/© 2016 Elsevier B.V. All rights reserved.

of 26 long-term paddy field experiments showed that the retention of rice residues increased SOC by 0.41 Mg ha^{-1} yr^{-1} in the Yangtze Delta Plain of eastern China (Rui and Zhang, 2010). Similar studies conducted in southern China showed that organic matter (OM) application had significant effects on C sequestration in paddy fields (Li et al., 2005, 2010). Field experiments conducted in the Philippines and India showed similar results (Yadav, 1998; Manna et al., 2005; Pampolino et al., 2008).

However, most field experiments have been conducted using a fixed rate of organic matter input (Yadav et al., 2000; Li et al., 2005; Rui and Zhang, 2010). In contrast, the rates of rice residue inputs in rice production systems managed by farmers are quite variable, so the change of SOC in field experiments does not adequately represent the reality of C sequestration in paddy ecosystems (Wu, 2011). Therefore, it is important to know how SOC responds to fluctuation in C inputs due to changes in paddy rice production. Decline in C inputs because of yield stagnation has been reported in many regions in the world since the end of the last century, following decades of increasing C inputs due to higher rice yields (Dawe et al., 2000; Yadav et al., 2000; Bhandari et al., 2002; Ladha et al., 2003; Peng et al., 2004; Ray et al., 2012; Grassini et al., 2013; Xiong et al., 2014). Xiong et al. (2014) reported that the evidently slowing growth rate was not compensated for by benefits from improved varieties and management. Meanwhile, extreme climate events (e.g., drought, flooding, or drought immediately followed by flooding) in recent years have resulted in serious negative impacts on crop production; one example is the 2009–2010 extreme drought in southwestern China (Fauna, 2010; Zhang et al., 2012). Peng et al. (2004) provided direct evidence of decreased rice yields associated with global warming in a study at the International Rice Research Institute in Los Baños, Philippines. In other Asian countries, long-term field experiments have also shown declining or stagnating yields in rice-based cropping systems (Dawe et al., 2000; Yadav et al., 2000; Bhandari et al., 2002; Ladha et al., 2003). However, the effects of that yield decline or stagnation on C stock in paddy soils are still unclear. A few studies have demonstrated inconsistent SOC responses to rice yield decline, mainly due to the differences in soil types, initial SOC level, and magnitude and duration of the decreased C inputs (Yadav, 1998; Yadav et al., 2000; Ladha et al., 2003). In subtropical China, it is extremely important to understand the consequences of decreasing C return to paddy soils on SOC stock, because stagnation and decline in rice yields are becoming common phenomena in this region (Grassini et al., 2013; Xiong et al., 2014).

To explore the actual changes in C stocks in subtropical China, the fluctuation of C inputs should be examined to determine the patterns of yield changes, from an increasing trend to a declining trend or stagnation, during recent decades. Thus, the present study evaluated the response of SOC stocks and the rate of SOC changes in a rice paddy ecosystem to the changes in actual C inputs. Using a long-term fertilization experiment in the subtropical region of China as a case study, we examined the trends in rice productivity, C inputs, and topsoil SOC contents and stocks over time under different fertilization regimes, to determine the effects of fertilization practice on rice production, green manure biomass, and SOC accumulation. We put special emphasis on clarification of the response of rice paddy SOC accumulation to the changes in C inputs in subtropical China, especially under the condition of a decreasing trend in paddy rice productivity.

2. Materials and methods

2.1. Experimental site

The experiment was carried out in the Taoyuan Agro-ecology Experimental Station of the Chinese Academy of Sciences; it is located in a typical hilly agricultural area in Taoyuan, Hunan Province (28°55′N, 111°26′E). This region belongs to the subtropical humid monsoon climate zone, with mean annual precipitation of 1448 mm, mean annual temperature of 16.5 °C, and a frost-free period of 283 days. The rice-cropping regime is dominated by a double rice crop rotation. The paddy soil was developed on quaternary red clay earth. Before the experiment started, the soil had a 0.20 m plow layer, which contained 14.2 g kg^{-1} organic C, 0.55 g kg^{-1} total P, and 1.82 g kg^{-1} total N. The soil bulk density (BD) was 1.25 g cm^{-3}. Weather data were provided by a weather station set up next to the experimental field.

2.2. Fertilization treatments

The long-term paddy field experiment was established in 1990. For this trial, a randomized block design with three replicates was performed. The area of each plot was 33.2 m^2. Four treatments were selected in this study: no fertilizer application as a control (CK treatment; but there was C input from crop residues, i.e., stubble and roots), organic matter addition (OM treatment; i.e., with C input of straw and of green manure in addition to the crop residues), chemical N, P, and K fertilizer (NPK treatment; added N, P, and K fertilizer, C input as for CK treatment), and chemical N, P, and K fertilizer plus organic matter (NPKOM treatment; added fertilizer as for NPK treatment, C input as for OM treatment). The four fertilizer treatments represented traditional organic matter management, chemical fertilizer, and combined organic and chemical fertilizer regimes that are used locally. The additional organic matter input of the OM and NPKOM treatments included rice straw returned to the field and Chinese milk vetch (*Astragalus sinicus*) as green manure, and the input amount depended on the yield of rice straw and green manure per year. Chemical N, P, and K were applied as urea for N, calcium superphosphate for P, and potassium chloride for K. The annual fertilizer application rates were 262.5 kg N ha^{-1} (1990–1996) or 182.3 kg N ha^{-1} (1997–2014), 39.3 kg P ha^{-1} (1990–2014), and 137.0 kg K ha^{-1} (1990–1996) or 197.2 kg K ha^{-1} (1997–2014), according to the treatment design above. Urea (N fertilizer) was applied in two splits for the first rice season (40% as basal fertilizer and 60% as tillering fertilizer), and three splits for the second rice season (40% as basal fertilizer, 50% as tillering fertilizer, and 10% as panicle fertilizer). The P and K fertilizers were applied as basal fertilizers before rice transplantation. The combined rice-growing period was from the end of April to the end of October. The rice and green manure were local varieties.

For CK and NPK treatments, all rice straws were harvested and removed from the plots, thus only stubble remained in the field. The plots were left fallow until the next rice was transplanted. For OM and NPKOM treatments, all harvested rice straw was cut into 5–10 cm pieces then incorporated back into the field. The residues of the first rice crop were plowed into the soil before the second rice was transplanted, and those of the second crop covered the soil surface during the fallow period and were plowed into the soil in the middle of the following April. For the OM and NPKOM treatments, the green manure was sown in October before harvesting the second rice and grown during the non-growing season for rice, then harvested and plowed into the soil with the spring plowing in the middle of April. During the trials, 3–5 cm of water was maintained above the soil surface throughout the rice growing period, although occasional drainage was also performed from the end of rice tillering to the panicle primordium differentiation stage. Field management and rice cultivation were performed according to local farming practices.

2.3. Sampling and analyses

Upon harvest, crops were cut approximately 5–10 cm above the soil surface. Rice grains from each plot were sun-dried and

Download English Version:

https://daneshyari.com/en/article/8487331

Download Persian Version:

https://daneshyari.com/article/8487331

Daneshyari.com