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How do environmental factors and different fertilizer strategies affect soil CO_2 emission and carbon sequestration in the upland soils of southern China?

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ABSTRACT

Upland soils have been identified as a major CO_2 source induced by human activities, such as fertilizer applications. The aim of this study is to identify the characteristics of soil CO_2 emission and carbon balance in cropland ecosystems after continuous fertilizer applications over decades. The measurements of soil surface CO_2 fluxes throughout the years of 2009 and 2010 were carried out based on a fertilization experiment (from 1990) in a double cropping system rotated with winter wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) in upland soil in southern China. Four treatments were chosen from the experiment for this study: no-fertilizer application (SR), nitrogen–phosphorus–potassium chemical fertilizers (NPK), NPK plus pig manure (NPKM) and pig manure alone (M). Results showed that the mean value of soil CO_2 fluxes from 08:00 to 10:00 am could represent its daily mean value in summer period (June–August) and that from 09:00 am to 12:00 pm for the rest season of a year. Soil temperature and moisture combined together could explain 70–83% of variations of CO_2 emission. Annual cumulative soil CO_2 fluxes in the treatments with manure applications (8.2 ± 0.8 and 11.0 ± 1.2 t C ha^{-1} in 2009, and 7.9 ± 0.9 and 11.1 ± 1.2 t C ha^{-1} in 2010 in NPKM and M, respectively) were significantly higher than those in the treatments with non-manure addition (2.5 ± 0.2 and 3.4 ± 0.2 t C ha^{-1} in 2009, and 2.1 ± 0.2 and 3.7 ± 0.3 t C ha^{-1} in 2010 in SR and NPK, respectively). However, the treatments with manure applications represented a carbon sink in the soil (carbon output/input ratio < 1.0), which demonstrated potential for carbon sequestration.

1. Introduction

Annual global soil CO_2 emissions contribute to about 25% of the total carbon (C) exchange between the atmosphere and terrestrial ecosystems (Schlesinger and Andrews, 2000). Therefore, an important approach to reduce CO_2 emissions into the atmosphere is to sequester C in soils (Mancinelli et al., 2010). Soil C emission into the atmosphere is thought to be controlled by factors such as, soil temperature and moisture, quantity and quality of substrate, vegetation type, microbial biomass and its activity, and field management (Curtin et al., 2000; Ding et al., 2007; Li et al., 2008). So, it is essential we fully understand the influence of these factors on soil CO_2 emission.

C storage in agro-ecosystems is very sensitive to management practices. Fertilization, especially manure application, has been identified as an essential practice apart from the functions for soil fertility and agricultural production because the amount of residue returned to soils can be increased (Zhang et al., 2009). The dynamics of C balance in a cropland ecosystem is determined by the soil heterotrophic respiration and net primary production of vegetation. An accurate calculation of the C balance of cropland systems is necessary to determine if the system is a sink or source of C under various field managements, especially manure applications (Li et al., 2010; Mancinelli et al., 2010). Whilst it is relatively straight forward to monitor the removal of economic products and residues from a cropland ecosystem, it is more difficult to estimate other components of C balance in the system, e.g. C fluxes from soils via CO_2 and residential time of organic matter added into soils through residual retention of crops and manure applications.

Upland red soil, developed from Quaternary red clay and classified as Ferralic Cambisol (FAO, 1988), covers 1.13 million km^2,

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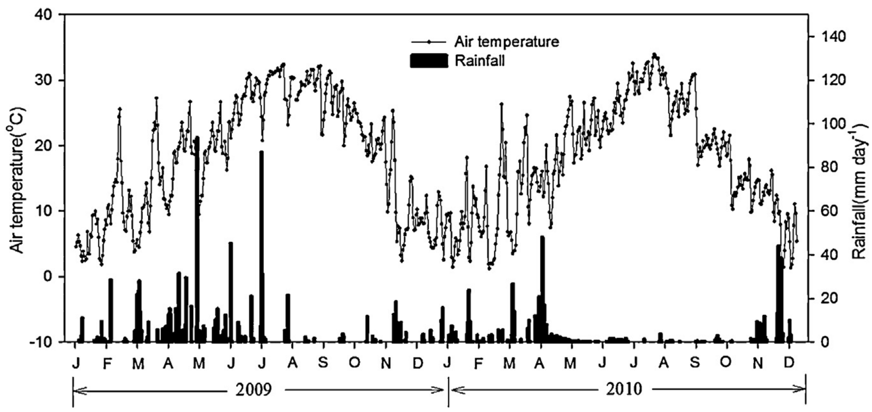

Fig. 1. Daily air temperature and rainfall at Qiyang long-term experimental site during 2009 and 2010.

accounting for 11% of the total land in China (Lu and Shi, 2000). It is a dominant soil type in southern China with subtropical monsoon climate. Under such a climate with high rainfall and temperature, the region may emit vast amounts of greenhouse gases (Yang et al., 2007). But very few reports on the measurement of soil CO_2 emission have been made. In addition, continuous fertilization experiments on cropland over decades in the region are extremely rare so that it restricts our capability to assess the impact of long-term continuous fertilization on soil CO_2 emission and C balance. Thus, the aims of this study, based on a 19-years long-term field experiment, are to (i) investigate how main environmental factors control diurnal and seasonal variations of soil CO_2 emission; (ii) identify the effect of long-term organic and inorganic fertilizer applications on soil CO_2 emissions; and (iii) estimate C sequestration potential under different fertilizer managements.

