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Effects of crop types and nitrogen fertilization on temperature sensitivity of soil respiration in the semi-arid Loess Plateau

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ABSTRACT

Temperature sensitivity of soil respiration (Q_{10}) is an important mechanism for the possible feedback between global carbon cycle and climate system. Knowledge of how crop types and nitrogen (N) fertilization affect Q_{10} is critical for estimating soil respiration and carbon cycling in agro-ecosystem. A two-year field experiment was conducted with cold-resistant (winter wheat; *Triticum aestivum* L.) and thermophilic (spring maize; *Zea mays* L.) crops at two N fertilization levels (no fertilization (CK) and 160 kg N hm^{-1}) from October 2013 to September 2015 in semi-arid Loess Plateau. Annual mean soil respiration and Q_{10} in maize were 20% (1.85 *vs.* 1.54 μmol m^{-2} s^{-1}) and 36% (2.49 *vs.* 1.83) higher than that in wheat. Nitrogen fertilization resulted in a 35% increase in annual mean soil respiration (1.95 *vs.* 1.44 μmol m^{-2} s^{-1}) and a 11% decrease in Q_{10} (2.05 *vs.* 2.28) compared with the CK treatment. Soil respiration was positively related to root biomass, whereas no significant relationship was found between root biomass and Q_{10}. Therefore, it can be concluded that soil respiration and temperature sensitivity of soil respiration are significantly influenced by crop types and N fertilization regimes, which should be considered in calculating carbon budget in agro-ecosystem using carbon models.

1. Introduction

Temperature sensitivity of soil respiration (often measured as Q_{10}) is regarded as an important mechanism for the possible feedback between global carbon cycle and climate system (Houghton et al., 1998; Huntingford et al., 2000). Q_{10} values differ significantly across ecosystems (Peng et al., 2009), estimated Q_{10} values ranged from 1.56 to 2.70 among grassland, forest and agro-ecosystem (Chen et al., 2010b), and in agro-ecosystem, the Q_{10} value appears to depend critically on agronomic management practices. Thus, knowledge of the variation of Q_{10} values with agronomic management practices is essential for accurately estimating soil respiration and carbon cycling in agro-ecosystem.

However, most previous studies in this field have focused solely on the impacts of agronomic management practices for a single crop type or rotation system. Critical to the success of agronomic management practices is the proper choice of crop types and fertilization regimes, especially in rain-fed agricultural areas, both of which have a significant effect on the soil environment (Huang et al., 2003; Jiang et al., 2015a), crop growth (Jiang et al., 2015a), root growth and morphology (Pregitzer et al., 2000b), and substrate quantity and quality (Leifeld and Von Lutzow, 2014). Soil respiration under cold-resistant crops was more sensitive to temperature changes compared with that under thermophilic crops (Jiang et al., 2015a). Above- and below-ground biomass, as well as the ratio between them, varied significantly among crops (Govaerts et al., 2007) and fertilization practices (Pregitzer et al., 2000a,b). In addition, plant species could also influence substrate quantity and quality (Fissore et al., 2008). To sum up, all of these factors can have a significant influence on the temperature sensitivity of soil respiration (Iqbal et al., 2010; Xu and Qi, 2001; Jiang et al., 2015a; Xu et al., 2015).

Soil environment (soil temperature and moisture) has been shown to be the major factor influencing soil respiration (Davidson and Janssens, 2006). The relationship of soil temperature and

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moisture with soil respiration is usually fitted by an exponential function (Hoff, 1899) and a quadratic regression function (Zhang et al., 2014), respectively. Previous studies have demonstrated that Q_{10} increased with the increase of below-ground root system (Hertel et al., 2009; Wang et al., 2015; Wu et al., 2014). A higher above-ground biomass allowed the allocation of more photosynthetic product to roots, thus resulting in an increase in Q_{10} (Millenaar et al., 2000). Q_{10} also varied with the quantity and quality of soil organic matter (SOM) (Conant et al., 2011, 2008; Karhu et al., 2010). In addition, N fertilization also influenced Q_{10} by means of root exudation, fine root biomass, and the C:N ratio in the soil (Pregitzer et al., 2000b; Leifeld and Von Lutzow, 2014).

However, conclusive evidence is still lacking as to the effect of soil environment, crop growth, root properties and substrate quantity and quality on Q_{10} under different crop types and fertilization regimes (Annunziata et al., 2013; Fan et al., 2015; Mazzoncini et al., 2011). We hypothesized that crop types and fertilization regimes affected all of these factors, which in turn affected the temperature sensitivity of soil respiration in the semi-arid Loess Plateau. In this study, we measured soil respiration, soil temperature and moisture, and above- and below-ground biomass in wheat and maize systems in the semi-arid Loess Plateau from October 2013 to September 2015. The main purposes of this study were to determine: 1) the difference in temperature sensitivity of soil respiration between different crop types (cold-resistant and thermophilic crops) and N fertilization regimes (no fertilization and 160 kg N hm^{-1}) and 2) factors influencing the temperature sensitivity of soil respiration.

2. Materials and methods

2.1. Site description

The arable land is estimated to be about 145,000 km^2 in the Loess Plateau, and more than 70% of crops are planted in rain-fed areas and thus are particularly susceptible to climate change (Jiang et al., 2015a; Wang et al., 2013). The study site is located in Wangdonggou (35°13′N, 107°40′E; 1220 m a.s.l), Changwu Country, Shaanxi Province, China (Fig. 1). It is a typical tableland-gully region in the southern Loess Plateau in the middle reaches of the Yellow River. It has a continental monsoon climate characterized by hot summers and cold winters. In the study area, the annual mean precipitation is 560 mm, 60% of which occurs between July and September; the annual mean air temperature is 9.4 °C, and ≥10 °C accumulated temperature is 3029 °C; the annual sunshine duration is 2230 h with a total radiation of 484 kJ cm^{-2}, and frost-free period is 171 days. All meteorological data were provided by Changwu State Key Agro-Ecological Experimental Station (Fig. 2).

