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Effects of straw incorporation along with microbial inoculant on methane and nitrous oxide emissions from rice fields

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HIGHLIGHTS

- This paper presents 3-year measurements of CH_4 and N_2O emissions from a rice system.
- Applying straw along with microbial inoculant affected CH_4 and N_2O emissions.
- Applying straw along with microbial inoculant enhanced soil CH_4 production potential.
- It is a good option to utilize straw resources due to increasing yields and maintaining GHGI.

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ABSTRACT

Incorporation of straw together with microbial inoculant (a microorganism agent, accelerating straw decomposition) is being increasingly adopted in rice cultivation, thus its effect on greenhouse gas (GHG) emissions merits serious attention. A 3-year field experiment was conducted from 2010 to 2012 to investigate combined effect of straw and microbial inoculant on methane (CH_4) and nitrous oxide (N_2O) emissions, global warming potential (GWP) and greenhouse gas intensity (GHGI) in a rice field in Jurong, Jiangsu Province, China. The experiment was designed to have treatment NPK (N, P and K fertilizers only), treatment NPKS (NPK plus wheat straw), treatment NPKSR (NPKS plus Ruilaite microbial inoculant) and treatment NPKSJ (NPKS plus Jinkuizi microbial inoculant). Results show that compared to NPK, NPKS increased seasonal CH_4 emission by 280–1370%, while decreasing N_2O emission by 7–13%. When compared with NPKS, NPKSR and NPKSJ increased seasonal CH_4 emission by 7–13% and 6–12%, respectively, whereas reduced N_2O emission by 10–27% and 9–24%, respectively. The higher CH_4 emission could be attributed to the higher soil CH_4 production potential triggered by the combined application of straw and microbial inoculant, and the lower N_2O emission to the decreased inorganic N content. As a whole, the benefit of lower N_2O emission was completely offset by increased CH_4 emission, resulting in a higher GWP for NPKSR (5–12%) and NPKSJ (5–11%) relative to NPKS. Due to NPKSR and NPKSJ increased rice grain yield by 3–6% and 2–4% compared to NPKS, the GHGI values for NPKS, NPKSR and NPKSJ were comparable. These findings suggest that incorporating straw together with microbial inoculant would not influence the radiative forcing of rice production in the terms of per unit of rice grain yield relative to the incorporation of straw alone.

1. Introduction

Methane (CH_4) and nitrous oxide (N_2O) are two important components of the Earth's atmosphere and the global biogeochemical carbon and nitrogen cycle. They are recognized as potent long-lived greenhouse gasses as well, 28 and 265 times higher in global warming potential than CO_2 on a 100-year time scale, respectively (IPCC, 2013). CH_4 and N_2O are directly or indirectly associated with global warming, together contributing up to 20% of the anticipated global warming (Smith et al., 2007). Rice fields have been considered as an important source of atmospheric CH_4, amounting to 15–20% of the global total anthropogenic CH_4 emission (Sass and Fisher, 1997). Substantial amounts of N_2O could also be emitted from rice fields under the integrated impact of N fertilizer input and water regime (Akiyama et al., 2005; Nishimura et al., 2004; Li et al., 2011; Ji et al., 2013). China is the largest rice producer in the world, with a planting area of 30 million ha, accounting for approximately 20% of the world's total (Frolking et al.,

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2002). The total annual CH_4 and N_2O emissions from the rice fields in China vary between 7.7 and 8.0 Tg yr^{-1} and between 88.0 and 98.1 Gg yr^{-1}, respectively (Yan et al., 2003; Zheng et al., 2004).

China enjoys a rich resource of crop straw, which reaches up to 620 Tg yr^{-1}, and is still on a rising trend at a rate of 1.4% annually (Zeng et al., 2007). As a viable option to improve soil fertility and carbon sequestration, straw incorporation has gained extensive support in China (Malhi et al., 2006; Lugato et al., 2006). Currently, approximately 25% of the crop straw is returned to the fields (Gao et al., 2009). Straw incorporated into rice fields supplies readily available carbon and nitrogen to the soil and subsequently influences GHG emissions. Straw addition significantly stimulates CH_4 emission from rice fields as it can selectively enhance the growth of particular methanogenic populations and provide substantial substrates (Bhattacharyya et al., 2012; Conrad and Klose, 2006). As for N_2O emission, it is increasingly recognized that straw incorporation has a potential to inhibit N_2O emission from rice fields (Zou et al., 2005; Wang et al., 2011; Yao et al., 2010, 2013; Bhattacharyya et al., 2012; Shen et al., 2014). A meta-analysis that calculated the response ratio of GHG emissions to straw incorporation in 176 published field studies has found that the practice reduced N_2O emission by 15.2% in paddy soils (Liu et al., 2014).

Although straw incorporation benefits nutrient cycling and soil carbon sequestration, it causes some adverse problems as well, such as imbalance of soil C/N ratio and tillage difficulty (Shindo and Nishio, 2005; Angeles et al., 2006), which hinder extensive extrapolation of straw incorporation. Among the solutions to alleviate these detrimental effects, incorporation of straw together with microbial inoculant, a microorganism agent accelerating straw decomposition, is increasingly adopted in recent years in China. The inoculants consist mostly of various microorganisms, which could accelerate straw decomposition process by synthesizing and excreting enzymes associated with straw degradation (Gaind and Nain, 2007; Pandey et al., 2009; Qian et al., 2012; Yu et al., 2010; Li et al., 2012; Zhang et al., 2005). Moreover, the combined application of straw and microbial inoculant promotes nutrient recycling and improves the balance between nutrient supply and plant demand, favoring high crop productivity (Li et al., 2001; Zhang et al., 2005; Pathak et al., 2006). To our knowledge, most of the studies only focus on effects of amending straw plus microbial inoculant on nutrient cycling and biological activities, but few is dedicated to exploration of impact of this practice on CH_4 and N_2O emissions in rice systems. Previous studies reported that incorporation of straw together with microbial inoculant significantly increased soil dissolved organic C (DOC) and influenced dynamic pattern of soil N availability (Ma et al., 2013; Zhang et al., 2005). Relative to the incorporation of straw alone, soil N content in soil receiving straw plus microbial inoculant decreases at first and then slightly increases (Zhang et al., 2005). Changes in content of soils C and N, as the important factors controlling GHG emissions, likely influence CH_4 and N_2O emissions.

