Soil & Tillage Research 150 (2015) 139–146

Contents lists available at ScienceDirect

Soil & Tillage Research

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

Changes in temperature sensitivity of soil respiration in the phases of a three-year crop rotation system

Jishao Jiang [a,b], Shengli Guo [a,b,c,d,*], Yanjun Zhang [c], Qingfang Liu [d], Rui Wang [d], Zhiqi Wang [c], Nana Li [c], Rujian Li [c]

[a] Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resources, Yangling, Shaanxi 712100, PR China
[b] University of Chinese Academy of Sciences, Beijing 100049, PR China
[c] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Northwest A&F University, Yangling, Shaanxi 712100, PR China
[d] College of Resources and Environment, Northwest A&F University, Yangling, Shaanxi 712100, PR China

ARTICLE INFO

Article history:
Received 21 September 2014
Received in revised form 7 January 2015
Accepted 2 February 2015

Keywords:
Soil respiration
Soil temperature
Soil moisture
Winter wheat
Millet
Pea

ABSTRACT

Understanding the temperature sensitivity of soil respiration (Q_{10}) and its controlling factors plays an important role in accurately estimating soil respiration and carbon cycling in agro-ecosystems. This manuscript presents a case study on how the Q_{10} value for soil respiration changes with soil temperature and moisture in the rotation phases. In a three-year crop rotation system (wheat/wheat/millet/pea) in a semi-arid region of China, the soil respiration rate, temperature and moisture were measured under different crop phases from July 2010 to June 2013. The soil respiration rate was significantly lower in the winter wheat phase (1.63 μmol m^{-2} s^{-1}) than the millet phase (2.40 μmol m^{-2} s^{-1}) and pea phase (2.21 μmol m^{-2} s^{-1}). However, the Q_{10} value was significantly higher in the wheat phase (2.76) than in the millet phase (1.85) and pea phase (1.47). The relationship between the Q_{10} values and soil temperature followed an exponential decay function in the rotation system, and the Q_{10} value was stable (1.8) with no obvious variation when the temperature exceeded 15 °C. The Q_{10} value tended to increase with soil moisture until reaching a threshold of 14.7% soil moisture and then declined. Our results indicate that temperature-respiration empirical models should be parameterized according to crop type in the rotation phases, especially when estimating soil respiration in cold-resistant crops under global warming.

1. Introduction

Soil respiration is an important carbon flux between the terrestrial ecosystem and the atmosphere, and it plays a critical role in global carbon cycling (Cox et al., 2000; Raich and Schlesinger, 1992). Among all of the factors controlling soil respiration, soil temperature (Lloyd and Taylor, 1994; Zhang et al., 2013) and soil moisture (Davidson et al., 2000; Suseela et al., 2012) remain dominant, and their effects may interact (Davidson et al., 1998). Understanding the response of soil respiration to temperature change is important for predicting possible feedback between the global carbon cycle and climate system (Davidson et al., 2006) and improving C cycle models (Del Grosso et al., 2005).

Numerous temperature-response functions have been developed (Janssens and Pilegaard, 2003), but the Q_{10} function is the most widely used in simulations of temperature sensitivity (Hoff, 1899). The Q_{10} value for soil respiration is the factor by which soil respiration increases with a 10 °C increases in temperature (Raich and Schlesinger, 1992). Numerous terrestrial carbon models, such as the Century, PnET, and Roth-C models, assume that Q_{10} is constant (2); however, there is increasing evidence suggesting that Q_{10} does not remain constant but tends to increase with decreasing soil temperature and increasing moisture (Janssens and Pilegaard, 2003; Kirschbaum, 1995; Qi and Xu, 2001; Schleser, 1982). Unfortunately, studies on the effects of soil temperature and moisture on Q_{10} were focused on forest ecosystems (Janssens and Pilegaard, 2003; Kirschbaum, 1995; Qi and Xu, 2001,b; Chen et al., 2010a,b; Luan et al., 2013), and limited information is available on Q_{10} in agro-ecosystems, especially in crop rotation systems.

* Corresponding author at: Institute of Soil and Water Conservation, Xinong Road 26, Yangling, Shaanxi 712100, PR China. Tel.: +86 29 87012411; fax: +86 29 87012210.
E-mail address: slguo@ms.iswc.ac.cn (S. Guo).

http://dx.doi.org/10.1016/j.still.2015.02.002

Crop rotation is a significantly beneficial practice for agriculture because it minimizes soil erosion, improves water use efficiency (Huang et al., 2003b; Toillon et al., 2013), improves soil C sequestration (Bell et al., 2012; Bolinder et al., 2010), and maintains high yields (Drury et al., 2004; Huang et al., 2003b), particularly in rain-fed farming regions. Two or three crop types are selected for the rotation cycle based on their different planting and harvesting dates, physiological properties, and demand for water and nutrients (Huang et al., 2003b). By alternating crop types, root and plant residues, the ratio between the above- and below-ground biomass (Govaerts et al., 2007), as well as soil nutrition (Huang et al., 2003b; Li et al., 2011) varies quantitatively and qualitatively. More importantly, soil temperature and moisture vary greatly among different crop types because of differences in the growth characteristics. For example, cold-resistant crops such as wheat and potato grow at low temperatures, whereas thermophilic crops such as maize, prosomillet and millet grow at high temperatures. Overall, changes in these factors can eventually alter the soil respiration rates and Q_{10} values of different cropping phases in a rotation system. However, no information is available on the variations of Q_{10} or the relationships between Q_{10} and soil temperature and moisture under different cropping phases in a rotation system.