The soil is a uniform loam of loess deposits belonging to Cumulic Haplustolls according to American Soil Classification System and originated from parent material of calcareous loess. Soil samples collected at 0–20 cm depth in 2013 are characterized by: pH 8.3 (1:1 soil/H_2O suspension), clay content (<0.002 mm) 24%, field capacity 22.4%, permanent wilting point 9.0%, $CaCO_3$ 10.5%, SOC 6.5 g kg^{-1}, and total soil N 0.80 g kg^{-1}.

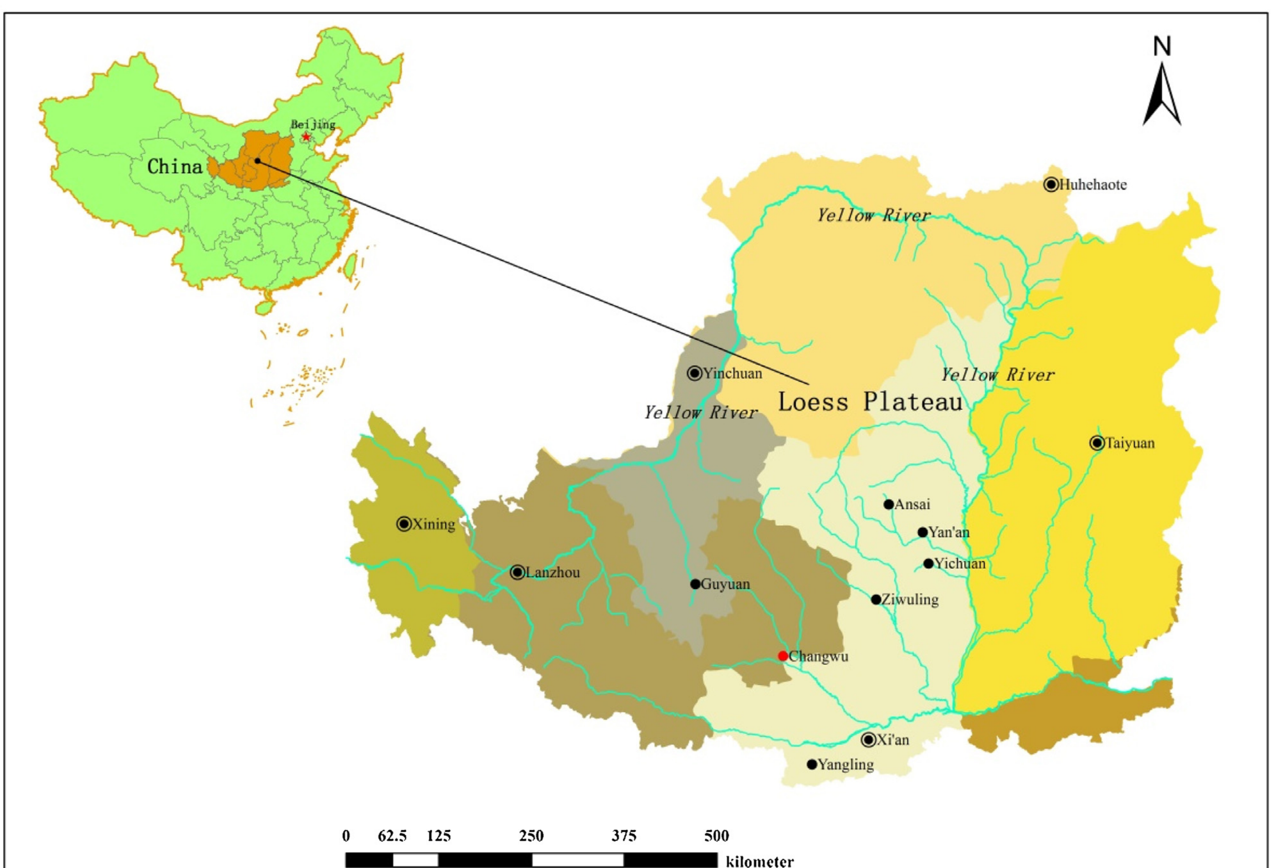

Fig. 1. A sketch map of the Loess Plateau.

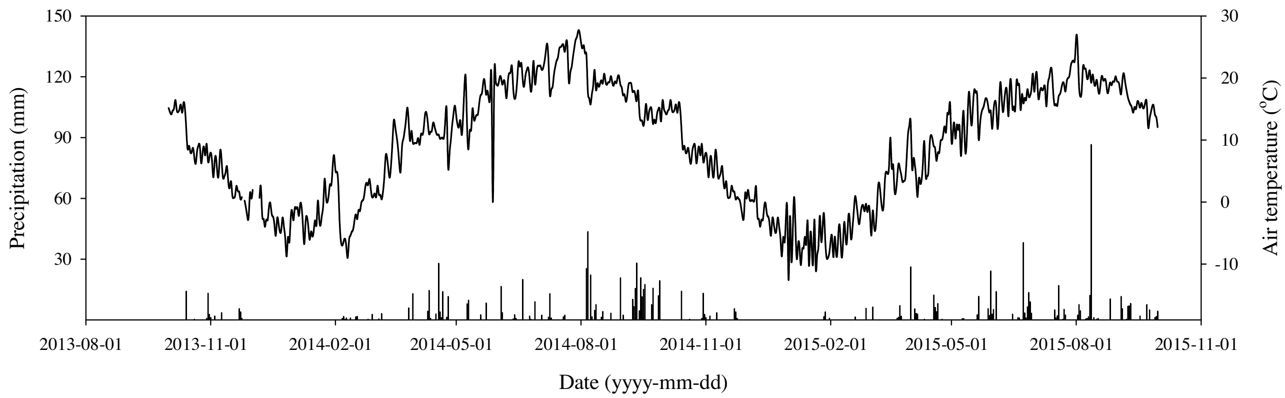

Fig. 2. Variation of precipitation (mm) and air temperature (°C) during the experiment period from 2013 to 2015.

