Agriculture, Ecosystems and Environment 139 (2010) 469–475

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Effect of biochar amendment on yield and methane and nitrous oxide emissions from a rice paddy from Tai Lake plain, China

Afeng Zhang[a], Liqiang Cui[a], Gengxing Pan[a,*], Lianqing Li[a], Qaiser Hussain[a], Xuhui Zhang[a], Jinwei Zheng[a], David Crowley[b]

[a] *Institute of Resource, Ecosystem and Environment of Agriculture, Nanjing Agricultural University, 1 Weigang, Nanjing 210095, Jiangsu, China*
[b] *Department of Environmental Sciences, University of California, Riverside, CA 92521, USA*

ARTICLE INFO

Article history:
Received 4 June 2010
Received in revised form 2 September 2010
Accepted 2 September 2010
Available online 6 October 2010

Keywords:
Biochar
CH_4 emission
N_2O emission
Rice paddy
Rice productivity
Soil property

ABSTRACT

A field trial was performed to investigate the effect of biochar at rates of 0, 10 and 40 t ha^{-1} on rice yield and CH_4 and N_2O emissions with or without N fertilization in a rice paddy from Tai Lake plain, China. The paddy was cultivated with rice (*Oryza sativa* L., cv. Wuyunjing 7) under a conventional water regime. Soil emissions of CH_4 and N_2O were monitored with a closed chamber method throughout the whole rice growing season (WRGS) at 10 day intervals. Biochar amendments of 10 t ha^{-1} and 40 t ha^{-1} increased rice yields by 12% and 14% in unfertilized soils, and by 8.8% and 12.1% in soils with N fertilization, respectively. Total soil CH_4-C emissions were increased by 34% and 41% in soils amended with biochar at 40 t ha^{-1} compared to the treatments without biochar and with or without N fertilization, respectively. However, total N_2O emissions were sharply decreased by 40–51% and by 21–28%, respectively in biochar amended soils with or without N fertilization. The emission factor (EF) was reduced from 0.0042 kg N_2O-N kg^{-1} N fertilized with no biochar to 0.0013 kg N_2O-N kg^{-1} N fertilized with biochar at 40 t ha^{-1}. The results show that biochar significantly increased rice yields and decreased N_2O emission, but increased total CH_4 emissions. Summary calculations based on this experiment data set provide a basis for estimating the potential reductions in GHG emissions that may be achieved by incorporating biochar into rice paddy soils in south-eastern China.

1. Introduction

Many studies have reported beneficial effects of biochar as a soil amendment for improving soil quality and crop productivity (Glaser et al., 2001, 2002; Mann, 2002; Lehmann, 2007; Lehmann et al., 2006, 2008; Yamato et al., 2006; Marris, 2006; Chan et al., 2007, 2008). There has also been increasing attention to the possibility of using biochar to mitigate climate change by diverting carbon into agricultural soils (Lehmann et al., 2006; Major et al., 2009). Before the Climate Change Conference in Copenhagen, 2009, the United Nations Convention to Combat Desertification proposed to the United Nations Framework Convention on Climate Change that biochar amendments could be used to replenish soil carbon pools, restore soil fertility and sequester CO_2 as a double win option (UNCCD, 2009). In calculating the actual benefits for mitigation of climate change, it is essential to also quantify the effects of biochar on production of methane (CH_4) and nitrous oxide (N_2O) from agricultural fields. Production of these greenhouse gases is of particular concern in wetland rice production where soils are routinely flooded and drained, thereby promoting CH_4 and N_2O emissions.

