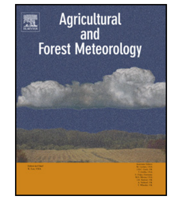
Agricultural and Forest Meteorology 180 (2013) 34–43

Contents lists available at SciVerse ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet



Seasonal variations in soil respiration, heterotrophic respiration and autotrophic respiration of a wheat and maize rotation cropland in the North China Plain

Quan Zhang, Hui-Min Lei*, Da-Wen Yang

State Key Laboratory of Hydroscience and Engineering, Department of Hydraulic Engineering, Tsinghua University, Beijing 100084, China

ARTICLE INFO

Article history:
Received 6 April 2012
Received in revised form 23 April 2013
Accepted 25 April 2013

Keywords:
Autotrophic respiration
Heterotrophic respiration
Maize
North China Plain
Soil respiration
Wheat

ABSTRACT

Determining soil respiration from croplands is necessary for evaluating the global terrestrial carbon budget and how it is altered in future climates. This study explored seasonal characteristics and controlling factors of soil respiration in a typical cropland area in the North China Plain. Total soil respiration (R_S) was partitioned into heterotrophic (R_H) and autotrophic (R_A) components using the root exclusion method. The experiments showed that the seasonal average R_S values were 5.25 μmol m^{-2} s^{-1} for the wheat growing season and 6.00 μmol m^{-2} s^{-1} for the maize growing season. Seasonal average R_H and R_A values were 3.34 μmol m^{-2} s^{-1} and 1.91 μmol m^{-2} s^{-1}, respectively, for wheat, and were 4.25 μmol m^{-2} s^{-1} and 1.75 μmol m^{-2} s^{-1}, respectively, for maize. The seasonal average ratio of R_A to R_S (R_A/R_S) was 36% for wheat and 29% for maize. Over a whole year, R_H was the dominant component of R_S in both the wheat and maize growing seasons. R_H increased exponentially with the average soil temperature collected in the upper 10 cm (T_{S0-10}), with a Q_{10} value of 1.65. Soil water content (θ) had no discernible influence on R_H when θ was between wilting point (θ_{wp}) and field capacity (θ_{fc}). A value of θ larger than θ_{fc} suppressed R_H, which can be characterized by a quadratic curve. R_A increased exponentially with T_{S0-10} in both of the wheat and maize growing seasons, and the corresponding Q_{10} values were 2.69 and 2.85, respectively. However, the temperature dependence of R_A in the two crop seasons cannot be explained by a single temperature response curve. Moreover, the R_A values for the wheat and maize growing seasons were more sensitive to temperature changes than R_H at the study site. Soil water content had no discernible influence on R_A in the wheat growing season but suppressed R_A when water logging occurred in the maize growing season. However, R_A recovered afterwards even when the soil water content was high. Comparisons between wheat respiration values collected at different sites showed that the seasonal average R_S, R_H and R_A all correlate positively with mean air temperature, indicating that air temperature remains a good indicator for variations in soil respiration in different climates.

1. Introduction

Soil is a large carbon pool containing approximately two to three times the amount of carbon in the atmosphere (Batjes, 1996; Eswaran et al., 1993; Post et al., 1982). Soil respiration is an important carbon flux between the terrestrial ecosystem and the atmosphere, estimated at 68 ± 4 Pg C yr^{-1} (Raich and Schlesinger, 1992) or 98 ± 12 Pg C yr^{-1} (Bond-Lamberty and Thomson, 2010), indicating large uncertainties in its estimation. Despite recent advancements in observational techniques, uncertainty in soil respiration estimations remains far greater than that in other components of the carbon cycle (Bond-Lamberty et al., 2004; Trumbore, 2006). To reduce this uncertainty, observations of soil respiration across ecosystem types are becoming critical, and intensive observations remain essential for developing simplified soil respiration models (Vargas et al., 2011b).

Among all of the factors controlling soil respiration, soil temperature (T_S) (Lloyd and Taylor, 1994; Raich and Schlesinger, 1992) and soil water content (θ) (Davidson et al., 2000; Manzoni et al., 2012; Mielnick and Dugas, 2000; Moyano et al., 2013) remain dominant, but their effects interact (Davidson et al., 1998; Rey et al., 2002).

