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Soil moisture influenced the interannual variation in temperature sensitivity of soil organic carbon mineralization in the Loess Plateau

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Received: 29 October 2014 – Accepted: 30 December 2014 – Published: 22 January 2015

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Published by Copernicus Publications on behalf of the European Geosciences Union.

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Abstract

Temperature sensitivity of SOC mineralization (Q_{10}) determines how strong the feedback from global warming may be on the atmospheric CO_2 concentration, thus understanding the factors influencing the interannual variation in Q_{10} is important to accurately estimate the local soil carbon cycle. In situ SOC mineralization was measured using an automated CO_2 flux system (Li-8100) in long-term bare fallow soil in the Loess Plateau ($35^\circ 12' \text{ N}$, $107^\circ 40' \text{ E}$) in Changwu, Shaanxi, China from 2008 to 2013. The results showed that the annual cumulative SOC mineralization ranged from 226 to 298 $\text{g C m}^{-2} \text{ y}^{-1}$ (mean = 253 $\text{g C m}^{-2} \text{ y}^{-1}$; CV = 13%), annual Q_{10} ranged from 1.48 to 1.94 (mean = 1.70; CV = 10%), and annual soil moisture content ranged from 38.6 to 50.7 % WFPS (mean = 43.8 % WFPS; CV = 11%), which were mainly affected by the frequency and distribution of precipitation. Annual Q_{10} showed a negative quadratic correlation with soil moisture. In conclusion, understanding of the relationships between interannual variation in Q_{10} of SOC mineralization, soil moisture and precipitation is important to accurately estimate the local carbon cycle, especially under the changing climate.

1 Introduction

Temperature sensitivity of soil organic carbon (SOC) mineralization (Q_{10}) is of critical importance because it determines how strong the feedback from global warming may be on the atmospheric CO_2 concentration (Ågren and Wetterstedt, 2007). However, this is an issue of considerable debatable (Davidson et al., 2006; Kirschbaum, 2006), because Q_{10} is not constant and variations in Q_{10} are the main source of controversies in this feedback intensity (Larionova et al., 2007; Karhu et al., 2010; Conant et al., 2011; Sakurai et al., 2012). Therefore, understanding the factors influencing Q_{10} of SOC mineralization is important to accurately estimate C cycle and the feedback from the expected warmer climate.

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Previous studies have shown that Q_{10} variations are closely related to soil temperature (Janssens and Pilegaard, 2003; Zheng et al., 2009; Bond-Lamberty and Thomson, 2010), substrate availability (Davidson et al., 2006; Zheng et al., 2009), substrate quality (von Lutzow and Kogel-Knabner, 2009; Luan and Liu, 2012), and the composition and size of the constituent microbial population (Djukic et al., 2010; Karhu et al., 2010; Vanhala et al., 2011). Soil moisture is the most significant limiting factor for underground physiological processes in dry and semi-dry ecosystems (Balogh et al., 2011; Cable et al., 2011; Wang et al., 2014). Soil water availability may indirectly affect Q_{10} by influencing the diffusion of substrates, because the diffusion of extracellular enzymes produced by microorganisms and available substrates must conduct in the liquid phase (Davidson et al., 1998; Illeris et al., 2004), but the response of Q_{10} to soil water availability is extremely complex and controversial (Davidson et al., 2000, 2006; McCulley et al., 2007). For example, Gulledge and Schimel (2000) found that Q_{10} was larger in wet years than in drought years, whereas the opposite result was found by Dorr and Mdnich (1987), and many other studies that mainly focused on the short-term or seasonal variation in Q_{10} (Davidson et al., 2006) have showed that Q_{10} was not affected by soil moisture (Fang and Moncrieff, 2001; Reichstein et al., 2002; Jassal et al., 2008). Additionally, soil water availability experienced marked seasonal and interannual fluctuations in these ecosystems due to uneven rainfall distribution caused by the abnormal increase of atmospheric CO_2 concentrations (Solomon et al., 2007). The uneven rainfall distribution inevitably influenced soil moisture availability (Coronato and Bertiller, 1996; Qiu et al., 2001; Cho and Choi, 2014). Xiao et al. (2014) have shown that the interannual changes in soil moisture storage in the Loess Plateau were decided by the difference in soil moisture storage between October and April, because precipitation from April to October of 2004 to 2010 accounted for at least 86 % of annual rainfall. However, to our knowledge, there are few studies investigating the relationship between interannual variation in Q_{10} for SOC mineralization and soil moisture under natural conditions.