2.2. Experimental design

The experiment field had been cropped with winter wheat and spring maize for at least 5 years before 2013. A two-year field experiment was conducted with cold-resistant (winter wheat) and thermophilic (spring maize) crops at two N fertilization levels (no fertilization (CK) and 160 kg N hm^{-1}). All treatments were arranged in a randomized block design with three replicates per treatment. Each plot was 18 m by 5.5 m and spaced 0.5 m apart, and the blocks were separated by a 1.0 m strip. Chemical N fertilizer (urea, 46.0% N) and triple super phosphate (46% P_2O_5, 39 kg P ha^{-1} yr^{-1}) were applied to the plots by top-dressing and then incorporated 5–7 days prior to sowing.

Tillage was performed to prepare the seed bed prior to sowing. Winter wheat (*Triticum aestivum* L., cv. Changwu 89 (1) 3–40) was planted in September, in 20 cm wide rows at a seeding rate of 150 kg ha^{-1}; and spring maize (*Zea mays* L., cv. Pioneer, 335) was planted in late April in 60 cm wide rows at 57,000 seeds ha^{-1}. Weeds were removed manually and plant protection measures were applied as required. There were no severe pest problems because of the high-altitude of the Loess Plateau. Winter wheat and spring maize were harvested manually by cutting close to the ground in late June and late September, respectively, and all harvested biomass was removed from the plots at physiological maturity each year.

2.3. Measurements of soil respiration, soil temperature and moisture

Soil respiration was measured using an automated soil CO_2 flux system equipped with a portable chamber of 20 cm in diameter (Li-8100, Lincoln, NE, USA). All visible living organisms were artificially removed prior to the measurement. At least two measurements were taken for each plot, with a 90 s enclosure period and a 30 s delay between the measurements, and the average of the two measurements was taken as the soil respiration. However, if the variation between these two measurements was larger than 15%, one or more measurements were taken until the variation was less than 15%. The field measurement was performed from 09:00 am to 11:00 am (Iqbal et al., 2010) every 15 days from October 2013 to September 2015, except in the period from December to February in which measurement was taken once a month due to cold weather. Soil bulk density at 0–20 cm depth was measured using a cutting ring (5 cm in both depth and diameter) (Li et al., 2006).

Soil temperature and moisture at 5-cm depth were measured (3 and 4 replicates per collar, respectively) in different directions at a distance of 10 cm away from the collar at the same time as the soil respiration measurement using a Li-Cor thermocouple probe and a Theta Probe ML2X with an HH2 moisture meter (Delta-TDevices, Cambridge, England), respectively. Soil water-filled pore space (WFPS) was calculated by the following equation (Ding et al., 2007):

$$\text{WFPS } (\%) = [\text{volumetric water content}/100 \times (2.65 - \text{soil bulk density})/2.65] \quad (1)$$

2.4. Grain yield, above- and below-ground biomass

Maize and wheat were manually harvested at their physiological maturity in a 16 m^2 area at the center of each plot. Samples were dried at 60 °C for 48 h to a constant weight to determine the above-ground biomass. To minimize root heterogeneity, six soil cores (0–20 cm) were taken in each plot (three cores at the middle of two rows, and the other three cores at rows) using a sharp iron tube (9 cm in diameter), and mixed well for the measurement of root biomass. Roots were separated from soils by soaking in water and gentle washing over a 0.25 mm mesh. Wet roots were oven dried at 60 °C for 48 h to a constant weight.

2.5. Data analysis

A univariate exponential function model was used to characterize the relationship between soil respiration and soil temperature (Davidson et al., 1998):

$$y = \beta_0 e^{\beta_1 x} \quad (2)$$

where y is the measured soil respiration (μmol m^{-2} s^{-1}), x is the measured soil temperature (°C) at a certain depth, and β_0 and β_1 are constants fitted by the least squares method.

The Q_{10} values were calculated by Eq. (3) (Xu and Qi, 2001):

$$Q_{10} = e^{10\beta_1} \quad (3)$$

Data (mean ± SD, $n = 3$) were subjected to ANOVA, followed by an LSD test for post hoc comparisons of means. Statistical significance was defined as $P \leq 0.05$. The seasonal soil respiration rate and the variance of cumulative respiration were analyzed using mixed and general linear models, respectively; and the relationship between soil respiration and temperature was determined by regression analysis. All analyses were performed using SAS software.

3. Results

3.1. Environment conditions

Soil temperature at 5-cm depth in different crops and fertilization treatments showed very similar seasonal and annual