Reductions in CH_4 and N_2O emissions have been identified as a urgent world tasks as these substances are important long-lived greenhouse gases (GHGs) with high warming potentials (IPCC, 2007a). Biochar amendments in agricultural soils have been shown to slow carbon and nitrogen release, which has been attributed to the high content of recalcitrant organic carbon in biochar and concomitant changes in soil properties that affect microbial activity (Glaser et al., 2001, 2002; Lehmann et al., 2003). Yanai et al. (2007) reported a sharp decrease in N_2O emissions from a wetted Typic Hapludand following the application of biochar derived from municipal bio-waste in a short laboratory chamber experiment. Rondon et al. (2006) similarly observed a reduction in the emission of N_2O by 15 mg N_2O m^{-2} from an acid savanna soil in the Eastern Colombian Plains following the application of biochar derived from mangrove wood. One of the explanations for the reduction in N_2O emissions from biochar-amended soils, includes reductions in the amounts of N that are available for denitrification as adsorption and retention of ammonium is much enhanced in soils containing biochar (Singh et al., 2010; Steiner et al., 2010). However, the degree

---

Abbreviations: AE_N, agronomic N use efficiency; EF, N fertilizer-induced emission factor of N_2O; GHGs, greenhouse gases; GWP, global warming potential; SOC, soil organic carbon; WRGS, whole rice growing season.

[*] Corresponding author. Tel.: +86 25 8439 6027; fax: +86 25 8439 6027.
E-mail addresses: gxpan@njau.edu.cn, gxpan1@hotmail.com (G. Pan).

0167-8809/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.agee.2010.09.003

to which N_2O emission can be reduced also have been shown to vary depending on the feedstock used to produce biochar (Zwieten et al., 2009) as well as by the type of soil, biochar application rate and soil moisture conditions.

Wide variations in the rates on CH_4 emissions from soils treated with biochar have been reported in the literature, with some studies showing reduced emissions and others showing elevated emissions. Rondon et al. (2006) showed that application of wood-derived biochar at a rate of 20 t ha^{-1} remarkably increased the annual methane sink in a non-fertile tropical soil. Likewise, in a previous study, Rondon et al. (2005) observed complete suppression of CH_4 emissions from a grass stand (*Brachiaria humidicola*) treated with biochar at 15 g kg^{-1} soil and from a soybean cropland treated with 30 g kg^{-1} soil. In contrast to these findings showing methane emission reductions, Knoblauch et al. (2008) reported no significant change in CH_4 production from a calcaric Fluvisol amended with charred rice residues at a mass percentage of 2.5% in both field and laboratory experiments. Whether or not biochar amendments have a beneficial effect in decreasing CH_4 emissions from agricultural soils may prove to be a critical issue for recommending when and where to use biochar amendments in world agriculture. To date, it appears that amounts of CH_4 emissions will depend on the soil type, the chemical properties of the biochar, and on the fertilization and water management regimes (Cai et al., 1997, 2000; Zou et al., 2007; Xiong et al., 2007; Zwieten et al., 2009).

World rice production is one of the most important anthropogenic sources for greenhouse gas production. Annual CH_4 emissions from rice paddies are estimated to range between 31 and 112 Tg $year^{-1}$, which contributes from 5 to 19% of the global total for this greenhouse gas (IPCC, 2007b). Estimates of total annual CH_4 and N_2O emissions from China's rice paddies range from 7.7 Tg CH_4 $year^{-1}$ and 88.0 Gg N_2O-N $year^{-1}$ to 8.0 Tg CH_4 $year^{-1}$ and 98.1 Gg N_2O-N $year^{-1}$, respectively (Xing and Zhu, 1998; Yan et al., 2003; Zheng et al., 2004; Liu et al., 2010). In China, 23% of the nation's croplands are used for rice production, accounting for about 20% of the world total (Frolking et al., 2002). Reductions in CH_4 and N_2O emissions from rice paddies in China are urged, with a total reduction of GHGs emission targeted at 40–45% per unit of GDP by 2020 (Anon., 2010). Until now, there are no reports on field studies that have examined the effects of biochar in Chinese agricultural soils, whether dealing with changes in crop productivity and soil quality or the emissions of CH_4 and N_2O from rice paddies. The purpose of the present study was to examine the influence of biochar amendments on rice yields and total emissions of CH_4 and N_2O over the whole growing period used for a rice production cycle in southeast China. By quantifying the total CO_2-equivalents during the whole rice growing season (WRGS) in a field experiment, it should be possible to determine the extent to which greenhouse gas emissions can be mitigated by using biochar in China's rice paddies.