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The Loess Plateau is located in northwest China covering an area of 640 000 km². It has a continental monsoonal climate. The mean annual rainfall for a 30 year period (1984–2013) is 560 mm, with the highest rainfall of 954 mm in 2008 and the lowest rainfall of only 296 mm in 1995. The rainfall from July to September accounts for an average of 57 % of yearly rainfall (Guo et al., 2012). Several recent studies have attempted to determine the dominant factors responsible for the variation of soil respiration in agricultural ecosystems (Lafond et al., 2011; Shi et al., 2011; Jurasinski et al., 2012). However, there have been no studies on the interannual variation in Q_{10} , nor the factors responsible for these changes. This highlights the need to accurately evaluate the response of SOM mineralization to increasing temperature under warmer climate scenarios in the eroded or degraded regions, because air temperature has been increasing over the past decades (Fan and Wang, 2011; Wang et al., 2012). Thus, the objectives of the present study are to (1) quantify the interannual variation in Q_{10} of SOC mineralization; (2) determine the effect of soil moisture on the this interannual variation; and (3) analyze the relationships among precipitation, soil moisture, and Q_{10} for the period 2008–2013 in the Loess Plateau, China.

2 Materials and methods

2.1 Site description

This study was a part of a long-term field experiment that began in 1984 in the State Key Agro-Ecological Experimental Station in the Loess Plateau in Changwu, Shaanxi, China (35° 12' N, 107° 40' E; 1200 m a.s.l.) (Fig. 1). This region had a continental monsoon climate with a mean annual precipitation of 560 mm for the period 1984–2013, over 60 % of which occurred from July to September. During this 30 year period, the annual mean air temperature was 9.4 °C and the monthly mean temperature between July and September was 19.4 °C. Site characteristics include the following: = 10 °C ac-

cumulated temperature of 3029 °C, annual sunshine duration of 2230 h, annual total radiation of 484 kJ cm⁻², and a frost-free period of 171 days.

The site was located in a typical rain-fed cropping region of the Loess Plateau highland in northwest China. The soil was classified as a loam (Cumulic Haplustoll, USDA Soil Taxonomy System) developed from loess deposits. Soils collected at the study site in 1984 at a depth of 0–20 cm contained 10.5 % CaCO₃, 6.5 g organic C kg⁻¹, 0.80 g total N kg⁻¹, and 200 mg NH₄OAc-extractable K kg⁻¹, and had a pH of 8.4 (with a 1 : 1 ratio of soil: H₂O), a water-holding capacity of 0.29 cm³ cm⁻³ (v/v), the wilting point of 11 %, a soil bulk density of 1.3 g cm⁻³, and a clay content of 24 %.

2.2 Experimental design and management

The purpose of this long-term experiment was to investigate the effects of different crop rotations and fertilizers on soil productivity, nutrient contents, and moisture contents in the semi-arid Loess Plateau. A total of 36 treatments were used in the experiment, including bare fallow, continuous monoculture or rotation of wheat, legume and maize with various fertilizer rates. However in this paper, we have used three bare fallow plots to study the mechanism of underground SOC mineralization rates. Each plot had a total area of 66.95 m² (10.3 m × 6.5 m), with a 0.5 m spacing between plots.

2.3 Measurements of SOC mineralization rate and soil microclimate

SOC mineralization rate was measured using an automated closed soil CO₂ flux system with a portable chamber (20 cm in diameter, Li-8100, Lincoln, NE, USA). Approximately one day before the first measurement, a polyvinyl chloride collar (20 cm in diameter and 12 cm in height) was inserted to a depth of 2 cm into each plot, and left in place throughout the experimental period from 2008 to 2013. All visible living organisms were removed before the measurement. If necessary, one or more additional measurements would be taken until the variations between two consecutive measurements were less than 15 %. The final instantaneous soil respiration for a given collar

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was the average of the two measurements with a 90 s enclosure period and 30 s delay between them. Field measurements were performed between 09.00 and 11.00 a.m. from March 2008 to November 2013, except in December, January, and February because of cold weather. A total of 17, 25, 26, 22, 26 and 17 SOC mineralization measurements were made in 2008–2013, respectively.

Soil temperatures and water contents at a 5 cm depth were measured at a distance of 10 cm from the chamber collar at the same time as the SOC mineralization rates using a Li-Cor thermocouple probe and a Theta Probe ML2X with a HH2 water content meter (Delta-T Devices, Cambridge, England), respectively. Soil water-filled pore space (WFPS) was calculated as follows: $WFPS (\%) = [\text{volumetric water content}/100 \times (2.65 - \text{soil bulk density})/2.65]$.

2.4 Data analysis

An exponential (or “ Q_{10} ”) function was used to simulate the relationship between SOC mineralization rate and soil temperature (Xu and Qi, 2001):

$$F = \beta_0 e^{\beta_1 T} \quad (1)$$

$$Q_{10} = e^{10\beta_1} \quad (2)$$

where F ($\text{mol m}^{-2} \text{s}^{-1}$) is the SOC mineralization rate, T ($^{\circ}\text{C}$) is the soil temperature at a depth of 5 cm, and β_0 and β_1 are the fitted parameters.

A quadratic polynomial function was used to simulate the relationship between SOC mineralization rate and soil moisture content (Tang et al., 2005):

$$F = \beta_3 \theta^2 + \beta_2 \theta + \beta_4 \quad (3)$$

where θ is the soil moisture at a depth of 0–5 cm, and β_2 , β_3 , and β_4 are the fitted parameters.