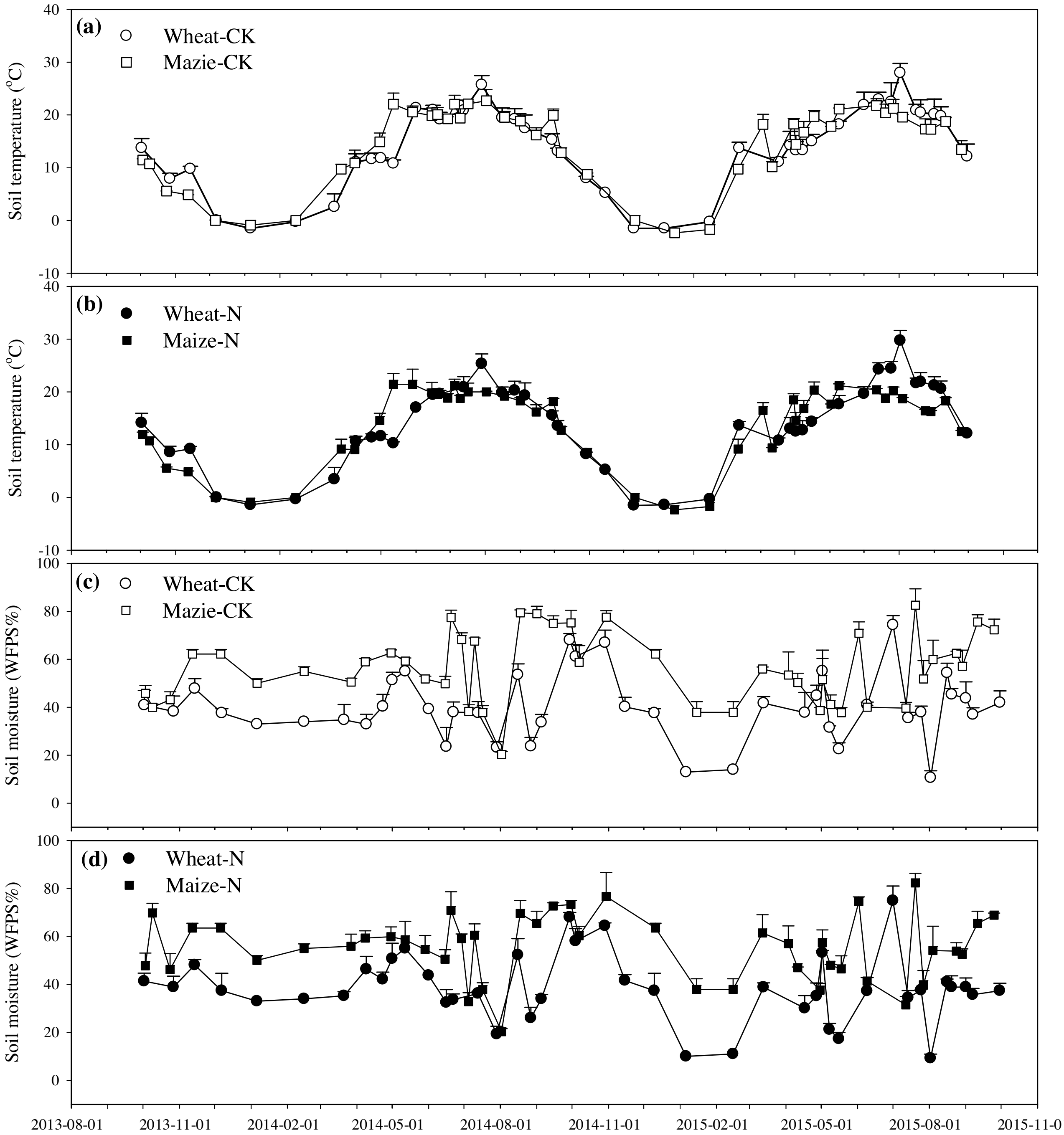

Fig. 3. Variation of soil temperature (°C) and soil moisture (%WFPS) during the experiment period from 2013 to 2015.

Table 1
Soil respiration and temperature sensitivity of soil respiration under different cropping systems and N fertilization treatments.

Treatment	2013–2014				2014–2015			
	Total	Growing	Fallow	Q_{10}	Total	Growing	Fallow	Q_{10}
Wheat								
CK	1.32 ± 0.68b	1.19 ± 0.65b	1.62 ± 0.73a	1.84 ± 0.07	1.26 ± 0.74b	1.18 ± 0.89b	1.37 ± 0.46a	1.97 ± 0.09
N	1.74 ± 9.80a	1.64 ± 0.89a	1.97 ± 0.53b	1.78 ± 0.05	1.83 ± 0.96a	1.77 ± 1.13a	1.92 ± 0.72b	1.73 ± 0.12
Maize								
CK	1.56 ± 0.82b	2.06 ± 0.56b	0.91 ± 0.62b	2.61 ± 0.45	1.62 ± 1.03b	2.12 ± 1.09b	0.99 ± 0.66b	2.68 ± 0.59
N	2.03 ± 1.06a	2.61 ± 0.81a	1.29 ± 0.88a	2.35 ± 0.41	2.16 ± 1.08a	2.71 ± 1.41a	1.37 ± 0.92a	2.29 ± 0.41

variations (Fig. 3a and b), which was in good agreement with the variation of air temperature. The lowest soil temperature was recorded in spring and winter, whereas the highest one was recorded in summer. The mean soil temperature in wheat and maize was 12.85 °C and 14.34 °C from October 2013 to September 2014 (referred to as Y_1 for convenience), and 14.13 °C and 13.71 °C from October 2014 to September 2015 (referred to as Y_2 for convenience) in the CK treatment; and 12.71 °C and 13.82 °C in Y_1, and 14.29 °C and 13.26 °C in Y_2 in the N fertilization treatment, respectively.

Soil moisture at 0–5 cm depth fluctuated significantly in response to the irregular rainfall (Fig. 3c and d). Annual mean soil moisture in wheat and maize was 39% and 57% WFPS in Y_1, and 40% and 53% WFPS in Y_2 in the CK treatment; and 40% and 56% WFPS in Y_1, and 37% and 52% WFPS in Y_2 in the N fertilization treatment, respectively.

3.2. Effects of crop type on soil respiration and Q_{10}

There was a significant difference in the soil respiration rate (Tables 1 and 2) and Q_{10} (Figs. 4 and 5) between the two crop types. The annual mean soil respiration rate in maize was 20% higher than that in wheat (1.85 *vs.* 1.54 μmol m^{-2} s^{-1}), with an increase of 18% in Y_1 (1.80 *vs.* 1.53 μmol m^{-2} s^{-1}) and 22% in Y_2 (1.89 *vs.* 1.55 μmol m^{-2} s^{-1}), respectively. However, it is important to noted that in the growing season, it was increased by 63% (2.37 *vs.* 1.45 μmol m^{-2} s^{-1}), with an increase of 65% (2.34 *vs.* 1.42 μmol m^{-2} s^{-1}) in Y_1 and 61% (2.39 *vs.* 1.48 μmol m^{-2} s^{-1}) in Y_2, respectively; whereas in the fallow season, it was decreased by 34% (1.14 *vs.* 1.73 μmol m^{-2} s^{-1}), with a decrease of 39% in Y_1 (1.10 *vs.* 1.80 μmol m^{-2} s^{-1}) and 28% in Y_2 (1.18 *vs.* 1.65 μmol m^{-2} s^{-1}), respectively. The maximum soil respiration was recorded in May in wheat and July in maize, respectively (Fig. 4).

The temperature sensitivity of soil respiration in maize (mean: 2.49; range: 2.29–2.61) was 36% higher than that in wheat (mean: 1.83; range: 1.73–1.91). Specifically, Q_{10} was 1.81 in Y_1 and 1.85 in Y_2 in wheat, and 2.48 in Y_1 and 2.49 in Y_2 in maize (Tables 1 and 3 and Fig. 5), respectively.