2. Materials and methods

2.1. Experiment site

The field experiment was located in Jingtang village, Yixing Municipality, Jiangsu Province, China (31°24′N and 119°41′E). Rice cultivation in the area has been carried out at this location for several thousand years (Xu, 2001), and this area is considered to be one of the most productive regions for rice production. Derived from lacustrine deposits, this area has 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 prevails in the area with a mean annual temperature of 15.7 °C and 1177 mm of precipitation. The chemical properties of the topsoil measured for soil sampled at 0–15 cm depth were: pH (H_2O) 6.5, soil organic carbon (SOC) 2.4%, total soil nitrogen 0.18%, bulk density 1.01 g cm^{-3}, and 39% clay content.

2.2. Production and basic properties of biochar

Biochar used for the field experiment was produced from wheat straw by the Sanli New Energy Company, Henan, China. The biochar was produced by pyrolysis of the wheat straw at 350–550 °C. The commercial process used by this company employs a vertical kiln made of refractory bricks, and proprietary process that converts 35% of the biomass to biochar in the form of granular particles having a 0.3 mm diameter. For the field study, the biochar mass was ground to pass through a 2 mm sieve, and mixed thoroughly to obtain a powder consistency that would mix more uniformly with the soil. Following the protocol described by Lu (2000), the biochar's properties were characterized for total organic C and N with an Elementar Vario max CNS Analyser (German Elementar Company, 2003). The pH of the char was measured for a 1:5 char/water suspension with a compound glass electrode (Seven Easy Mettler Toledo, China, 2008). Total ash content was determined using 720 °C ignition in a muffle furnace for 3 h, and the mineral element content was determined by acid digestion and elemental analysis by atomic adsorption spectroscopy. The biochar had C and N contents of 46.7% and 0.59%, respectively, a total ash content of 20.8%, and a pH (H_2O) of 10.4. With respect to elemental analysis, the biochar contained 1% Ca, 0.6% Mg, 0.4% Fe and 2.6% K. The high ash content was likely due to dust and soil particles that contaminated the straw while collected in the field.

2.3. Field experiment

The biochar was applied to the field plots at rates of 0, 10 and 40 t ha^{-1} (C0, C1 and C2, respectively), and was applied in treatments with or without N fertilization (N1 and N0, respectively). In treatments receiving N fertilization, urea was applied at 300 kg N ha^{-1}, of which 40% was applied as a base fertilizer before transplanting, 40% at the tillering stage, and the remaining 20% at the panicle stage. For nutrient balance, calcium biphosphate and KCl were also applied as basal fertilizers before transplanting at rates of 125 kg P_2O_5 ha^{-1} and 125 kg K_2O ha^{-1}, respectively. Each treatment plot was 4 m × 5 m in area and the field plots were arranged in a randomized complete block design. The individual plots were separated by protection rows that were 0.8 m in width, each with an irrigation and drainage outlet. Biochar and N fertilizers were broadcast on the soil surface and incorporated into the soil by plowing to depth of about 12 cm in May, 2009. Additional N fertilizer applied at the later dates was broadcast and manually mixed into the soil. To maintain consistency, plowing and mixing treatments were also performed for the plots without biochar or N fertilization. Each treatment was replicated in triplicate.

For crop production, rice (*Oryza sativa* L., cv. Wuyunjing 7) was sown in a nursery bed on 15 May, after which the seedlings were transplanted on 13 June and harvested on 14 October, 2009. The water regime was managed using an alternating flooding and drainage cycle F–D–F–M (flooding–drainage–reflooding–moist, respectively during the seedling, panicling, spiking and ripening stages) through the whole growing season. In detail, paddy flooding was maintained from 10 June to 23 July, a subsequent drainage performed for about 1 week before reflooding from 1 August till 17 September and followed by a final intermittent irrigation till harvesting. All crop management was kept consistent across the plots.

2.4. CH_4 and N_2O emission monitoring

An aluminum flux collar was installed in each plot before flooding without covering the rice plants. The top edge of the collar