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Change in net global warming potential of a rice–wheat cropping system with biochar soil amendment in a rice paddy from China

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ABSTRACT

Soil amendment of biochar produced via pyrolysis of waste biomass had been proposed as a potential countermeasure to mitigate climate change in agriculture. An overall accounting of net greenhouse gas balance (NGHGB) and greenhouse gas intensity (GHGI) was conducted of a whole rice–winter wheat rotation year of 2010–2011 in a paddy soil under biochar soil amendment at different rates from Southeast China. Fluxes of soil carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) were measured using a static chamber method, and the net ecosystem exchange of CO_2 (NEE) was estimated by the difference between net primary production (NPP) and soil CO_2 emissions (R_H) for both rice and winter wheat growing seasons. While no change observed in R_H, NPP of both rice and winter wheat was similar between the treatments except for an increase under BSA at 10 t ha^{-1} over the control. However, seasonal total N_2O emission was significantly and greatly decreased by 45.1% and 39.5% of rice growing season, and by 37.6% and 41.2% of winter wheat growing season under BSA treatment of 20 t ha^{-1} and 40 t ha^{-1} respectively over the control. Whereas, a 30.6% increase in seasonal total CH_4 emission was observed only under BSA of 20 t ha^{-1} of the rice growing season. However, BSA both at 20 t ha^{-1} and 40 t ha^{-1} exerted a great reduction in both NGHGB and GHGI of wheat cropping season but of the rice season. As an overall effect, a net reduction in GHGI by 10–20% with BSA was significant across all the biochar treatments. And this reduction could be accounted mainly by the consistent decrease in N_2O emission across rice and wheat growing cycles with insignificant changes in soil respiration and CH_4 flux during rice season. Whereas there could be variable changes in crop yield and net ecosystem GHGs balance with biochar rates and with crop cycles, biochar soil amendment (BSA) could have a great potential to reach a low carbon intensity production with sustaining crop productivity of a whole rice and wheat rotation system in rice-based agriculture of China.

1. Introduction

Atmospheric carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) had been recognized as the most important long-lived greenhouse gases (GHGs) that had significantly contributed to global warming due to their great radiative forcing (IPCC, 2007a). Global agriculture contributed 10–12% to the total global anthropogenic emissions of GHGs estimated as 5.1–6.1 Pg CO_2-equivalents year^{-1} in 2005 (IPCC, 2007b). However, there could be a great potential to reduce net GHGs emission in agriculture by increasing soil organic carbon (SOC) storage and/or decreasing CH_4 and N_2O emissions through improving crop management (Mosier et al., 2006; Smith et al., 2008).

Biochar produced via pyrolysis of crop residues had been considered as a key option of environmental management for mitigating global warming potential while sustaining crop productivity in agriculture (Lehmann et al., 2006; Lehmann, 2007; Laird, 2008; Sohi et al., 2010; Stavi and Lal, 2012). Due to the long residence time, input of stable organic carbon through biochar soil amendment (BSA) could act as a tool for long-term C storage and sequestration (Lehmann et al., 2006). However, changes in biogeochemical processes of C and N cycling could result from BSA as it altered soil properties and microbial access to carbon substrate (Lehmann et al., 2011). Accordingly, the size and dynamics of CO_2, CH_4 and N_2O emissions could be modified with BSA in terms of net

Abbreviations: BSA, biochar soil amendment; GHGs, greenhouse gases; GHGI, greenhouse gas intensity; NEE, net ecosystem exchange of CO_2; NGHGB, net greenhouse gas balance; NPP, net primary production; R_H, CO_2 emission from soil respiration.

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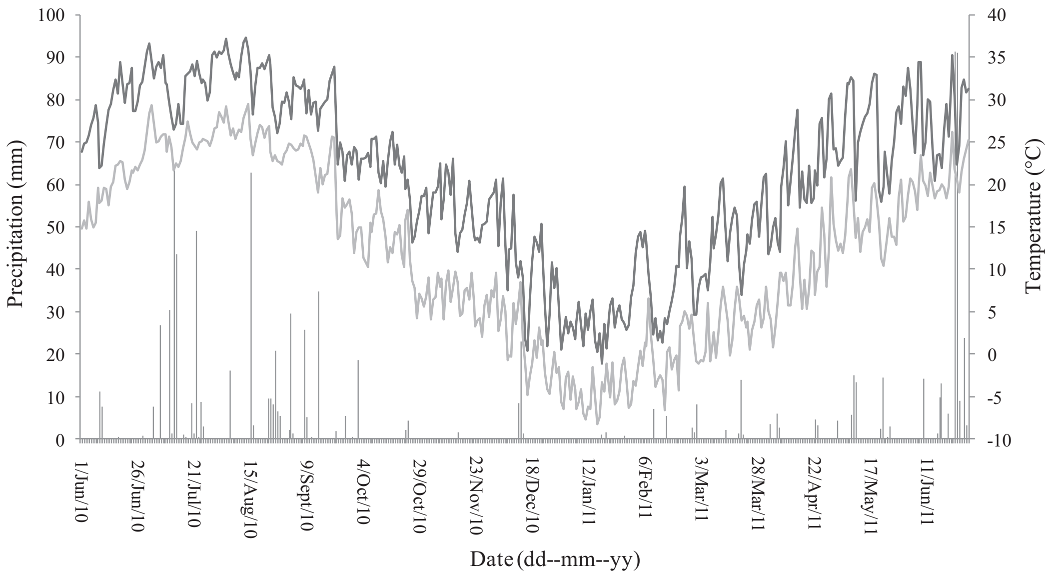

