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Original article

# Effects of biochar amendment on the net greenhouse gas emission and greenhouse gas intensity in a Chinese double rice cropping system

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ABSTRACT

The impacts of biochar amendment on the net greenhouse gas emission (NGHGE) and greenhouse gas intensity (GHGI) of double rice cropping systems are not well examined. In this study, a field experiment was carried out to investigate the effects of biochar amendment on NGHGE and GHGI emissions in a subtropical double rice cropping system managed with intermittent flooding during two rice-growing seasons and drainage during a fallow season from April 2012 to April 2013. Three biochar treatments were studied, with application rates of 0, 24 and 48 t $ha^{-1}$ (named CK, LC and HC, respectively). In each treatment, the fluxes of methane ($CH_4$), nitrous oxide ($N_2O$) and soil heterotrophic respiration (Rh) were measured using a static chamber/gas chromatography method. Key soil properties related to greenhouse gas (GHG) emissions were also determined throughout an entire double rice cycle. The results showed that biochar amendment significantly reduced annual $CH_4$ emissions by up to 40% compared with the CK treatment, possibly due to the soil pH increase after biochar amendment other than increased soil aeration. In contrast, annual $N_2O$ emissions significantly increased by 150% and 190% in the two biochar treatments, compared with the CK treatment, which may be related to the increase of soil dissolvable organic C or $NH_4^+$ in the biochar treatments. The cumulative Rh significantly increased by 19% in the HC treatment possibly due to the additional carbon dioxide ($CO_2$) emissions from decomposition of the labile C within biochar, but showed no increase and even a decrease in the LC treatment throughout the study period. Annually, the global warming potential for $CH_4$ and $N_2O$ emissions, NGHGEs, and GHGIs in the biochar amendment treatments were reduced by 31–36%, 1551–2936% and 1452–2894%, respectively ($p < 0.05$). Our collective data may suggest that as the rice grain yield was improved by the biochar amendment found in this study, the biochar application in paddy fields may be an effective measure for GHG emission mitigation in the subtropics.



## 1. Introduction

Biochar is the carbon (C)-rich solid obtained from biomass pyrolysis [1]. It has high C content and is highly stable due to its conjugated aromatic structures, which make it more recalcitrant to be degraded in the natural environment than the pre-processed feedstock material [2]. Thus, it can be stored for long periods in soil as a measure of carbon sequestration [3]. Biochar amendment can also be used to increase crop yields [1]. As reported by Alburquerque et al. [4], biochar amendment can increase wheat yield by 20–30% compared with an unamended control. Moreover, several studies have shown that biochar amendment contributes to reducing soil greenhouse gas (GHG) emissions [5–7]. Wu et al. [5] reported that wheat straw-derived biochar amendment dramatically reduced nitrous oxide ($N_2O$) emissions, but had no significant effect on carbon dioxide ($CO_2$) and methane ($CH_4$) emissions, compared with an unamended Chernozemic soil. In an incubation study, Liu et al. [6] found that both the rice straw- and bamboo-derived biochar amendments reduced $CH_4$ and $CO_2$ emissions in

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**Table 1**
Basic soil and biochar properties used in this study.

| | Total C g $kg^{-1}$ | Total N g $kg^{-1}$ | Total P g $kg^{-1}$ | Total K g $kg^{-1}$ | pH | Bulk density g $cm^{-3}$ | Ash content % | Sand % | Silt % | Clay % |
|---|---|---|---|---|---|---|---|---|---|---|
| Soil | 18.9 | 2.1 | 0.39 | 28.4 | 5.1 | 1.31 | – | 42.4 | 30.4 | 27.2 |
| Biochar | 418.3 | 5.8 | 0.58 | 9.2 | 9.3 | 0.18 | 37.2 | – | – | – |

paddy soils. Karhu et al. [7] reported that the birch derived biochar amendment increased $CH_4$ uptake by 96%, but showed no significant effect on $N_2O$ and $CO_2$ emissions in on an upland agricultural soil in Southern Finland. Those studies indicated that except for increasing soil carbon sequestration, biochar amendment to agricultural soils could also reduce $CH_4$ or $N_2O$ emissions and increase crop yields in some degree.

In previous field studies, the effects of biochar amendment on GHG emissions were primarily analyzed in rice-wheat rotation systems or upland fields [7–10]. Few studies have examined the impact of biochar in the double rice cropping system (in which the paddy field is cultivated with rice (one for early rice and the other for late rice) twice a year), which constitute a large area in subtropical and tropical regions of Asia (e.g. China, Thailand, Malaysia and Vietnam). In a former study of Liu et al. [11], the wheat straw biochar amendment depressed $N_2O$ emissions in the late rice season of the double rice cropping system at two sites in Southern China. Using the corn stalk biochar to amend to a soil collected from a double rice field, however, Xie et al. [12] found that biochar amendment via an incubation experiment did not influence $CH_4$ and $N_2O$ emissions. The double rice cropping system is usually submerged during the rice-growing season, with soils under this regime possessing a low Eh and relatively high soil organic C content. These conditions are highly conducive to GHG emissions, especially for $CH_4$ [13,14], which is the main greenhouse gas emitted from paddy fields. Biochar amendment could improve soil aeration [15,16] and thus may increase $CH_4$ oxidization and therefore reduce $CH_4$ in the double rice cropping system. In addition, when considering the effects of biochar amendment on GHG emissions, the emissions or net exchanges of the three main greenhouse gases (i.e. $CO_2$, $CH_4$, and $N_2O$) should be considered comprehensively to calculate the net greenhouse gas emissions (NGHGE) [17]. However, the effects of biochar amendment on NGHGE (a full-scale evaluation of the effects of biochar on GHG mitigation) remain rarely quantified in the double rice cropping system.