3.3. Effects of N fertilization on soil respiration and Q_{10}

Nitrogen fertilization resulted in a significant increase in soil respiration rate (Tables 1 and 2), as the mean annual soil respiration under N fertilization (1.95 μmol m^{-2} s^{-1}) was 35% higher than that in the CK treatment (1.44 μmol m^{-2} s^{-1}). In addition, the mean annual soil respiration was increased by 34% (2.19 *vs.* 1.64 μmol m^{-2} s^{-1}) in the growing season, with an increase of 31% (2.13 *vs.* 1.63 μmol m^{-2} s^{-1}) in Y_1 and 36% (2.24 *vs.* 1.65 μmol m^{-2} s^{-1}) in Y_2, respectively. In a similar vein, it was increased by 33% (1.64 *vs.* 1.23 μmol m^{-2} s^{-1}) in the fallow season, with an increase of 28% (1.63 *vs.* 1.27 μmol m^{-2} s^{-1}) in Y_1 and 39% (1.65 *vs.* 1.19 μmol m^{-2} s^{-1}) in Y_2, respectively.

However, N fertilization resulted in a decrease of 11% in Q_{10} (range: 3–15%) (Tables 1 and 3). In wheat, Q_{10} was 1.84 and 1.78 in Y_1, and 1.97 and 1.73 in Y_2 in the CK and N fertilization treatment; while in maize, it was 2.61 and 2.07 in Y_1, and 2.33 and 2.01 in Y_2 in the CK and N fertilization treatment, respectively. These results clearly suggested a negative correlation between Q_{10} values and N fertilization levels.

3.4. Effects of crop type and N fertilization on the grain yield, above-ground biomass and fine root biomass

The grain yield (2.93 *vs.* 8.90 t ha^{-1}), above-ground biomass (7.17 *vs.* 17.0 t ha^{-1}) and fine root biomass (1.71 *vs.* 2.33 t ha^{-1}) in maize were significantly higher than that in wheat (all $P < 0.05$) (Tables 4 and 5).

N fertilization resulted in a significant increase in the grain yield (2.13 *vs.* 9.18 t ha^{-1}; $P < 0.05$), above-ground biomass (5.45 *vs.* 18.68 t ha^{-1}; $P < 0.05$) and root biomass (1.69 *vs.* 2.32 t ha^{-1}; $P < 0.05$) (Tables 4 and 5).

4. Discussion

4.1. Soil respiration and Q_{10} in the Loess Plateau

In this study, the annual soil respiration ranged from 1.10 to 2.24 μmol m^{-2} s^{-1} with a mean of 1.70 μmol m^{-2} s^{-1}, which was within the range of soil respiration for global cropland (0.47–4.16 μmol m^{-2} s^{-1}) reported in a meta-analysis (Chen et al., 2010a). However, the mean soil respiration in wheat and maize (1.54 and 1.85 μmol m^{-2} s^{-1}) was much lower than that (5.25 and 6.00 μmol m^{-2} s^{-1}) in the temperate North China Plain (Zhang et al., 2013), which could be attributed to the poor soil properties such as low SOC content (6.5 g kg^{-1} in this study *vs.* 11.3 g kg^{-1} in Zhang et al. (2013)) and limited water supply in the semi-arid Loess Plateau. The Q_{10} values in this study ranged from 1.81 to 2.49, which were also within the range of global Q_{10} values (mean: 2.4; range: 1.3–3.3) (Raich and Schlesinger, 1992). The average Q_{10} value (2.16) was close to that of croplands (2.25 ± 0.28) in China (Peng et al., 2009).

4.2. Effect of crop type and fertilization on soil respiration

Our results clearly demonstrated that crop type had a significant influence on soil respiration. The mean annual soil respiration and mean soil respiration in the growing season were higher in maize than that in wheat; while the opposite was observed for that in the fallow season (Table 1). This may be related to the difference in photo-thermal characteristics, especially the fallow duration, between maize and wheat. The fallow period of wheat cropping system is from July to September during which both temperature and precipitation are high; while that of maize cropping system is from October to next April during which both temperature and precipitation are low in the Loess Plateau. In the

Table 2
Mean soil respiration under different cropping systems and N fertilization treatments.

Treatment	2013–2014			2014–2015			Mean		
	Total	Growing	Fallow	Total	Growing	Fallow	Total	Growing	Fallow
Cropping system									
Wheat	1.53 ± 0.30b	1.42 ± 0.32b	1.80 ± 0.23a	1.55 ± 0.40b	1.48 ± 0.42b	1.65 ± 0.39a	1.54	1.45	1.73
Maize	1.80 ± 0.33a	2.34 ± 0.39a	1.10 ± 0.25b	1.89 ± 0.38a	2.39 ± 0.23a	1.18 ± 0.27b	1.85	2.37	1.14
Fertilization									
CK	1.44 ± 0.17b	1.63 ± 0.62b	1.27 ± 0.50b	1.44 ± 0.25b	1.65 ± 0.18b	1.18 ± 0.27b	1.44	1.71	1.23
N	1.89 ± 0.21a	2.13 ± 0.69a	1.63 ± 0.48a	2.00 ± 0.23a	2.24 ± 0.66a	1.65 ± 0.39a	1.95	2.19	1.64

Different letters indicate significant differences at $P < 0.05$, unit: μmol m^{-2} s^{-1}.

