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CO_2 emission in a subtropical red paddy soil (Ultisol) as affected by straw and N-fertilizer applications: A case study in Southern China

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ABSTRACT

Soil sequestration of atmospheric CO_2 through land application of inorganic N fertilizer along with organic residues may have beneficial effects as a strategy to offset the increase in the concentration of CO_2 in the atmosphere. A field study was conducted to assess the effect of application of N fertilizer and rapeseed (*Brassica napus* L.) straw in a paddy field. To understand rice-, rhizosphere- and N-induced CO_2 flux, CO_2 flux was measured during the growth stages of rice (*Oryza sativa* L.) from row, inter-row and bare soil at the experimental station of Heshengqiao at Xianning, Hubei, China.

The study included seven treatments: (CK) control, (N0) fertilizer PK, (N1) fertilizer NPK (50% N), (N2) fertilizer NPK (100% N), (N3) fertilizer NPK (200% N), (N0 + S) fertilizer NP + traw, (N2 + S) fertilizer NPK (100% N) + straw. There was a distinct variation in soil CO_2 fluxes, with the higher values being observed during the reproductive stage of crop growth while the lower fluxes were observed during the maturity stage. Soil CO_2 fluxes from row (797–1214 g C m^{-2} $season^{-1}$) were significantly higher than from inter-row (289–403 g C m^{-2} $season^{-1}$) and bare soil (148–241 g C m^{-2} $season^{-1}$), due to the contribution of rhizosphere respiration. Among different treatments, N fertilization significantly increased the CO_2 flux from row with the highest being observed from N2 + S and lowest from N0 + S treatment. No significant differences among different treatments were observed from inter-row and bare soil. From bare soil, soil CO_2 flux was decreased in response to N fertilizer application; this suggested suppression in microbial activity in response to increased N fertilizer application.

Soil temperature accounted for 68 and 38% of CO_2 flux variability from row and inter-row, respectively, while no significant correlation was found from bare soil. Soil temperature explained 69% of N-induced CO_2 flux variability from row, while no effect was observed from inter-row and bare soil. Soil temperature was also significantly correlated with rice- and rhizosphere-induced CO_2 flux accounting for 42 and 31% of CO_2 flux variability, respectively.

The amount of soil carbon sequestration was estimated by taking the difference between net primary production (NPP) and the amount of carbon in harvested rice. The values ranged from −176 to −89 g C m^{-2} $season^{-1}$ with the highest value observed from N2 + S treatment; this suggested that N fertilizer application with straw has the potential to mitigate the global carbon budget. The current findings indicate that N addition increases the CO_2 flux. However, integrated use of N fertilizer along with rapeseed straw may be a preferred strategy in sequestering C in red soil.

1. Introduction

Soil respiration is one of the primary fluxes of C between soils and the atmosphere, with a global release of 75 Pg C per year (Schlesinger and Andrews, 2000). Understanding controls on soil respiration is critical because relatively small changes in respiration rates may dramatically alter atmospheric concentrations of CO_2 as well as rates of soil C sequestration. It is expected to reduce CO_2 emission from soils and/or to increase sequestration of atmospheric CO_2 in soils. Accordingly, characterization of soil CO_2 emission is increasingly important. Soil CO_2 emission integrates all components of soil CO_2 production, including rhizosphere respiration and soil microbial respiration.

Variations of soil CO_2 flux are affected by agronomic management practices such as organic and inorganic fertilization (Ding et al.,

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2006). Agricultural management practices affect soil CO_2 flux by changing the soil environment such as soil aeration, soil pH, soil moisture, soil temperature, C/N ratio of substances, etc. These soil environmental characteristics can have a significant impact on soil microbial activity and the decomposition processes that transform plant-derived C to soil organic matter (SOM) and CO_2 (Franzluebbers et al., 1995). Previous research has shown that soil CO_2 flux rates are strongly related to soil temperature and soil moisture conditions (Franzluebbers et al., 1995; Ren et al., 2007; Iqbal et al., 2008; Liu et al., 2008).

Rhizosphere respiration has been estimated to be 25–45% of gross primary productivity and accounts for 15–71% of ecosystem respiration (Rochette et al., 1999). Similarly, nitrogen fertilizers applied to soils influence soil CO_2 emission, though their actual effects vary (Lee et al., 2007). The relative benefits of balanced fertilizer using crop residues, organic manures and green manuring in maintaining the organic C levels in arable soils are of increasing concern (Ladd et al., 1994). While chemical fertilizers are increasingly applied to paddies in Asia (FAOSTAT, 2005), the effect of chemical fertilizers or combined applications of organic and chemical fertilizers is particularly crucial for predicting the future trend of CO_2 emission from Asian paddies and possible approaches to mitigate climatic change by agricultural practices. However, there is a lack of data on extensive crops, particularly in the south region of China. Red soil, one of the important typical soils in subtropical regions of China, which can be classified as Ultisols in the Soil Taxonomy System of the USA and Acrisols and Ferralsols in the FAO legend (FAO/UNESCO, 1974), cover about 1.13 million km^2 or 11.8% of the country land surface, produces 80% of the rice (*Oryza sativa* L.) and supports 22.5% of the population (Zhao, 2002). In southern China, including 15 provinces, red soil covers 0.28 million km^2 of cultivated land (Zhao, 2002). However, with the rapid economic and social development, red soils are subject to degradation as characterized by low organic carbon content and low crop productivity. Therefore, it is necessary to investigate soil CO_2 evolution from red soils for better understanding the mechanisms that regulate C storage and loss processes in the extensively cultivated paddy field. Furthermore, the effects of N fertilization and rice growth on variation in CO_2 emission under anaerobic conditions from paddy soils are not well known.