Abbreviations: R_H, heterotrophic respiration; R_{HC}, temperature-corrected heterotrophic respiration; R_A, autotrophic respiration; R_S, total soil respiration; T_S, soil temperature; T_{S0-10}, average soil temperature of the upper 10 cm; T_{COM}, soil temperature at comparative treatments (with roots); T_{CON}, soil temperature at control treatments (without roots); θ, soil volumetric water content; θ_{wp}, wilting point; θ_{fc}, field capacity; θ_s, saturated soil water content; SOC, concentration of soil organic carbon; Q_{10}, temperature sensitivity coefficient of soil respiration; LAI, leaf area index; NEE, net ecosystem exchange; R_{eco}, ecosystem respiration; GPP, gross primary productivity; NCP, the North China Plain.

* Corresponding author. Tel.: +86 10 62787394; fax: +86 10 62796971.
E-mail addresses: Zhangquan09@mails.tsinghua.edu.cn (Q. Zhang), leihm@tsinghua.edu.cn (H.-M. Lei), Yangdw@tsinghua.edu.cn (D.-W. Yang).

0168-1923/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agrformet.2013.04.028

A majority of studies support that T_S controls soil respiration in an exponential manner (Kirschbaum, 1995; Lloyd and Taylor, 1994; Luo et al., 2001). Soil water content controls CO_2 production process and alters CO_2 diffusivity by altering the soil effective porosity (Daly et al., 2008, 2009; Riveros-Iregui et al., 2007). In particular, low θ limits respiration substrate availability, and therefore reduces soil respiration (e.g., Curiel Yuste et al., 2007; Talmon et al., 2011; Xu et al., 2004), while high θ reduces soil respiration by blocking CO_2 transport because of low soil effective porosity (e.g., Bowden et al., 1998; Davidson et al., 2000; Gaumont-Guay et al., 2006). In addition to T_S and θ, soil respiration is also controlled by other factors, such as the concentration of soil organic carbon (SOC) (Talmon et al., 2011; Wan and Luo, 2003) which supplies substrate to microorganism respiration, photosynthetic activity (Ekblad and Högberg, 2001; Kuzyakov and Cheng, 2001; Palmroth et al., 2006; Tang et al., 2005) which supplies substrate to root respiration, and vegetation type (Barron-Gafford et al., 2011; Raich and Schlesinger, 1992; Raich and Tufekcioglu, 2000) which regulates soil microhabitat. However, the impacts of these factors on soil respiration may vary across ecosystems in different regions. Quantitatively describing the impacts of main biotic and abiotic factors on soil respirations of different ecosystems is therefore necessary to accurately estimate soil respiration.

Carbon dioxide efflux from the soil surface into the atmosphere is defined as total soil respiration (R_S), which consists mainly of heterotrophic respiration (R_H) and autotrophic respiration (R_A) (Buchmann, 2000). Changes in R_S result from both changes in R_H and R_A, which are two completely different processes that react differently to biotic and abiotic factors (Baggs, 2006; Carbone et al., 2011; Sulzman et al., 2005). R_H originates from the decomposition of soil organic carbon and is determined mainly by SOC and the metabolic rate of organisms (Davidson et al., 2006; Jiang and Boyd, 2006). R_A originates from root metabolism, which is connected with the substrate consumption of photosynthesis (Horwath et al., 1994). R_A is therefore supposed to be dependent on the time history of photosynthetic activities (Högberg et al., 2001; Stoy et al., 2007; Vargas et al., 2011a) as well as other processes related to crop. Therefore, partitioning R_S into R_H and R_A is an ecologically meaningful step to quantify the mechanisms controlling R_S.

The carbon cycle of agro-ecosystems can significantly affect the global carbon balance (Foley et al., 2005), and soil respirations of agro-ecosystems may vary substantially around the world due to numerous types of cropland management. Soil respiration in agro-ecosystems has been studied for several decades, and recent progresses have consisted mainly of (1) partitioning R_S into R_H and R_A to explore underlying mechanisms of soil respiration (e.g., Moyano et al., 2007; Suleau et al., 2011) and (2) exploring the dependence of soil respiration on soil type, crop type and fertility management practice (e.g., Amos et al., 2005; Hernandez-Ramirez et al., 2011; Lohila et al., 2003). However, the findings from these studies were mainly derived in Europe and the USA where the cropping system and cropland management are significantly different from those employed in China where croplands comprise the third largest land use type, following forests and grasslands (Liu et al., 2005). A change in the carbon balance of croplands will unquestionably affect the carbon cycle in China.

