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Wheat straw management affects CH_4 and N_2O emissions from rice fields

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ABSTRACT

A 3-year field experiment was conducted in Jiangsu Province, China from 2004 to 2006 to investigate CH_4 and N_2O emissions from paddy fields as affected by various wheat straw management practices prior to rice cultivation. Five methods of returning wheat straw, no straw, evenly incorporating, burying straw, ditch mulching and strip mulching, were adopted in the experiment. Evenly incorporating is the most common management practice in the region. Results showed that compared with no straw, evenly incorporating increased CH_4 emission significantly by a factor of 3.9–10.5, while decreasing N_2O emission by 1–78%. Methane emission from burying straw was comparable with that from evenly incorporating, while N_2O emission from burying straw was 94–314% of that from evenly incorporating. Compared with evenly incorporating, CH_4 emission was decreased by 23–32% in ditch mulching and by 32% in strip mulching, while N_2O emission was increased by a factor of 1.4–3.7 in ditch mulching and by a factor of 5.1 in strip mulching. During the rice-growing season, the emitted N_2O was negligible compared to that of emitted CH_4. No significant difference in grain yield was observed between ditch mulching, burying straw, evenly incorporating and no straw. Compared with no straw, the grain yield was increased by 27% in strip mulching. Based on these results, the best management practice for returning wheat straw to the soil is strip mulching wheat straw partially or completely onto the field surface, as the method reduced CH_4 emission from rice fields with no decrease in rice yield.

1. Introduction

Methane (CH_4) and nitrous oxide (N_2O) are potent greenhouse gases with global warming potentials (GWP) 25 and 298 times greater than that of carbon dioxide (CO_2), respectively, on a 100-year horizon (Intergovernmental Panel on Climate Change, 2007). Moreover, CH_4 affects the chemistry and oxidation capacity of the atmosphere, and increasing atmospheric N_2O is an important factor in stratospheric ozone depletion.

Rice fields have been identified as one of the important sources of atmospheric CH_4, contributing approximately 15–20% of the global total anthropogenic CH_4 emission (Sass and Fisher, 1997; Aulakh et al., 2001). Several recent experiments have shown that substantial amounts of N_2O are emitted from rice fields, which may be attributed to the combined effect of N fertilization and water management (Cai et al., 1997; Chen et al., 1997; Nishimura et al., 2004; Yu et al., 2004). To meet the increasing global demand for food, rice production will increase in area and intensity, potentially increasing CH_4 and N_2O emissions. The Kyoto protocol came into force in 2005, listing both CH_4 and N_2O after CO_2 as greenhouse gases that should be controlled. Therefore, it is urgent to establish technologies and practices for reducing CH_4 and N_2O emissions from rice fields while sustaining or increasing rice production.

China has 13 million ha of rice-wheat cropping, mainly in the four provinces along the Yangtze River Valley, namely Jiangsu, Anhui, Hubei, and Sichuan (Zheng, 2000). Crop production inevitably results in large amounts of straw residues. Returning crop straw to the field is highly recommended in China as a measure to increase soil fertility and soil organic carbon storage (Singh et al., 2004; Tirol-Padre et al., 2005). However, the common practice of incorporating crop straw evenly into the topsoil provides a source of readily available C, which has been proved to markedly enhance CH_4 emission (Watanabe et al., 1995; Singh et al., 1996; Cai, 1997; Zou et al., 2005) and slightly reduce N_2O emission (Bronson et al., 1997; Zou et al., 2005) from rice paddies. Thus, it may be possible to both sustain soil productivity and mitigate CH_4 and N_2O emissions. Proper management of fresh crop straw could achieve these goals.

Apart from the common practice of incorporating wheat straw evenly into the topsoil, burying wheat straw in several parallel ditches with no-tillage is another method of returning fresh crop

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straw prior to rice cultivation (Han et al., 1992; Zhong et al., 2003; Wang et al., 2006), however, its effects on CH_4 and N_2O emissions have never been reported, as far as we know. Yan et al. (2005) reported that the increase in the average seasonal CH_4 flux in response to the increased addition of organic matter was logarithmic, not linear. Therefore, concentrating straw into rows within a rice field may reduce CH_4 emission from the field as a whole, compared to an even layer of buried straw. In addition, previous studies have reported options for mitigating CH_4 emission from rice fields, including organic amendments derived from aerobically composted straw (Yagi et al., 1997; Wassmann et al., 2004), incorporation of crop straw in the winter cropping season instead of the rice-growing season (Lu et al., 2000; Xu et al., 2000), and zero-tillage rice cultivation with rice straw applied on the surface (Chareonsilp et al., 2000; Harada et al., 2005). These findings suggested that CH_4 emission could be reduced with the fresh straw exposed to light and more oxidizing conditions.

In this study, we used five wheat straw application methods prior to rice cultivation from 2004 to 2006, and conducted simultaneous measurements of CH_4 and N_2O emissions. The objective was to quantify CH_4 and N_2O emissions as affected by various wheat straw management practices.

2. Materials and methods

2.1. Field sites and experimental design

Two field studies were performed in Jiangsu province, China. In the 2004 and 2005 seasons, field plots were established at a rice field located at Dapu town, Yixing city, Jiangsu province, China (31°17′N, 119°54′E). The soil of the experimental field was classified as Typic Epiaquepts (USDA Taxonomy 1975), with soil properties as follows: initial pH (H_2O) 6.23, total C 1.26%, and total N 0.13%. In 2006, due to land requisition, the field experiment was transferred to a rice paddy located at Xingxiang town, Jurong city, Jiangsu province, China (31°58′N, 119°18′E). The soil of the paddy field was classified as Typic Haplaquepts (USDA Taxonomy 1975). Soil pH (H_2O) was 5.9, and total C and N were 0.82% and 0.11%, respectively.