In light of this, simultaneous measurements were done of CH_4 and N_2O emissions in a rice field during rice season for 3 years (from 2010 to 2012). The objectives of this study were to quantify the effects of combined application of straw and microbial inoculant on CH_4 and N_2O emissions and rice grain yield and to evaluate the impact of this strategy on global warming potential (GWP) and greenhouse gas intensity (GHGI).

2. Materials and methods

2.1. Field site and experimental design

The experimental site is situated in Baitu Town, Jurong City, Jiangsu Province, China (31°58′ N, 119°18′ E). Under the subtropical monsoon climate, this region enjoys a mean annual temperature of 15.1 °C and mean annual precipitation of 1018.6 mm. The cropping regime is dominated by summer rice–winter wheat rotation. The soil at the investigated site is classified as Typic Haplaquepts (Soil Survey Staff, 1975), with loamy texture, consisting of 14.2% clay, 68.7% silt and 17.1% sand. The soil total C and N contents and soil pH is 11.5 g kg^{-1}, 1.3 g kg^{-1} and 6.9, respectively. The data of mean air temperature and precipitation during the study period were cited from the Jurong Weather Station (Fig. 1).

The field experiment from 2010 to 2012 was designed to have four treatments in triplicate laid out in a randomized block design: i.e. Treatment NPK (use of chemical N, P and K fertilizers only), Treatment NPKS (NPK plus wheat straw), Treatment NPKSR (NPKS plus Ruilaite brand microbial inoculant), and Treatment NPKSJ (NPKS plus Jinkuizi brand microbial inoculant). The rate of straw incorporation was 4.8 Mg ha^{-1}. Wheat straw, containing 41.3% and 0.5% (C:N ratio of 86) of total carbon and nitrogen, was collected after harvest and chopped into pieces, about 0.1 m in length. The Ruilaite brand microbial inoculant is a product of the Chengdu Hecheng Biotechnology Co., Ltd., containing *Bacillus subtilis* (4.2×10^8 cell g^{-1}), *Pichia pastoris* (0.1×10^8 cell g^{-1}), *Rhizopus oryzae* (0.1×10^8 cell g^{-1}) and *Pdeiococcus pentosaceus* (2.6×10^8 cell g^{-1}), and the Jinkuizi microbial inoculant is a product of the Foshan Jinkuizi Science and Technology Co. Ltd., containing *B. subtilis* (3.6×10^8 cell g^{-1}), *Paenibacillus polymyxa* (0.5×10^8 cell g^{-1}), *Bacillus brevis* (1.0×10^8 cell g^{-1}) and *Bacillus licheniformis* (0.3×10^8 cell g^{-1}).

A local rice cultivar, Zhendao 624, was planted in this study. Urea (240 kg N ha^{-1}) used as synthetic N fertilizer was applied in split, 50% as basal fertilizer, 25% as tillering fertilizer, and 25% as panicle fertilizer. P and K fertilizers ($Ca(H_2PO_4)_2$: 450 kg ha^{-1}; KCl: 225 kg ha^{-1}) were broadcasted as basal fertilizer before rice transplanting. The basal fertilizer was applied 1 day before rice transplanting and the topdressing was surface broadcasted. Ruilaite microbial inoculant is a spraying microbial inoculant and its application rate is 75 g ha^{-1}. Before application, it was blended with water (equivalent to 100 folds of its own weight) for 24 h and then diluted with water to 20,000 times of its own weight. Then, the solution was sprayed on the straw. Jinkuizi microbial inoculant was broadcasted at a rate of 30 kg ha^{-1}. Detailed crop management events are listed in Table 1.

2.2. Field sampling and measurements

Air samples were collected using the manual static chamber method (Ma et al., 2009). The chamber covered a field area of 0.25 m^2 (0.5 × 0.5 m) and was placed on a plastic base in each plot (3 × 4 m). All chambers were equipped with a fan inside to guarantee gas mixed completely. The chamber was 0.5 or 1.0 m high, depending on the crop growth and plant height. Four gas samples from each chamber were collected using 18 mL vacuum vials at 15 min intervals between 08:30 AM and 11:30 AM on every sampling day. Gas samples were, in general, taken at 3–4 days intervals for the continuously flooding and reflooding periods, every 2 days for the MSA period, and just once a week for the remaining time.

Soil redox potential (Eh) at 10 cm depth was monitored on every sampling day, using a portable oxidation–reduction potential meter, and soil temperature at 10 cm depth, and field floodwater level, too, using a digital thermometer (Model 2455, Yokogawa, Japan) and a ruler, respectively. Soil samples (0–0.15 m) were obtained from each plot for analysis of soil inorganic N content and dissolved organic C (DOC) concentration. Soil moisture content was determined gravimetrically after drying at 105 °C for 8 h. Rice was harvested and grains were dried and weighed, separately, on a plot basis.

2.3. Incubation experiment

In order to measure CH_4 production potential, soil cores (0–0.15 m) were collected, 3 from each plot at the regreening (July 10), tillering (July 24), booting (August 20), grain-filling (September 26), and ripening (October 21) stages of rice crop cultivation in 2012. Soil cores collected each time from the same plot were cleared of plant debris