In China in the 1980s, approximately 60 Pg $year^{-1}$ of straw were produced from 100 million ha of cultivated soil, of which 80% was burned either in the field or for cooking (Cheng and He, 1990). The use of straw is becoming less common due to increasing environmental concerns and the availability of fossil fuels in rural areas. Applying of straw in combination with inorganic fertilizer is an attractive alternative to burning because it can provide essential nutrients for crops (Edmeades, 2003), while also reducing C release to the atmosphere. However, Ajwa and Tabatbai (1994) found that as much as 27–58% of added organic C in corn and alfalfa residues was released as CO_2 during the 30 d incubation period. In contrast, less organic C in wheat (*Triticum aestivum* L.) straw was decomposed during a similar period (Ghidey and Alberts, 1993). Decomposition rates, therefore, vary with plant type (Kirchmann et al., 2004). In China, current practice with rapeseed (*Brassica napus* L.) straw includes grinding and application directly to soils, when the crops are being harvested by machine. Using rapeseed straw as a fertilizer, however, presents a substantial challenge. Nevertheless, knowledge on the effect of fertilization on CO_2 emission under anaerobic conditions from paddy soils is still insufficient. The present study was conducted to demonstrate the variation of CO_2 emission under intensively cultivated paddy soil. The objectives of the study were to: (1) investigate rice-, rhizosphere and N-induced CO_2 emission; (2) evaluate the influence of application of rapeseed straw in combination with inorganic fertilizer on soil CO_2 emission from intensively cultivated paddy soil; and to (3) approximate the effect of nitrogen fertilization on the potential of carbon sequestration from the paddy field.

2. Methods and materials

2.1. Site description

The field experiment was conducted on a well drained paddy soil located at the experimental station of Heshengqiao, Southern China (29°02′–30°18′N, 133°31′–144°58′E). The selected site was representative of the regional features of land use in Southern China. Altitude ranges from 86 to 147 m above sea level. The mean annual sunlight hours are 1857 h and the mean annual wind is 1.5 m s^{-1}. This region has a typical subtropical monsoon climate with an annual mean temperature of 16.8 °C and an annual frost-free period of 340 days. Annual rainfall averages 1577 mm, concentrated during the period of May to August and open pan evaporation is 990 mm per year.

Red soil of this area can be classified as Ultisols in the Soil Taxonomy System of the USA and Acrisols and Ferralsols in the FAO legend (FAO/UNESCO, 1974). Soil was clayey, kaolinitic thermic Typic Plinthudults with over 2 m deep profile derived from quaternary red clay, subjected to severe erosion. The paddy has been continuously cultivated with rice-rape rotation since 1996. During the growing seasons, an annual average rate of inorganic N, P, K (270, 59, 187 kg ha^{-1}, respectively) was applied to the field. The field was conventionally tilled twice a year. Relevant physical and chemical properties of soils are listed in Table 1.

2.2. Experimental design

Measurements were conducted on three kinds of plots in the paddy field: (1) row, (2) inter-row, (3) bare soil. A randomized block design was used to prepare three replicates of each plot of each of the seven treatments in June 2007. Each plot measured 10 m × 5 m. The treatments description along with fertilizers applied is described in Table 2. The rapeseed straw used in the experiment was ground to 3–5 mm lengths. In first week of June 2007, 21 days old seedlings were transplanted at 20 cm × 20 cm spacing giving a population of 25 hills m^{-2}. After transplanting, the field was continuously kept flooded with 5-cm water level. CO_2 flux from each plot was measured at different growth stages starting from transplantation till maturity. About 14 days before harvest, the water was drained from the plots so that the soil was dry during the harvest.

2.3. Measurement of soil CO_2 flux

Soil CO_2 emissions were measured using the static closed chambers technique as described by Xiao et al. (2005), and was analyzed with a portable infrared analyzer ZEP-5 (ZEP-5, Fuji

Table 1
Selected physico-chemical properties of the soils.

Properties	Values
Texture	Sandy loam
Bulk density (Mg m^{-3})	1.37
pH (1:2.5, soil:water)	5.11
Water holding capacity (g/100 g)	56.83
Cation exchange capacity [cmol (p^+) kg^{-1}]	8.3
Total organic carbon (g kg^{-1})	16.87
Total N (g kg^{-1})	2.55
C/N ratio	6.62
Available N (mg kg^{-1})	306
Available P (mg kg^{-1})	16
Available K (mg kg^{-1})	239