2. Materials and methods

2.1. Study site

This study was based on a long-term field experiment that has been conducted since September 1990 at the experimental station of the Chinese Academy of Agricultural Sciences, located at Qiyang (26°45′ N, 111°52′ E), Hunan Province of southern China where red soil is a dominant soil type. Annual temperature is 18 °C and annual rainfall is about 1431 mm yr^{-1}. Averaged annual evaporation is 1374 mm with a peak in July (http://cdc.cma.gov.cn).The dynamics of daily air temperature and precipitation are shown in Fig. 1. The average annual temperature in 2009 and 2010 were 18.3 and 17.8 °C, respectively. The highest temperature was found in August, and the lowest in February. Precipitation in 2009 and 2010 was 948 and 594 mm yr^{-1}, respectively. About 70% of annual precipitation fell between April and August (30% of precipitation fell in June–August) in 2009 and about 70% of annual precipitation fell between April and November in 2010. Annual accumulated temperature when the daily temperature is greater than 10 °C is ca. 5600 degree-days.

The initial soil samples were taken in the start of the long-term experiment (1990), the top soil (−20 cm) had a soil organic carbon (SOC) of 8.5 g kg^{-1}, total nitrogen (TN) of 1.1 g kg^{-1}, total phosphorus (TP) of 0.5 g kg^{-1}, total potassium (TK) of 13.3 g kg^{-1}, available nitrogen (Navs) of 79 mg kg^{-1}, available P (Pavs) of 11 mg kg^{-1}, available K (Kavs) of 122 mg kg^{-1}. Their changes during the experiment at the site are shown in Table 1. The soil in this region is quite acidic, having a pH of 5.7 (1:1, w/v, water) and low organic matter content due to intense weathering of soil minerals, rapid decomposition of soil organic matter under the warm and moist climate and less input of organic matter into the soil when the long-term experiment started. As a result, the soil had a lower C–N ratio in the top soil.

2.2. Experimental design

The cropping system is a rotation of winter wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) from the start of the experiment. Four fertilization treatments from the experiment were used in this study: non-fertilizer application (SR thereafter), inorganic nitrogen (N), phosphorus (P) and potassium (K) combination (NPK thereafter), inorganic NPK fertilizers and pig manure combination (NPKM thereafter) and pig manure alone (M thereafter). There were two replicates per treatment. Each treatment plot had an area of 196 m^2 and was isolated by 100-cm width cement baffle plates along the boundaries.

N, P and K fertilizers were urea, calcium superphosphate, and potassium chloride, respectively. The N content in pig manure was 16.7 ± 1.1 and 17.6 ± 0.9 g kg^{-1} in 2009 and 2010, respectively, using the method described by Black (1965). The C content from oven-dried manure was 382 ± 26 and 369 ± 31 g kg^{-1} in 2009 and 2010, respectively, using the method of vitriol acid-potassium dichromate oxidation (Walkley and Black, 1934). The C/N ratio of manure was 23 and 21 in 2009 and 2010, respectively. Quantities of fertilizer application for each treatment during the growing seasons are shown in Table 2. All the treatments except SR received the same amount of N (300 kg ha^{-1}) but other nutrient elements varied. In the fertilizer treatments, fertilizer and manure were applied as basal dressing for summer maize while 30% of it as basal dressing and rest as top dressing for winter wheat in mid-November.

For each experimental year, winter wheat (*T. aestivum* L.) 'Xiangmai 4' was sown in early November in previous year and harvested in early May, while summer maize (*Zea mays* L.) hybrid 'Yedan 13' was intercropped in early April, and harvested in July. Then a fallow season was followed until the next growing season of winter wheat. There are four rows of winter wheat within a strip (100 cm) and two rows of maize were between the wheat trips with a row distance of 50 cm. Crops were harvested manually by cutting straws close to the ground. Thus, stubble left in the field could be negligible. All above-ground biomass are removed from the fields. Herbicides and pesticides were applied during the growth periods whenever needed.

2.3. Soil sample analysis

Soil samples were collected from the topsoil (0–20 cm) after maize harvested each year. 5–10 cores with 5 cm in diameter were randomly sampled for each plot. Soils from the cores were mixed thoroughly and then four replicates (2 kg soil for each replicate)