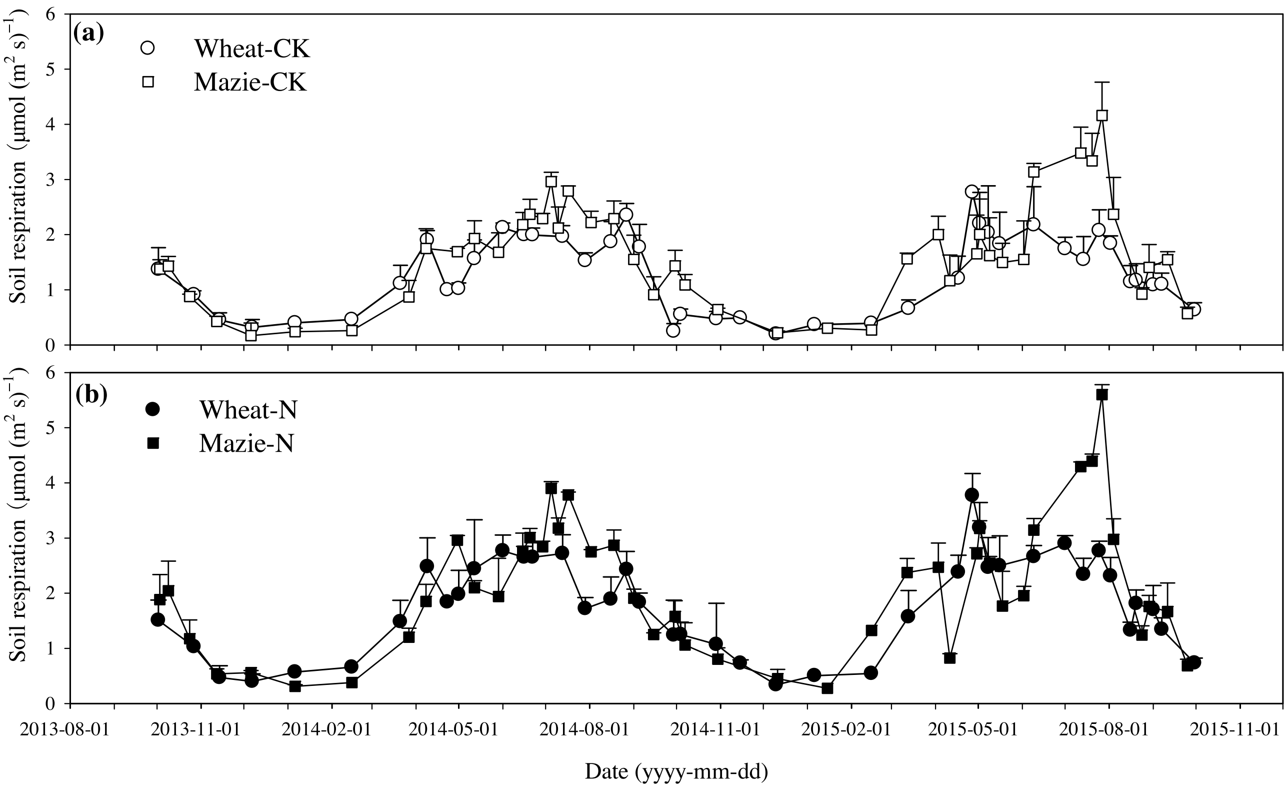

Fig. 4. Dynamics of soil respiration ($\mu mol\,m^{-2}\,s^{-1}$) from 2013 to 2015 in wheat and maize systems under different N fertilization treatments in the semi-arid Loess region.

fallow season, the soil respiration in wheat was 47% higher than that in maize (1.73 *vs.* 1.18 $\mu mol\,m^{-2}\,s^{-1}$), and the cumulative soil respiration accounted for 32% and 34% of the annual cumulative soil respiration in wheat and maize, respectively. This necessitates the use of appropriate agronomic management to adjust soil respiration, especially in wheat cropland where the mean soil respiration in the fallow season (1.73 $\mu mol\,m^{-2}\,s^{-1}$) was 12% higher than the mean annual soil respiration (1.54 $\mu mol\,m^{-2}\,s^{-1}$). Rotation of maize with another crop resulted in a reduction in the bare soil period and the compensation of soil C loss by net C assimilation from the cover crop (Ceschia et al., 2010). Therefore, rotation of wheat with a crop growing from July to September may have the potential to reduce C losses in wheat cropland in the Loess Plateau.

N fertilization is a common practice to improve soil fertility and crop yield in the Loess Plateau where there is a low soil N level. However, the effect of N fertilization on soil respiration remains controversial. Some studies have shown that N fertilization resulted in an increase in plant growth and consequently the translocation of C to the root system either as exudates for microbial respiration or as root respiration (Craine et al., 2001; Song and Zhang, 2009; Deng et al., 2010; Kou et al., 2007). However, some other studies have shown that N fertilization resulted in a reduction in soil respiration (Cardon et al., 2001; Giardina et al., 2004). In our study, soil respiration was increased by 30–45% under N fertilization treatment (Table 1).

Root biomass has been shown to have a significant effect on the soil respiration (Wang et al., 2015; Verlinden et al., 2013). In our study, root biomass was 36% higher in maize than that in wheat (2.33 *vs.* 1.71 $t\,ha^{-1}$). Maize (C4 plant) has a higher photosynthetic activity than wheat (C3 plant), thus resulting in a higher biomass and the allocation of more photosynthetic products to roots, and consequently an increase in soil respiration (Suyker et al., 2005; Kuzyakov and Cheng, 2001). In addition, root biomass was 37% higher in the N fertilization treatment than that in the CK treatment (2.32 *vs.* 1.69 $t\,ha^{-1}$), because N fertilization improved soil nutrients and crop growth, as well as root exudation and biomass production (Pregitzer et al., 2000a,b). There was a significant positive correlation between soil respiration and root biomass for all treatments (Fig. 6(a)), indicating that root growth contributed to soil respiration. In addition, given the significant influence of temperature on the root activity (Zhang et al., 2013; Kuzyakov and Gavrichkova, 2010), the difference in temperature in the growing season may be another reason for the difference in soil respiration between maize and wheat.

4.3. Effect of crop type and fertilization on Q_{10}

Temperature sensitive of soil respiration was influenced not only by crop type but also by N fertilization (Table 2). Similar to soil respiration, Q_{10} was 36% higher in maize than that in wheat. However, Q_{10} was decreased by 11% in N unfertilized soils against unfertilized soils, which was in agreement with previous studies (Jiang et al., 2015b). Soil respiration showed a positive linear correlation with root biomass (Fig. 6(a)) However, although no significant correlation was noted between Q_{10} and root biomass, Q_{10} increased significantly with increasing root biomass in the CK and N fertilization treatments separately, indicating that Q_{10} was effected by root biomass and changes in substrate quantity and quality due to N fertilization. The mechanism may be related to the enzyme-kinetic hypothesis, which predicts that the degradation of low-quality substrate has a higher temperature sensitivity than simple substrate because it requires higher total activation energy to fully mineralize substrate (Bosatta and Agren, 1999). The energetic costs of N assimilation could be greatly reduced with a larger dose of N readily available for uptake (Bowden et al., 2004).