The interactions of soil temperature with moisture content can more accurately simulate soil respiration than either soil temperature or moisture alone (Tang et al., 2005).

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Our data indicated that SOC mineralization rate increased with increasing soil moisture content to a maximum at approximately 46 % WFPS, and then decreased with further increase of soil moisture content. After comparing different functions and resulting residual plots, a bivariate model was used to simulate the effect of soil moisture content and temperature on SOC mineralization rate:

$$F = \beta_0 e^{\beta_1 T \theta + \beta_2 T \theta^2} \quad (4)$$

The annual cumulative SOC mineralization rate was estimated by linear interpolating between measurement dates to obtain the mean daily SOC mineralization rate for each plot, and then summing the mean daily SOC mineralization rate for a given year.

The relationships between Q_{10} and meteorological factors were investigated using the SAS software (version 8.0; SAS Institute, Cary, NC). All other statistical analyses were performed with ANOVA at $P = 0.05$.

3 Results

3.1 Interannual variation in Q_0

The temporal variation in the SOC mineralization rate was correlated with that of the soil temperature in all six years (Fig. 2b and c), and it increased exponentially with soil temperature ($P < 0.01$). The annual Q_{10} in our sites was 1.65 in 2008, 1.94 in 2009, 1.72 in 2010, 1.48 in 2011, 1.86 in 2012, and 1.55 in 2013, respectively, with a mean Q_{10} of 1.72 and a CV of 10 % (Table 2); the mean annual SOC mineralization rate ranged from 0.83 (2012) to 1.22 mol m⁻² s⁻¹ (2008), with a mean of 0.99 mol m⁻² s⁻¹ and a CV of 17 %; and the annual cumulative SOC mineralization ranged from 226 (2012) to 298 g C m⁻² y⁻¹ (2009), with a mean of 253 g C m⁻² y⁻¹ and a CV of 13 % (Table 1).

3.2 Interannual variation in soil microclimate

Soil temperature and soil moisture at a depth of 0–5 cm showed significant temporal variations over the six-year observation period (Fig. 2b). The seasonal mean soil moisture content was 38.6% WFPS in the dry season and 49.2% WFPS in the wet season. The mean annual soil moisture content ranged from 38.6 (2013) to 50.7% WFPS (2011), with a mean of 43.8% WFPS and a CV of 11%. The seasonal mean soil temperature was 14.50°C in the dry season and 20.39°C in the wet season. The mean annual soil temperature ranged from 14.90 (2011) to 18.42°C (2009), with a mean of 17.05°C and a CV of only 7%.

3.3 Effect of soil moisture on the interannual variation of Q_{10}

Annual Q_{10} showed a negative quadratic correlation with annual mean soil moisture (Fig. 3b). Additionally, the seasonal SOC mineralization rate increased exponentially with soil temperature, and showed a negative quadratic correlation with soil moisture content (Table 2). The response surface of SOC mineralization rate to soil temperature and moisture including both seasonal and interannual scales clearly described how soil microclimate influenced SOC mineralization rate (Fig. 4).

4 Discussion

The range of annual Q_{10} (1.48–1.94, with a CV of 10%) in our sites for the period 2008–2013 was within the range of the global mean Q_{10} for different ecosystems (1.3–3.3) (Raich and Schlesinger, 1992). However, the mean annual Q_{10} in our sites (1.70) was lower than the global mean (2.4) (Raich and Schlesinger, 1992) and the mean for China (2.19) (Peng et al., 2009), probably due to the low SOM contents, small microbial communities, and dry soil conditions in semi-arid regions (Conant et al., 2004; Gershenson et al., 2009; Cable et al., 2011).

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The annual Q_{10} was negatively linearly correlated with annual mean precipitation, but this correlation did not reach statistical significance ($P > 0.05$); whereas it was significantly related to soil moisture content (Fig. 3). This was in agreement with previous studies (Suseela et al., 2012; Poll et al., 2013). However, Q_{10} was found to be negatively correlated with mean annual precipitation ($P < 0.01$) in different forest ecosystems in China, which could be due to the relatively abundant rainfall in the forest ecosystems (700–1956 mm) (Peng et al., 2009). Soil moisture was the major limiting factor that drove underground biological processes, especially in water-limited regions (Reth et al., 2005; Balogh et al., 2011; Wang et al., 2014). Although precipitation was the only source of water for soil moisture underneath long-term bare fallow soil, there was no significant relationship between annual mean soil moisture and annual precipitation amount ($P > 0.05$) (Fig. 5a), but rainfall frequency and distribution were closely related to annual mean soil moisture content (Fig. 5b). Similar results have also been found in other studies (Coronato and Bertiller, 1996; Qiu et al., 2001; Cho and Choi, 2014). The annual precipitation during the six-year observation period of 2008–2013 ranged from 481 mm (2009) to 644 mm (2011), with a CV of 12 % (Table 1). The annual mean soil moisture content was high (51 % WFPS) in 2011 due to relatively uniform distribution of precipitation, and low (38 % WFPS) in 2010 and 2013 due to relatively uneven distribution of precipitation. For example, the rainfall amount on 23 July 2010 (118 mm) and 22 July 2013 (121 mm) was about 20 and 23 % of that in 2010 (588 mm) and 2013 (523 mm), respectively. However, the annual mean soil moisture was moderate (43–47 % WFPS) in 2008, 2009 and 2012 due to the normal distribution of precipitation. Similarly, the interannual soil moisture regulation in the forest ecosystems in the Loess Plateau was determined not only by rainfall amount but also by rainfall distribution (Li et al., 1998).