Previous studies on soil respiration in agro-ecosystems of China were conducted mainly in the Loess Plateau (e.g., Li et al., 2010; Liu et al., 2010; Zhang et al., 2011), the Tibetan Plateau (e.g., Shi et al., 2006; Xu et al., 2010), and the Northeast China Plain (e.g., Han et al., 2007). In the North China Plain (NCP), although characteristics of soil respiration have been reported previously, only short-term observations were conducted in these studies (e.g., Chen et al., 2004; Huang et al., 2006), and only a few studies partitioned R_S into R_H and R_A for wheat (e.g., Deng et al., 2009; Zhang et al., 2009). In addition, the closed static chamber method or a gas chromatographic method was commonly used in these studies (Han et al., 2008). However, these two methods have no standard measuring protocols, and as a result, their accuracy depends on the equipment design, measurement duration, and experimental condition (Healy et al., 1996; Hutchinson and Rochette, 2003; Kabwe et al., 2002; Pumpanen et al., 2004). Because of these limitations, questions underlying the mechanisms controlling soil respiration in this region remain unanswered. Long-term measurements of R_S and its components (i.e., R_H and R_A) with new standard instruments are needed to explore the characteristics of soil respiration and their dependence on the corresponding controlling factors over long time scales.

In the present study, three years of soil respiration measurements are reported for a typical cropland area in the NCP. The main objectives of this study are to (1) quantify the seasonal variations in R_S, R_H and R_A and to (2) quantitatively investigate the responses of R_H and R_A to their dominant biotic and abiotic factors.

2. Materials and methods

2.1. Site description

Experiments were conducted in a typical cropland (Weishan flux site, N36°39′, E116°03′) in the NCP, China. The climate in this region is temperate as affected by the Asian monsoon. From 1984 to 2007, the mean annual total precipitation was 532 mm, and the mean annual air temperature was +13.3 °C. The soil texture is silt loam according to the World Reference Base (WRB), consisting of 32% sand and 10% clay. In 2011, the SOC and total nitrogen concentration were measured at 11.32 gC kg^{-1} soil and 1.16 gN kg^{-1} soil, respectively, in the upper 20 cm and were 5.71 gC kg^{-1} soil and 0.55 gN kg^{-1} soil, respectively, in the depth from 20 cm to 40 cm. For the soil of the upper 5 cm, the wilting point (θ_{wp}), field capacity (θ_{fc}) and saturated soil water content (θ_s) are 0.10, 0.33 and 0.45 $m^3\ m^{-3}$, respectively. The pH values fluctuated between 7.2 and 7.6 in 2010.

The double cropping system of winter wheat and summer maize is the farming style at this site, as well as the dominant farming style in the NCP. Winter wheat is usually sowed in October and harvested in June of the following year. The wheat residuals are smashed onto the field surface by the harvester, leaving stubble of about 10 cm high. Summer maize is sowed in June without tillage and harvested in October. Between harvesting maize and sowing wheat, a thorough plowing is conducted with a tillage depth of about 40 cm. Meanwhile, the maize residuals are completely smashed and mixed with soil through tillage. In the wheat growing season, the plant density was about 775 plants m^{-2}, with a ridge spacing of 0.24 m. In the maize growing season, the plant density was about 4.9 plants m^{-2}, with a ridge spacing of 0.63 m.

Wheat is irrigated in winter and spring when precipitation is scarce. The irrigation amount ranges from 100 mm yr^{-1} to 200 mm yr^{-1}, depending on soil water status. No irrigation is conducted in the maize growing season when precipitation is abundant. Nitrogen fertilizer is applied three to four times during the wheat growing season, and two to three times during the maize growing season. The total annual nitrogen application ranges from 50 gN m^{-2} to 60 gN m^{-2} (through our inventory from 2005 to 2011).

2.2. Experimental design

A flux tower was set up at the site (Fig. 1) in 2005. An eddy covariance system and a micrometeorological station were installed on this tower. Soil respiration was measured with a portable soil respiration system LI-8100 (LI-COR, Inc., Lincoln, NE, USA), which was calibrated regularly (i.e., once or twice per year depending on the operating frequency). The measured soil CO_2 efflux was assumed