Fig. 1. Daily precipitation (vertical bars) and maximum (dark curve) and minimum (gray curve) air temperature over the rice–wheat rotation cycle studied.

soil–atmosphere exchange (Scheer et al., 2011). Suppression of N_2O emissions under BSA had been evidenced both by laboratory (Yanai et al., 2007; Spokas and Reicosky, 2009; Singh et al., 2010) and by field experiments (Liu et al., 2012a,b; Zhang et al., 2010, 2012a,b) though the extent of this reduction in N_2O emission under BSA seemed variable across both laboratory (Spokas and Reicosky, 2009; Clough et al., 2010) and field studies (Karhu et al., 2011; Scheer et al., 2011). However, changes in soil respiration from croplands with stable carbon input under BSA appeared varying with soil types and management practices (Zimmerman et al., 2011). A significant increase in soil respiration was reported in a work by Bell and Worrall (2011) with an unplanted soil amended with lump-wood biochar at a high rate of 62.5 t ha^{-1} though not significant in many other studies (Hilscher et al., 2009; Major et al., 2010a; Karhu et al., 2011; Zhang et al., 2012a,b). Likewise, changes in CH_4 fluxes with BSA had been also shown very variable across soil and crop types as well as experiment conditions (Spokas and Reicosky, 2009; Knoblauch et al., 2010; Karhu et al., 2011; Scheer et al., 2011; Zhang et al., 2010, 2012b).

Emission tradeoffs among different individual greenhouse gases would be a critical issue for addressing the net GHGs mitigation in agriculture. For the last decade, a trade-off between CH_4 and N_2O fluxes had been often reported of rice paddies shifting from continuous waterlogging to midseason drainage (Cai et al., 1997, 1999; Yagi et al., 1997; Zheng et al., 2000; Zou et al., 2005). Yet, soil carbon sequestration with fertilization practices in croplands had been given serious concerns for the tradeoff by potentially increased non-CO_2 GHGs emission, particularly with combined fertilization of organic/inorganic fertilizers, especially with manure (Powlson et al., 2011; Schlesinger, 2010; Shang et al., 2011; Six et al., 2004). As an example, a substantial increase in CH_4 emission was often observed with SOC sequestration under crop residue amendment in rice paddies (Adhya et al., 2000; Cai et al., 2000; Ma et al., 2009). Moreover, in a field study, a sharp decrease in N_2O emission but a substantial increase in CH_4 emission was found in a rice paddy following wheat straw biochar amendment (Zhang et al., 2010).

Therefore, it would be critical to quantify the overall radiative forcing of a certain agricultural management practice for understanding its role in mitigating climatic impacts in agriculture (Frolking et al., 2004; Robertson and Grace, 2004; Mosier et al., 2006; Johnson et al., 2007). This could be done with the net greenhouse gas balance of CO_2, CH_4 and N_2O (NGHGB, CO_2-equivalents) based on their individual global warming potential (GWP) in a given time horizon (Robertson and Grace, 2004; Mosier et al., 2006). An alternative parameter of greenhouse gas intensity (GHGI), an indicator of NGHGB relative to crop production capacity, had been also used for assessing the efficiency of a mitigation measure on production (Li et al., 2006; Mosier et al., 2006; Liu et al., 2012a,b).

Rice had been the primary staple food crop for nearly 50% of the world's population, being particularly important in Asia. China had been the second largest country of rice cultivation in the world with a rice cultivation area of 30 Mha, possessing 20% of the global rice area and 23% of the country's total croplands (Frolking et al., 2002). The typical cropping system of rice-based agriculture had been paddy rice in wet summer season and wheat or rape seed in dry winter season. It would be important to understand an overall effect of BSA on the net greenhouse gas emission reduction in a whole rotation year of rice–wheat cropping system in terms either of net ecosystem CO_2 exchange (NEE) or of NGHGB.

Thus, the objectives of the present study were to address if BSA could be a promising measure to mitigate GHGs in rice-based cropping system of China by quantifying the overall net annual ecosystem greenhouse gas balance and GWP intensity from different individual GHGs from a rice paddy in a rotation year of rice and wheat subsequently after biochar amendment.

2. Materials and methods

2.1. Experiment site

A field experiment with monitoring of both soil emissions and ecosystem CO_2 balance was carried out in a rice–wheat rotation year over 2010–2011 in a typical rice paddy in Jingtang village (31°24′ N and 119°41′ E), Yixing Municipality, Jiangsu Province, China. The site was located in the Tai Lake region where rice had been cultivated for several thousands of years in the area. The soil of the site was a typical high-yielding paddy soil classified as a hydroagric Stagnic Anthrosol (Gong, 1999) and an Entic Halpudept (Soil Survey Staff 1994). A subtropical monsoon climate prevailed in the area with mean annual temperature and precipitation of 15.7 °C and 1177 mm, respectively. Data of precipitation and temperature