The annual Q_{10} showed a negative quadratic relationship with soil moisture content, as it increased with increasing soil moisture content to a maximum at approximately 42 % WFPS, and then decreased with further increase of soil moisture content (Fig. 3b), which was in agreement with other studies (Bowden et al., 1998; Conant

et al., 2004; Smith, 2005). This could be attributed to the following reasons: firstly, lower soil water availability could reduce Q_{10} by limiting respiration substrate availability and soil pore water became increasingly disconnected, thus slowing down the diffusion rate of solutes (Wan et al., 2007; Balogh et al., 2011), and decreasing the activity and quantity of organisms due to drought stress (Davidson et al., 2006). Secondly, higher soil moisture could also reduce Q_{10} by limiting O_2 diffusion rate (Davidson et al., 1998; Byrne et al., 2005; Saiz et al., 2007) because of low effective soil porosity, as the diffusion rate of O_2 through water was much slower than that through air (Cook and Knight, 2003; Manzoni et al., 2012), thus the decomposition activity of aerobic microbes was inhibited due to lack of oxygen (Davidson et al., 2000). Finally, the diffusion rate of both soluble organic matter and O_2 were not inhibited, also the survival of microorganisms not subject to water stress at suitable soil water content, instead increasing temperature increased the diffusion of soluble organic matter, thus resulting in an increase in Q_{10} (McCulley et al., 2007). Overall, soil moisture content may be the most important factors that affected the interannual variation in Q_{10} .

The variation in the temperature sensitivities of SOC mineralization could have potential implications for climate carbon modeling (Davidson and Janssens, 2006; Conant et al., 2011), as uncertainty remains regarding environmental controls over SOC mineralization (Larionova et al., 2007; Karhu et al., 2010; Conant et al., 2011; Sakurai et al., 2012). The previous results have emphasized the importance of seasonal variation in precipitation and soil moisture in determining the temperature sensitivities of SOC mineralization (Xu and Qi, 2001; Davidson et al., 2006; Davidson and Janssens, 2006), but have rarely taken into account the interannual variation in soil moisture resulting from the uneven distribution of precipitation. Carbon cycle modeling without considering this interannual variation in soil moisture may produce misleading conclusions.

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5 Conclusions

Understanding the factors influencing the temperature sensitivity of SOC mineralization is important to accurately estimate local carbon cycle. The results of this study showed that the annual cumulative SOC mineralization, mean soil moisture, and Q_{10} showed a large interannual variation, with a CV of 13, 11 and 10%, respectively. The annual Q_{10} showed a negative quadratic correlation with annual mean soil moisture, which was determined by uneven distribution and frequency of rainfall. In conclusion, the interannual variation in soil moisture content should be considered in carbon cycle models in semi-arid areas.

References

- Ågren, G. I. and Wetterstedt, J.: What determines the temperature response of soil organic matter decomposition?, *Soil Biol. Biochem.*, 39, 1794–1798, 2007.
- Balogh, J., Pinter, K., Foti, S., Cserhalmi, D., Papp, M., and Nagy, Z.: Dependence of soil respiration on soil moisture, clay content, soil organic matter, and CO_2 uptake in dry grasslands, *Soil Biol. Biochem.*, 43, 1006–1013, 2011.
- Bond-Lamberty, B. and Thomson, A.: A global database of soil respiration data, *Biogeosciences*, 7, 1915–1926, doi:10.5194/bg-7-1915-2010, 2010.
- Bowden, R. D., Newkirk, K. M., and Rullo, G. M.: Carbon dioxide and methane fluxes by a forest soil under laboratory-controlled moisture and temperature conditions, *Soil Biol. Biochem.*, 30, 1591–1597, 1998.
- Byrne, K. A., Kiely, G., and Leahy, P.: CO_2 fluxes in adjacent new and permanent temperate grasslands, *Agr. Forest Meteorol.*, 135, 82–92, 2005.
- Cable, J. M., Ogle, K., Lucas, R. W., Huxman, T. E., Loik, M. E., Smith, S. D., Tissue, D. T., Ewers, B. E., Pendall, E., and Welker, J. M.: The temperature responses of soil respiration in deserts: a seven desert synthesis, *Biogeochemistry*, 103, 71–90, 2011.
- Cho, E. and Choi, M.: Regional scale spatio-temporal variability of soil moisture and its relationship with meteorological factors over the Korean peninsula, *J. Hydrol.*, 516, 317–329, 2014.