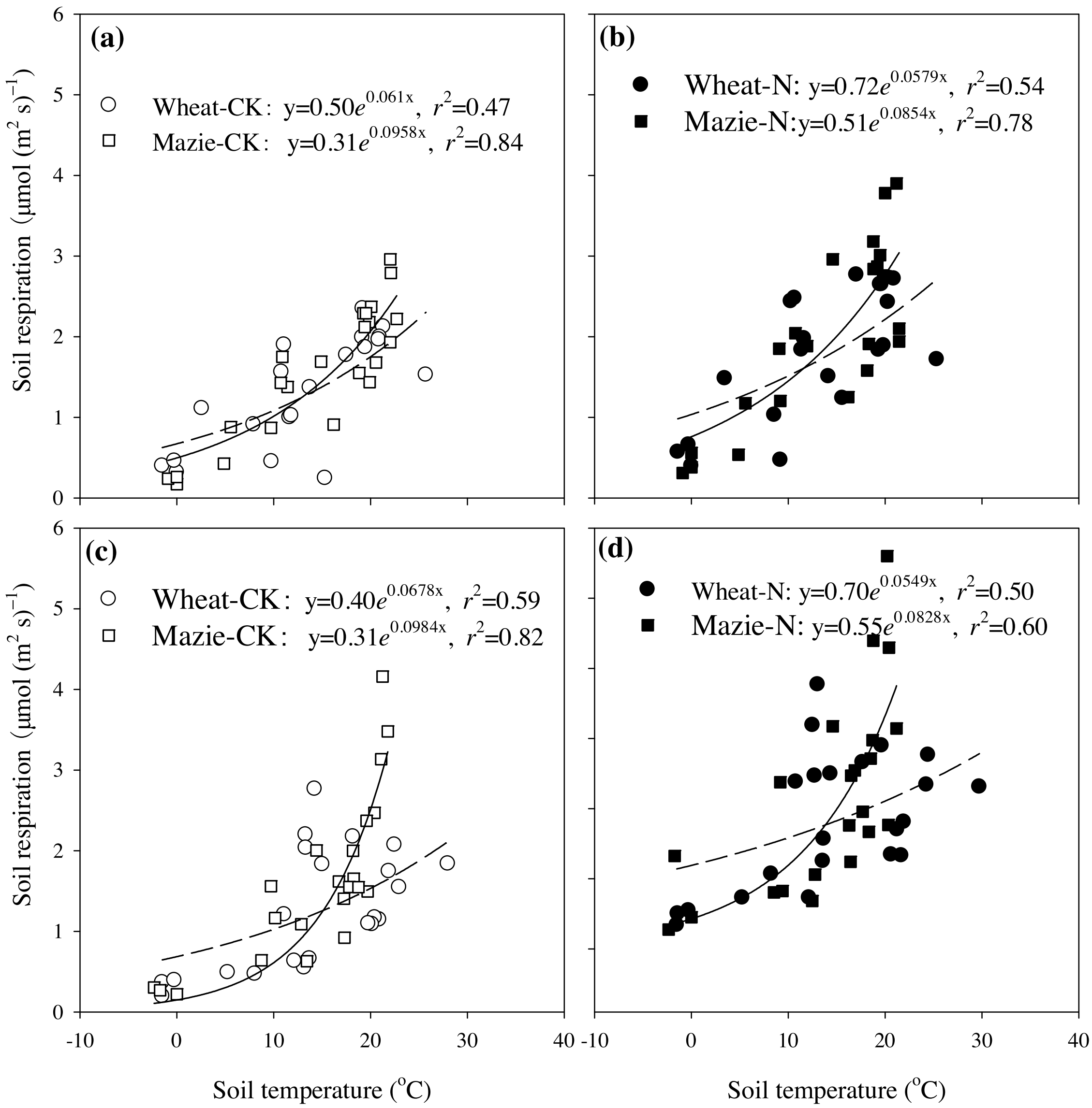

Fig. 5. Relationship between soil respiration (μmol m^{-2} s^{-1}) and soil temperature (°C) at 5-cm depth.

Thus, the increase in the N uptake by crops reduced the C: N ratio in the root residues and crop litter, which were easily mineralized and thus less energy was required for chemical and microbial decomposition (Leifeld and Von Lutzow, 2014). N fertilization also contributed to the decomposition of easily degradable SOC (Van Veen et al., 1989).

Table 3
Mean temperature sensitivity of soil respiration (Q_{10}) under different cropping systems and N fertilization treatments.

Treatment	Year		Mean
	2013–2014	2014–2015	
Cropping system			
Wheat	1.81 ± 0.04b	1.85 ± 0.17b	1.83
Maize	2.48 ± 0.18a	2.49 ± 0.28a	2.49
Fertilization			
CK	2.23 ± 0.45a	2.33 ± 0.50a	2.28
N	2.07 ± 0.40b	2.01 ± 0.40b	2.04

Different letters indicate significant differences at $P < 0.05$.

4.4. Agronomic implications

Fallow and fertilization are important agronomic management practices to maintain soil productivity and crop yield in agro-ecosystem (Franklin, 2007; Ruan et al., 2010; Shao et al., 2014; Zhu, 1989). Summer fallow is important for soil respiration because of it is coincident with the high temperature and precipitation, which could stimulate soil microbe activities. In our study, soil respiration accumulated in summer fallow season (148–200 kg C m^{-2}) accounted for 32–39% of the annual accumulated soil respiration (459–621 kg C m^{-2}). Soil respiration in the N fertilization was 35% higher than that in CK treatment. Therefore, ignoring the effect of summer fallow and N fertilization may lead to an underestimation of the carbon emissions in this region. In addition, crop types and N fertilization significantly influenced temperature sensitive of soil respiration. In our study, Q_{10} values ranged from 1.81 to 2.49 in different crops, and Q_{10} was decreased by 11% in N unfertilized soils against unfertilized soils. Consequently, the effect of crop type and N fertilization on the temperature sensitive of soil respiration should also be taken into account in calculating carbon budget in agro-ecosystem using carbon models.