The two fields were previously cultivated under a double-cropping system of rice rotated with winter wheat. Both rice and wheat straws were produced in rice-wheat rotation system, and either removed or applied to the subsequent crop. The harvested rice straw was surface applied at 3.75 t ha^{-1} dry weight at Dapu town and removed at Xingxiang town at the beginning of the antecedent wheat season. The harvested wheat straw was chopped to approximately 0.1 m lengths, and then applied to the two fields before rice transplanting.

Five methods of returning wheat straw were carried out, in triplicate, in a randomized block design. The five methods were as follows: (i) no wheat straw application (no straw); (ii) ditches were filled with soil to field level, and wheat straw was spread evenly over the field and raked into the 0.1 m topsoil (evenly incorporating); (iii) wheat straw was evenly buried in the ditches and covered with 0.02 m of soil to field level with no-tillage (burying straw); and (iv) the depth of ditches was reduced to half of the original depth with soil, wheat straw was evenly mulched onto the elevated ditches so that the final height was 0.06 m higher than the field surface, then wheat straw mulches were covered with 0.02 m of soil with no-tillage (ditch mulching); and (v) ditches were filled with soil to the field level, and wheat straw was evenly mulched onto the field surface in blocks 3 m long, 0.25 m wide and 0.1 m high, then wheat straw mulches were covered with 0.02 m of soil with no-tillage (strip mulching). After the rice season, wheat straw in all treatments except no straw was evenly incorporated in the fields and drainage ditches were re-established. The ditches were 16 m long, 0.25 m wide, 0.14 m deep and 1.8 m apart at Dapu town and 3 m long, 0.25 m wide, 0.1 m deep and 1 m apart at Xingxiang town. No straw, evenly incorporating and burying straw were adopted in 2004, and seven ditches were filled with wheat straw at each replicate plot of burying straw. In 2005, ditch mulching was applied instead of burying straw, because CH_4 emission of burying straw was not lower than that of evenly incorporating in 2004 as we had hypothesized. Six ditches were filled with wheat straw at each replicate plot of ditch mulching in 2005. All five methods of returning wheat straw were carried out in 2006. Wheat straw was buried in two areas of each replicate plot of burying straw, ditch mulching and strip mulching in 2006. The experimental setup of two sites is shown in Table 1.

2.2. Sampling and measurements

Methane and N_2O fluxes were simultaneously monitored using the static chamber technique. The flux chamber (0.5 m length × 0.5 m width × 1 m height) covered six hills of rice in the paddy field, and the plant density inside the chamber (hill spacing was 0.25 m × 0.17 m, with three seedlings per hill) was the same as that outside the chamber. Plastic bases for the chambers were installed before rice transplantation in all plots, and remained there until rice harvest. Removable wooden boardwalks (2 m long) were set up at the beginning of the rice season to avoid soil disturbances during sampling and measurements. Gas samples were collected at 2–3 day intervals for 10 days after fertilizer application, then at 4–5 day intervals until the last 2 months of rice growth when a 7 day sampling interval was used. Four gas samples from each chamber were collected using 18 ml vacuum vials at 10 min intervals between 08:00 and 12:00 h in the morning on every sampling day.

In contrast to the evenly incorporating treatment, wheat straws at each replicate plot of burying straw, ditch mulching and strip mulching were concentrated in seven ditches in 2004, six mulches in 2005, and two ditches or mulches in 2006. Two chambers were installed in each replicate plot to monitor CH_4 and N_2O fluxes in burying straw, ditch mulching and strip mulching treatments. Chamber A covered a ditch or mulch and some of the field on either side of it, and Chamber B covered the field between two neighboring ditches or mulches. Methane and N_2O fluxes measured through Chamber B (F_B) were those of the non-ditch or non-mulch area, while those measured through Chamber A (F_A) were the average of the ditch and non-ditch or the mulch and non-mulch. Therefore, CH_4 and N_2O fluxes of the ditch (F_{ditch}) or the mulch (F_{mulch}) were calculated as follows: F_{ditch} (or F_{mulch}) $= 2F_A - F_B$, because the ditch or the mulch accounted for only half of the area covered by chamber A. Methane and N_2O fluxes of burying straw, ditch mulching and strip mulching were the average flux for the whole area of the plot weighted by the corresponding area and fluxes of the ditch and non-ditch or the mulch and non-mulch.

The gas concentrations were analyzed by gas chromatograph (Shimadzu GC-14B, Japan) equipped with a flame ionization detector for CH_4 analyses and an electron capture detector for N_2O analyses. Methane and N_2O fluxes were determined from the linear increase of gas concentration at each sampling time (0, 10, 20 and 30 min during the time of chamber closure) and adjusted for area and volume of the chamber. Total CH_4 and N_2O emissions were calculated as follows:

$$T_{CH_4} (or\ T_{N_2O}) = \sum_{i=1}^{n} (F_i \times D_i)$$

where D_i indicates the number of days, F_i indicates measured flux in the ith sampling interval, and n is the number of sampling intervals.