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- Conant, R. T., Dalla-Betta, P., Klopatek, C. C., and Klopatek, J. M.: Controls on soil respiration in semiarid soils, *Soil Biol. Biochem.*, 36, 945–951, 2004.
- Conant, R. T., Ryan, M. G., Ågren, G. I., Birge, H. E., Davidson, E. A., Eliasson, P. E., Evans, S. E., Frey, S. D., Giardina, C. P., and Hopkins, F. M.: Temperature and soil organic matter decomposition rates—synthesis of current knowledge and a way forward, *Glob. Change Biol.*, 17, 3392–3404, 2011.
- Cook, F. and Knight, J.: Oxygen transport to plant roots: modeling for physical understanding of soil aeration, *Soil Sci. Soc. Am. J.*, 67, 20–31, 2003.
- Coronato, F. R. and Bertiller, M. B.: Precipitation and landscape related effects on soil moisture in semi-arid rangelands of Patagonia, *J. Arid Environ.*, 34, 1–9, 1996.
- Davidson, E., Belk, E., and Boone, R. D.: Soil water content and temperature as independent or confounded factors controlling soil respiration in a temperate mixed hardwood forest, *Glob. Change Biol.*, 4, 217–227, 1998.
- Davidson, E. A., Verchot, L. V., Cattanio, J. H., Ackerman, I. L., and Carvalho, J. E. M.: Effects of soil water content on soil respiration in forests and cattle pastures of eastern Amazonia, *Biogeochemistry*, 48, 53–69, 2000.
- Davidson, E. A., Janssens, I. A., and Luo, Y. Q.: On the variability of respiration in terrestrial ecosystems: moving beyond Q(10), *Glob. Change Biol.*, 12, 154–164, 2006.
- Djukic, I., Zehetner, F., Mentler, A., and Gerzabek, M. H.: Microbial community composition and activity in different Alpine vegetation zones, *Soil Biol. Biochem.*, 42, 155–161, 2010.
- Dörr, H. and Münnich, K.: Annual variation in soil respiration in selected areas of the temperate zone, *Tellus B*, 39, 114–121, 1987.
- Fan, X. H. and Wang, M. B.: Change trends of air temperature and precipitation over Shanxi Province, China, *Theor. Appl. Climatol.*, 103, 519–531, 2011.
- Fang, C. and Moncrieff, J. B.: The dependence of soil CO₂ efflux on temperature, *Soil Biol. Biochem.*, 33, 155–165, 2001.
- Gershenson, A., Bader, N. E., and Cheng, W.: Effects of substrate availability on the temperature sensitivity of soil organic matter decomposition, *Glob. Change Biol.*, 15, 176–183, 2009.
- Gulledge, J. and Schimel, J. P.: Controls on soil carbon dioxide and methane fluxes in a variety of taiga forest stands in interior Alaska, *Ecosystems*, 3, 269–282, 2000.
- Guo, S., Zhu, H., Dang, T., Wu, J., Liu, W., Hao, M., Li, Y., and Syers, J. K.: Winter wheat grain yield associated with precipitation distribution under long-term nitrogen fertilization in the semiarid Loess Plateau in China, *Geoderma*, 189, 442–450, 2012.

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- Illeris, L., Christensen, T. R., and Mastepanov, M.: Moisture effects on temperature sensitivity of CO₂ exchange in a subarctic heath ecosystem, *Biogeochemistry*, 70, 315–330, 2004.
- Janssens, I. A. and Pilegaard, K.: Large seasonal changes in Q₁₀ of soil respiration in a beech forest, *Glob. Change Biol.*, 9, 911–918, 2003.
- 5 Jassal, R. S., Black, T. A., Novak, M. D., Gaumont-Guay, D., and Nescic, Z.: Effect of soil water stress on soil respiration and its temperature sensitivity in an 18-year-old temperate Douglas-fir stand, *Glob. Change Biol.*, 14, 1305–1318, 2008.
- Jurasinski, G., Jordan, A., and Glatzel, S.: Mapping soil CO₂ efflux in an old-growth forest using regression kriging with estimated fine root biomass as ancillary data, *Forest Ecol. Manag.*, 10 263, 101–113, 2012.
- Karhu, K., Fritze, H., Hämäläinen, K., Vanhala, P., Jungner, H., Oinonen, M., Sonninen, E., Tuomi, M., Spetz, P., and Kitunen, V.: Temperature sensitivity of soil carbon fractions in boreal forest soil, *Ecology*, 91, 370–376, 2010.
- Kirschbaum, M. U. F.: The temperature dependence of organic-matter decomposition—still a topic of debate, *Soil Biol. Biochem.*, 38, 2510–2518, 2006.
- 15 Lafond, J. A., Allaire, S. E., Dutilleul, P., Pelletier, B., Lange, S. F., and Cambouris, A. N.: Spatiotemporal analysis of the relative soil gas diffusion coefficient in two sandy soils: variability decomposition and correlations between sampling dates at two spatial scales, *Soil Sci. Soc. Am. J.*, 75, 1613–1625, 2011.
- 20 Larionova, A. A., Yevdokimov, I. V., and Bykhovets, S. S.: Temperature response of soil respiration is dependent on concentration of readily decomposable C, *Biogeosciences*, 4, 1073–1081, 2007.
- Li, H. J., Wang, M. B., and Chai, B. F.: Study on characteristics of soil water of planted forest and its relation to precipitation in northwestern shanxi, *J. Soil Erosion Soil and Water Conserv.*, 25 4, 60–65, 1998.
- Luan, J. and Liu, S.: temperature sensitivity of soil respiration: uncertainties of global warming positive or negative feedback, *Acta Ecol. Sin.*, 32, 4902–4913, 2012.
- Manzoni, S., Schimel, J. P., and Porporato, A.: Responses of soil microbial communities to water stress: results from a meta-analysis, *Ecology*, 93, 930–938, 2012.
- 30 McCulley, R. L., Boutton, T. W., and Archer, S. R.: Soil respiration in a subtropical savanna parkland: response to water additions, *Soil Sci. Soc. Am. J.*, 71, 820–828, 2007.
- Peng, S. S., Piao, S. L., Wang, T., Sun, J. Y., and Shen, Z. H.: Temperature sensitivity of soil respiration in different ecosystems in China, *Soil Biol. Biochem.*, 41, 1008–1014, 2009.