Table 4
Grain yield, above-ground biomass and root biomass under different cropping systems and N fertilization treatments.

Treatment	2013–2014			2014–2015		
	Grain yield	Aboveground biomass	Root biomass	Grain yield	Aboveground biomass	Root biomass
Wheat						
CK	1.42 ± 0.05b	3.27 ± 0.59b	1.73 ± 0.20b	0.98 ± 0.01b	2.25 ± 0.04b	1.22 ± 0.19b
N	5.06 ± 0.05a	11.64 ± 0.12a	2.03 ± 0.21	4.26 ± 0.01a	11.50 ± 0.12a	1.83 ± 0.19a
Maize						
CK	3.40 ± 0.90b	8.20 ± 1.60b	2.00 ± 0.19b	2.70 ± 1.22b	8.07 ± 4.12b	1.73 ± 0.19b
N	11.7 ± 0.60a	21.40 ± 4.30a	2.50 ± 0.33a	17.70 ± 9.50a	30.17 ± 13.20a	2.98 ± 0.19a

Different letters indicate significant differences at $P < 0.05$, unit: t ha^{-1}.

Table 5
Mean grain yield, above-ground biomass and root biomass under different cropping systems and N fertilization treatments.

Treatment	2013–2014			2014–2015			Mean		
	Grain yield	Above-ground biomass	Root biomass	Grain yield	Above-ground biomass	Root biomass	Grain yield	Above-ground biomass	Root biomass
Cropping system									
Wheat	3.24 ± 2.57b	7.46 ± 5.92b	1.88 ± 0.21b	2.62 ± 2.32b	6.88 ± 6.54b	1.53 ± 0.43b	2.93	7.17	1.71
Maize	7.55 ± 5.87a	14.8 ± 9.33a	2.25 ± 0.35a	10.2 ± 10.61a	19.12 ± 15.63a	2.35 ± 0.78a	8.90	17.0	2.33
Fertilization									
CK	2.41 ± 1.40b	5.74 ± 3.49b	1.87 ± 0.19b	1.84 ± 1.22b	5.16 ± 4.12b	1.51 ± 0.41b	2.13	5.45	1.69
N	8.38 ± 4.70a	16.52 ± 6.90a	2.27 ± 0.33a	10.98 ± 9.50a	20.84 ± 13.20a	2.41 ± 0.76a	9.68	18.68	2.32

Different letters indicate significant differences at $P < 0.05$, unit: t ha^{-1}.

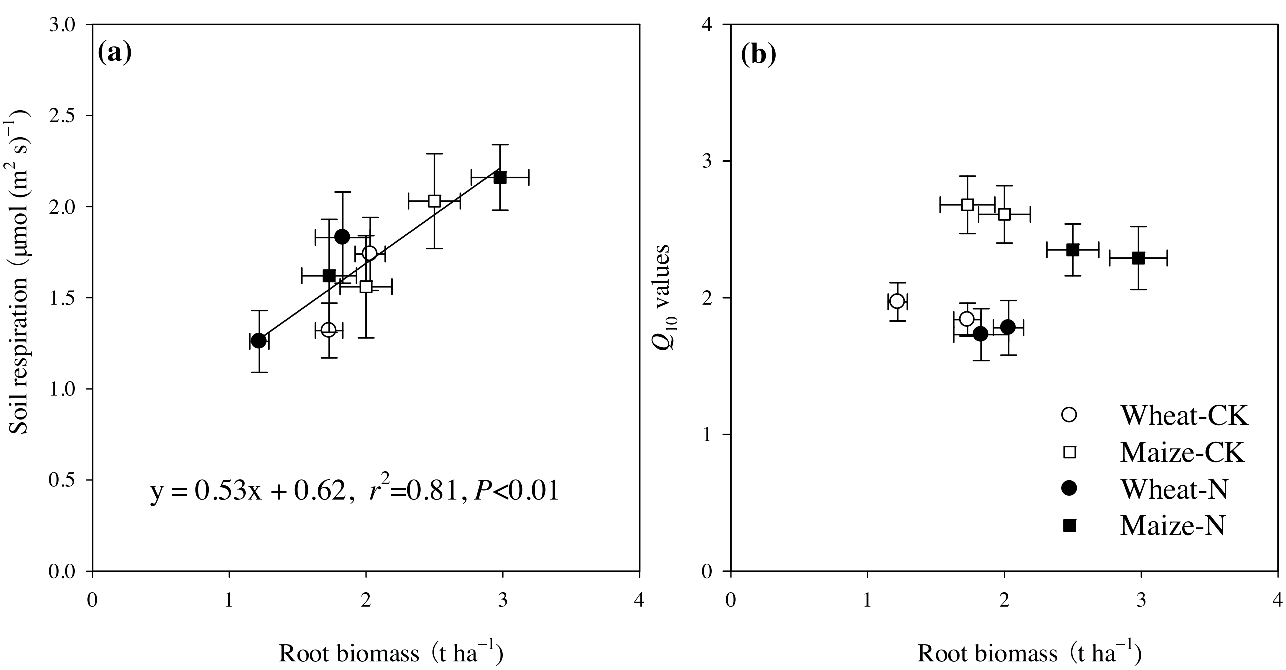

Fig. 6. Relationship between soil respiration (a), Q_{10} (b) and root biomass.

5. Conclusions

Soil respiration and temperature sensitivity of soil respiration were significantly affected by crop types and N fertilization. Annual mean soil respiration and Q_{10} in maize were 20% (1.85 *vs.* 1.54 μmol m^{-2} s^{-1}) and 36% (2.49 *vs.* 1.83) higher than that in wheat. N fertilization resulted in a 35% increase in annual mean soil respiration (1.95 μmol *vs.* 1.44 μmol m^{-2} s^{-1}) and a 11% decrease in Q_{10} (2.05 *vs.* 2.28) compared with that in the CK treatment. Soil respiration was positively related to root biomass, whereas no significant relationship was found between root biomass and Q_{10}.

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