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Changes in Grain Yield of Rice and Emission of Greenhouse Gases from Paddy Fields after Application of Organic Fertilizers Made from Maize Straw

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Abstract: A field experiment was conducted at the farm of Yangzhou University, Yangzhou, China, to study the effects of organic fertilizers made from maize straw on rice grain yield and the emission of greenhouse gases. Four organic fertilizer treatments were as follows: maize straw (MS), compost made from maize straw (MC), methane-generating maize residue (MR), and black carbon made from maize straw (BC). These organic fertilizers were applied separately to paddy fields before rice transplanting. No organic fertilizer was applied to the control (CK). The effects of each organic fertilizer on rice grain yield and emission of greenhouse gases were investigated under two conditions, namely, no nitrogen (N) application (0N) and site-specific N management (SSNM). Rice grain yields were significantly higher in the MS, MC and MR treatments than those in CK under either 0N or SSNM. The MS treatment resulted in the highest grain yield and agronomic N use efficiency. However, no significant difference was observed for these parameters between the BC treatment and CK. The changes in the emissions of methane (CH_4), carbon dioxide (CO_2), or nitrous oxide (N_2O) from the fields were similar among all organic fertilizer treatments during the entire rice growing season. The application of each organic fertilizer significantly increased the emission of each greenhouse gas (except N_2O emission in the BC treatment) and global warming potential (GWP). Emissions of all the greenhouse gases and GWP increased under the same organic fertilizer treatment in the presence of N fertilizer, whereas GWP per unit grain yield decreased. The results indicate that the application of organic fertilizer (MS, MC or MR) could increase grain yield, but also could enhance the emissions of greenhouse gases from paddy fields. High grain yield and environmental efficiency could be achieved by applying SSNM with MR.
Key words: organic fertilizer; site-specific nitrogen management; rice; grain yield; greenhouse gas; maize straw

Reduction of greenhouse gas emissions in the world has become an increasing concern with the increase of global warming. Studies have shown that carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are important emission sources of agricultural greenhouse gases, and have a key function in global climate warming. Rice is one of the most important crops in the world, and its planting area accounts for one-third of the planting areas of cereals. An increase in rice production is essential to ensure global food security. Paddy fields are essential emission sources of greenhouse gases, especially CH_4 emission (Cai et al, 2005). China is the largest rice-producing and rice-consuming country, and the paddy area accounts for approximately 22% of the world's rice planting areas (Zou et al, 2003). Therefore, reducing the emission of CO_2, CH_4 and N_2O from paddy fields will significantly help mitigate global warming.

Crop straw, an energy substance that contains abundant carbon, has an important function in maintaining and improving soil fertility for the sustainable development of agriculture (Jiang et al, 2001). In recent years in China, farmers burn a high amount of crop straw to economize on manpower and farming time with the changes in rural labor structure. Straw burning not only wastes resources and pollutes the environment, but also negatively affects the soil

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ecosystem (Bi et al, 2009; Ge et al, 2013). To maximize the use of straw resources, different types of organic fertilizers have been made from crop straw and applied into farmland in some districts. The incorporation of straw into soil not only reduces environmental pollution by preventing straw burning, but also improves soil fertility and increases crop yield (Yang et al, 2011). Up to now, researchers have focused on the effects of paddy field physical and chemical properties on greenhouse gas emissions, yield and soil fertility under the application of organic fertilizers (Zou et al, 2003; Luo et al, 2010; Liu et al, 2011). However, information on different nitrogen managements and organic fertilizer applications and their interactions on rice yield and emissions of greenhouse gases from paddy fields are limited.

In this study, four types of organic fertilizers, namely, maize straw (MS), compost made from maize straw (MC), methane-generating maize residue (MR) and black carbon made from maize straw (BC), were applied to paddy field before rice transplanting. The effects of each organic fertilizer on rice grain yield and the characteristics of greenhouse gas (CO_2, CH_4 and N_2O) emissions from the paddy field were investigated under no nitrogen application (0N) and site-specific N management (SSNM). The effect of different organic fertilizers on yield and environment was evaluated to provide a theoretical basis for improving rice yield and developing ecological agriculture.

MATERIALS AND METHODS

Experimental conditions

Experiments were conducted at the farm of Yangzhou University, Yangzhou, Jiangsu Province, China, during the rice growing season (May to October) since 2008. The soil of the field was a sandy loam with 20.2 g/kg organic matter, 103.4 mg/kg alkali hydrolysable N, 24.9 mg/kg Olsen-phosphorus (P), and 85.9 mg/kg exchangeable potassium (K). Four types of organic fertilizers (MS, MC, MR and BC) were applied to paddy fields before rice transplantation each year. The C content of the various organic fertilizers (2 400 kg/hm^2) was calculated to determine the appropriate amount of C application for each organic fertilizer. No organic fertilizer was applied to the control (CK). Given the production of gases, such as CO_2, during the production of organic fertilizers from straw, the C loss rates of MC, MR and BC treatments were 52%, 60% and 38% of that of MS, respectively. Two levels of N application, namely, 0N and SSNM, were applied. The N application in SSNM was based on the target yield and soil fertility to determine the total amount of N application rate, as well as the leaf color by soil plant analysis development (SPAD; chlorophyll meter readings) to adjust the amount of top-dress N fertilizer (Yang et al, 2008). Both 0N and SSNM were designed for each organic fertilizer treatment with 10 treatment combinations. The experiment was split-plot designed, i.e., organic fertilizer treatments were the primary plots, and N fertilizer treatments were subplots. Plot dimensions were 4 m × 5 m, and plots were separated by a 0.5 m-wide alley and covered with a plastic film barrier. Rice and wheat were planted annually. A total of 150 kg/hm^2 N was applied to the SSNM plots during the wheat growing season.

Rice materials and cultivation in 2012

Contents of organic matter, alkali hydrolysable N, Olsen-P and exchangeable K in soil were determined after wheat harvest in 2012 (Table 1). A high-yielding japonica rice cultivar Yangjing 4038 was used with the growth duration of 155 d from sowing to physiological maturity. The total number of leaves on the main stem was 17, and the number of elongation

Table 1. Content of nutrients in soil under application of different organic fertilizers in 2012.

Treatment		Organic matter	Alkali hydrolysable N	Olsen-phosphorus	Exchangeable
Nitrogen fertilizer	Organic fertilizer	(%)	(mg/kg)	(mg/kg)	potassium (mg/kg)
No N fertilizer (0N)	Maize straw	2.08	108.9	28.1	95.1
	Compost made from maize straw	2.24	113.4	28.3	98.3
	Methane-generating maize residue	2.35	115.6	28.9	96.7
	Black carbon made from maize straw	2.38	105.1	27.1	95.2
	CK (no organic fertilizer)	1.94	103.9	25.1	93.3
Site-specific N management (SSNM)	Maize straw	2.12	110.5	29.3	97.5
	Compost made from maize straw	2.48	116.4	30.1	99.8
	Methane-generating maize residue	2.52	118.2	30.4	98.2
	Black carbon made from maize straw	2.53	106.7	29.1	95.9
	CK (no organic fertilizer)	2.05	105.8	28.5	94.2