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- Poll, C., Marhan, S., Back, F., Niklaus, P. A., and Kandeler, E.: Field-scale manipulation of soil temperature and precipitation change soil CO₂ flux in a temperate agricultural ecosystem, *Agr. Ecosyst. Environ.*, 165, 88–97, 2013.
- Qiu, Y., Fu, B. J., Wang, J., and Chen, L. D.: Spatial variability of soil moisture content and its relation to environmental indices in a semi-arid gully catchment of the Loess Plateau, China, *J. Arid Environ.*, 49, 723–750, 2001.
- Raich, J. W. and Schlesinger, W. H.: The global carbon-dioxide flux in soil respiration and its relationship to vegetation and climate, *Tellus B*, 44, 81–99, 1992.
- Reth, S., Reichstein, M., and Falge, E.: The effect of soil water content, soil temperature, soil pH-value and the root mass on soil CO₂ efflux-A modified model, *Plant Soil*, 268, 21–33, 2005.
- Reichstein, M., Tenhunen, J. D., Rouspard, O., Ourcival, J. M., Rambal, S., Dore, S., and Valentini, R.: Ecosystem respiration in two Mediterranean evergreen Holm Oak forests: drought effects and decomposition dynamics, *Funct. Ecol.*, 16, 27–39, 2002.
- Saiz, G., Black, K., Reidy, B., Lopez, S., and Farrell, E. P.: Assessment of soil CO₂ efflux and its components using a process-based model in a young temperate forest site, *Geoderma*, 139, 79–89, 2007.
- Sakurai, G., Jomura, M., Yonemura, S., Izumi, T., Shirato, Y., and Yokozawa, M.: Inversely estimating temperature sensitivity of soil carbon decomposition by assimilating a turnover model and long-term field data, *Soil Biol. Biochem.*, 46, 191–199, 2012.
- Shi, W. Y., Tateno, R., Zhang, J. G., Wang, Y. L., Yamanaka, N., and Du, S.: Response of soil respiration to precipitation during the dry season in two typical forest stands in the forest-grassland transition zone of the Loess Plateau, *Agr. Forest Meteorol.*, 151, 854–863, 2011.
- Smith, V. R.: Moisture, carbon and inorganic nutrient controls of soil respiration at a sub-Antarctic island, *Soil Biol. Biochem.*, 37, 81–91, 2005.
- Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K., Tignor, M., and Miller, H.: *Climate Change 2007: the Physical Science Basis. Contribution of Working Group I to the 4th Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge Univ. Press, Cambridge, UK, 2007.
- Suseela, V., Conant, R. T., Wallenstein, M. D., and Dukes, J. S.: Effects of soil moisture on the temperature sensitivity of heterotrophic respiration vary seasonally in an old-field climate change experiment, *Glob. Change Biol.*, 18, 336–348, 2012.

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Table 1. Cumulative SOC mineralization rate ($\text{gCm}^{-2}\text{year}^{-1}$), annual precipitation amount (mm), annual precipitation events (times), and air temperature ($^{\circ}\text{C}$) from 2009 to 2013. Data are represented as mean \pm SD.