The objectives of this study were to (1) quantify the variations in soil respiration rates and Q_{10} values, (2) examine the variations in the soil temperature and moisture during different rotation phases, and (3) explore the relationships between the Q_{10} values and soil temperature and moisture in a wheat/wheat/millet/pea (W/W/M/P) rotation system in the semiarid Loess Plateau, China.

2. Materials and methods

2.1. Site description

In the Loess Plateau, China, the area of arable land is 14.5×10^4 km^2, and more than 70% of the crops are planted in rain-fed land, which is highly susceptible to climate change impacts (Wang et al., 2013). This region has an annual rainfall of less than 600 mm, and over 60% of the annual precipitation falls during summer (Huang et al., 2003b). Because of the distribution of the precipitation, bare soil is at risk of erosion from heavy rainstorms (Kang et al., 2001) and there is insufficient water supply in the planting season after summer (Huang et al., 2003a). Considering the high risk of soil erosion and the importance of soil water in the planting season, wheat monoculture is not a sustainable management practice in the region (Huang et al., 2003a). Crop rotation practices in the Loess Plateau are beginning to replace winter wheat monoculture.

A long-term field experiment was established in September 1984 at the State Key Agro-Ecological Experimental Station in the Loess Plateau (35°12′N, 107°40′E; 1220 m.a.s.l.) in Changwu County, Shaanxi Province, China. The study area is representative of a typical rain-fed farming region and is characterized by a semiarid continental monsoon climate, with a mean annual rainfall of 560 mm (1984–2013). The wettest period is July–September, the driest period is May–June, and light precipitation is common during December and January. The open pan evaporation is 1440 mm. The mean annual temperature is 9.4 °C, but the average air temperature is 19.4 °C during July and September. All meteorological data were obtained from the Changwu Meteorological Station, which is 200 m from the experimental site. The daily mean air temperature and precipitation data during the study (July 2010–June 2013) are presented in Fig. 1.

The soil at the site is a loam (Cumulic Haplustoll; USDA Soil Taxonomy System) that developed from loess deposits; it contains 24% clay (<0.002 mm), 10.5% $CaCO_3$, 6.5 g kg^{-1} organic C, and 0.80 g kg^{-1} total N. The soil has a field water-holding capacity (WHC) of 0.29 cm^3 cm^{-3}, a pH of 8.4 (1:1 soil:H_2O suspension), and a bulk density of 1.3 Mg m^{-3} of the top soil layer (0–20 cm).

2.2. Experimental design and crop management

One three-year rotation system from the long-term field experiment was chosen for its regionally representative crop types, i.e., winter wheat (*Triticum aestivum* L., cv. 'Changwu 89 (1) 3–4′), millet (*Panicum miliaceum*, a local cultivar), pea (*Pisum sativum* L., a local cultivar). To explore the effect of each cropping phase on the soil respiration and Q_{10} values, three treatments were devised with different crop sequences: wheat/millet/pea/wheat (W/M/P/W), millet/pea/wheat/wheat (M/P/W/W) and wheat/wheat/millet/pea (W/W/M/P). Detailed information on the cropping system is given in Fig. 2. To determine the effects of previous crops on the soil respiration and Q_{10} values, we separated the winter wheat phases into a P–wheat phase (where the previous crop is peas) and a W–wheat phase (where the previous crop is wheat).

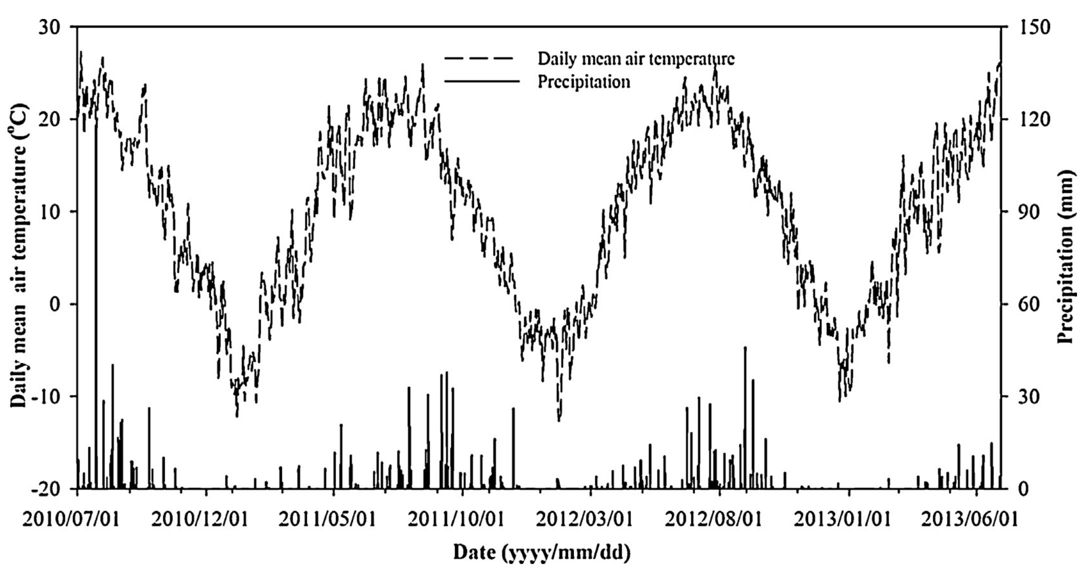

Fig. 1. Seasonal air temperature and precipitation during the study.