In the present study, a field experiment was performed in a paddy field in subtropical central China with the following ultimate aims: (i) to measure the fluxes of $CH_4$, $N_2O$ and soil heterotrophic respiration (Rh), (ii) to identify the key soil properties that influence these GHG emissions and (iii) to quantify the annual NGHGE and greenhouse gas intensity (GHGI) in a double rice cropping system with the different biochar amendment rates. The specific hypothesis tested in this study was that the biochar amendment in the double rice cropping systems can: (i) reduce GHG emissions and (ii) decrease the global warming potential for $CH_4$ and $N_2O$ emissions (GWP), NGHGE and GHGI.

## 2. Materials and methods

### 2.1. Experimental site and biochar

The plot experiment was performed in a paddy field (113°19′52″E, 28°33′04″N, 80 m a.s.l.), typical of those used for double rice production in Jinjing of Changsha County in Hunan Province in subtropical central China. The soils at the site is classified as Stagnic Anthrosols [18] developed from granite-weathered red soil. The study region is characterized by a subtropical humid monsoon climate. The annual mean precipitation, air temperature, sunshine hours, and frost-period are 1330 mm, 17.5 °C, 1663 h and 274 days, respectively. Sanli New Energy Ltd. (Shangqiu, China) provided the biochar, which was produced from wheat straw at a pyrolysis temperature of 500 °C. The basic properties of the soil and biochar are listed in Table 1.

### 2.2. Treatment design and field management

Treatments were laid out in a randomized block design with triplicates. The plot area was 35 $m^2$ (7 m by 5 m). Three treatments were arranged: CK (control treatment, no biochar amendment), LC (low biochar amendment rate treatment, with biochar amended at 24 t $ha^{-1}$, corresponding to 1% of the 0–20 cm layer topsoil weight), and HC (high biochar amendment rate treatment, with biochar amended at 48 t $ha^{-1}$, corresponding to 2% of the 0–20 cm layer topsoil weight). Our biochar amendment rates were within the range of 10–50 t $ha^{-1}$ found in the literature [7–10,19–21]. The biochar was evenly applied on the experimental fields and then thoroughly mixed with topsoil to simulate plowing on April 25, 2012.

Rice (*Oryza sativa* L.) cultivars were Xiangzaoxian No. 45 in the early rice season and T you 207 in the late rice season, respectively. The N fertilizers (i.e. urea at 120 kg N $ha^{-1}$ for early rice and 150 kg N $ha^{-1}$ for late rice) were applied with three time splits: basal application before transplanting and top dressing during the early tillering stage and heading stage with a ratio of 5:3:2. Furthermore, P (calcium superphosphate) and K (potassium sulfate) fertilizers were applied as basal fertilizers at rates of 40 kg $P_2O_5$ and 100 kg $K_2O$ $ha^{-1}$, respectively, in both rice seasons. Water management followed local farming practice. After transplanting, the paddy field was flooded for approximately 30 d with 5–8 cm of water. Thereafter, a two-week mid-season drainage was imposed, followed by intermittent irrigation until one week before the rice harvest. To facilitate the rice harvesting procedure, the paddy fields were drained one week before the harvest, which was conducted on July 12, 2012, and October 24, 2012, for the early and late rice, respectively.

### 2.3. Sampling and analyzing greenhouse gases and soils

#### 2.3.1. Gases sampling and analyzing

Greenhouse gas fluxes were determined using the static chamber/gas chromatography method. In each experimental plot, two base frames constructed of stainless steel (covering an area of 0.41 $m^2$) were inserted 20 cm into the soil after plowing the field. A boardwalk was constructed to access each chamber. Moreover, twelve rice seedlings (in the early rice season) and nine rice seedlings (in the late rice season) were transplanted in one frame for measuring $CH_4$ and $N_2O$ fluxes; no rice seedlings were transplanted in the other frame for measuring Rh rates. Chambers with a bottom area of 0.64 m × 0.64 m and a height of 1.0 m and water seals were temporarily mounted onto the frames for gas flux measurements. Greenhouse gases were sampled between 9:00 and 11:00 in oneday morning every week (twice a week during fertilization and midseason drainage periods) from April 29, 2012 to July 12, 2012,