Years	Cumulative SOC mineralization rate	Precipitation amount	Precipitation events	Air temperature
2008	293 \pm 10	520	105	9.76
2009	298 \pm 9	481	99	10.26
2010	238 \pm 50	588	101	10.39
2011	234 \pm 48	644	100	9.43
2012	226 \pm 19	481	98	9.43
2013	240 \pm 30	523	71	11.08

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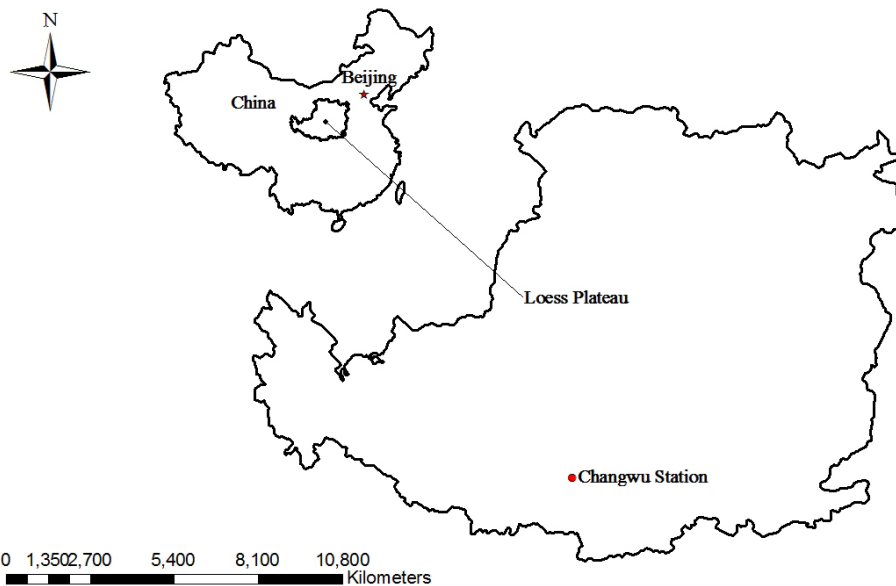



Figure 1. Location of the State Key Agro-Ecological Experimental Station.

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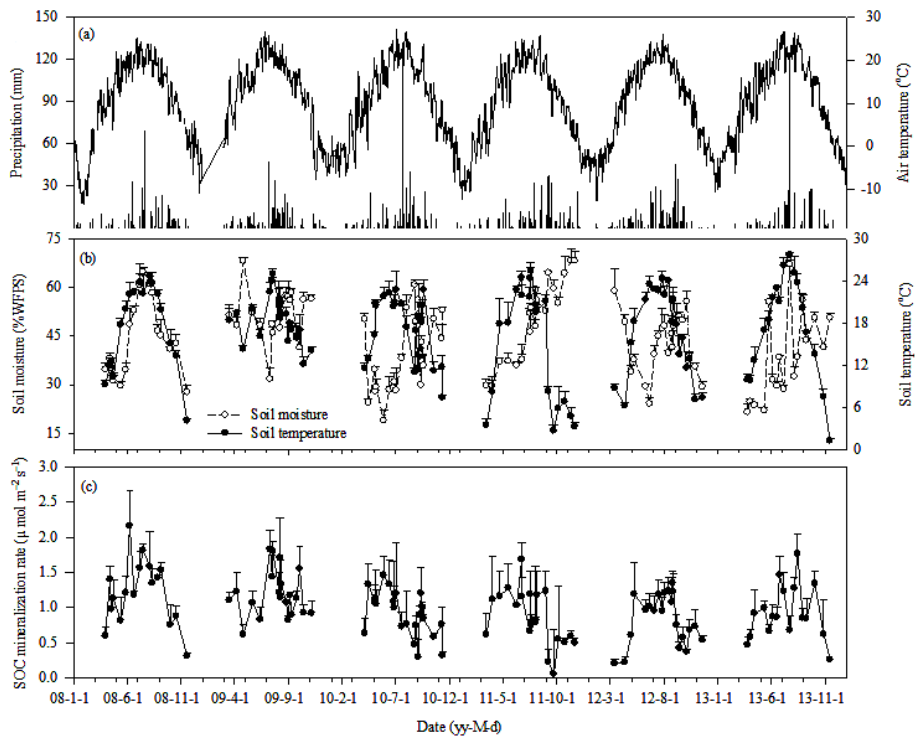


Figure 2. Temporal variations of (a) precipitation and air temperature, (b) soil moisture and soil temperature, and (c) SOC mineralization rate from 2008 to 2013.

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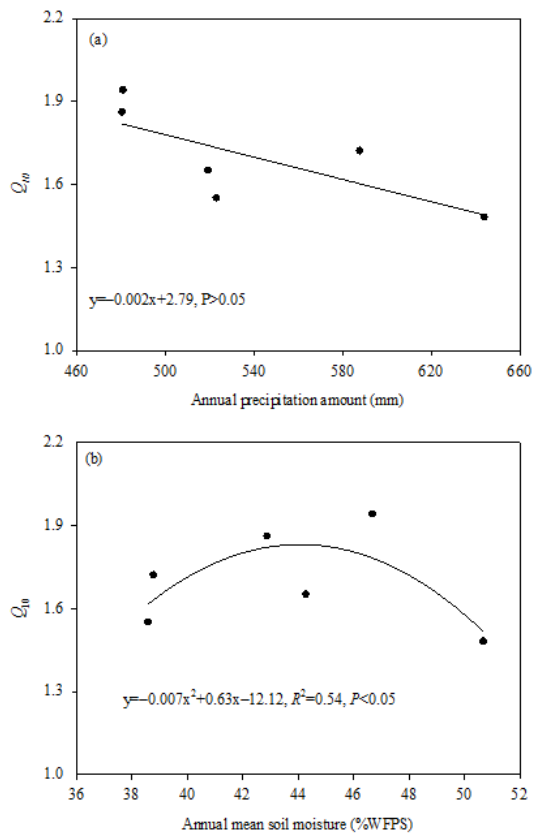


Figure 3. Regression analysis performed between (a) Q_{10} and annual precipitation amount, and (b) Q_{10} and annual mean soil moisture.

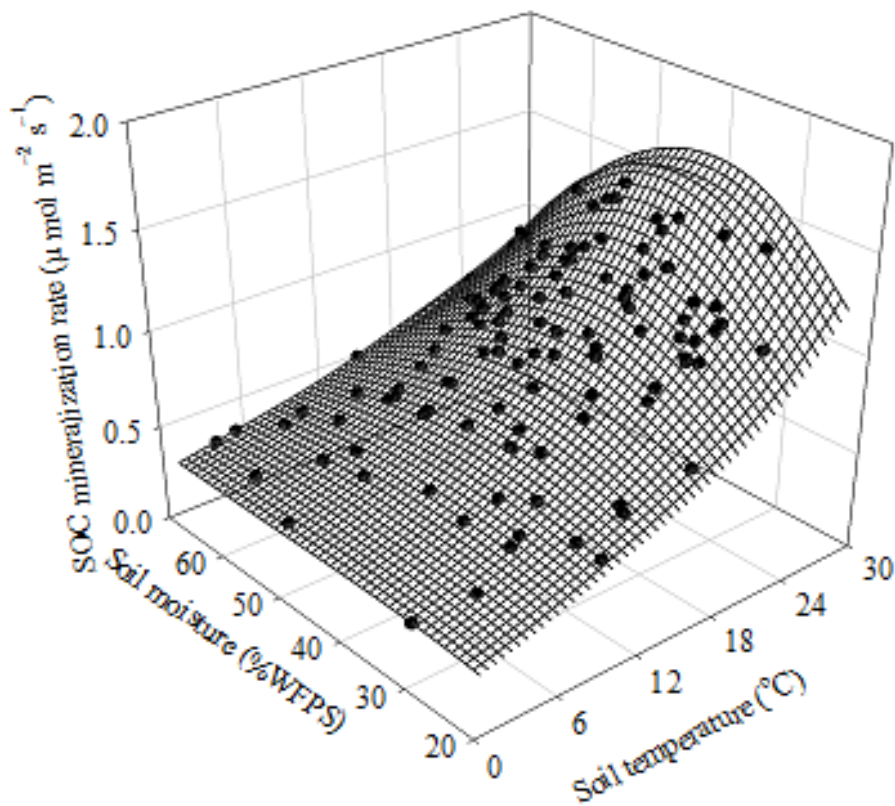


Figure 4. Response surface of SOC mineralization rate as a function of soil moisture and soil temperature from 2008 to 2013.

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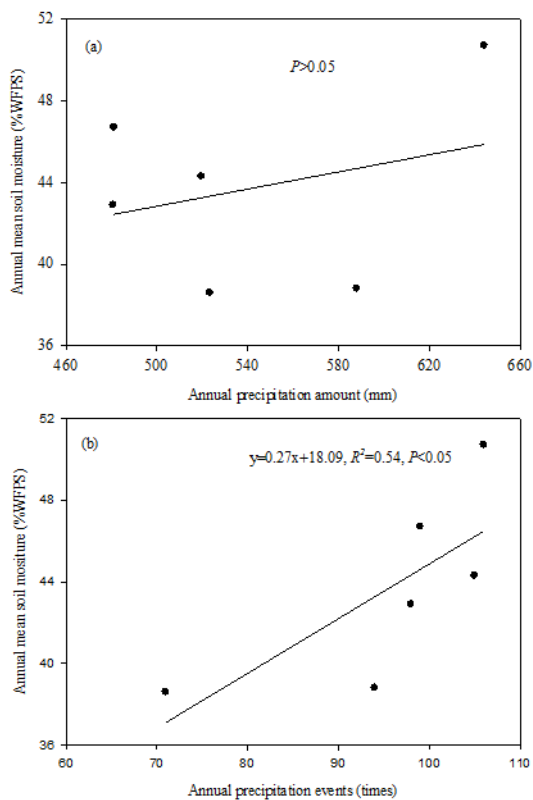


Figure 5. Regression analysis performed between **(a)** annual mean soil moisture and annual precipitation amount, and **(b)** annual mean soil moisture and annual precipitation events.