Response of Soil Respiration to Precipitation Variation in Alfalfa Grassland on the Western Loess Plateau: Hysteresis and Diel Q_{10}

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Abstract

Soil respiration (Rs) plays an important role in the terrestrial carbon cycle, but how precipitation variation affects Rs in alfalfa grassland is poorly understood. To explore the effects of precipitation variation on Rs, this experiment was conducted by using rainfall shelters to simulate 30% precipitation reduction (P-30), normal precipitation (CK) and 30% precipitation increase (P+30) for an alfalfa (*Medicago sativa*) grassland in the Qingyang city, Gansu province, China. Rs was measured continuously using an automated soil respiration system (model LI-8100A with an LI-8150 multiplexer, LI-COR, Nebraska, USA) during the overwintering preparation period of alfalfa. The results showed that the Rs under P-30 and P+30 conditions were significantly higher than under CK treatment by 12.3% and 21.8% (P<0.05), respectively. The Q_{10} (temperature sensitivity of soil respiration) under P-30 condition was significantly higher than P+30 treatment by 12.3%. The mean time lag between Rs and soil temperature (Ts) was 2hrs in three precipitation treatments, with Rs getting to the peak earlier than Ts. The Q_{10} decreases with increasing volumetric water content (VWC), and Rs increases with temperature increasing during the overwintering preparation period of alfalfa. Therefore, the effects of precipitation variation on Rs, identified in this study, will facilitate the assessment and simulation of ecosystem carbon cycling of artificial alfalfa grassland ecosystem on the Loess Plateau.

Introduction

Climate change altered precipitation regimes, which profoundly impacted the terrestrial ecosystem carbon balance (O'Gorman, 2015). Soil respiration (Rs) plays a vital role in the terrestrial ecosystem carbon cycle and is extremely sensitive to altered precipitation regimes (Luo et al., 2006). There are many factors affect Rs rate, but altered precipitation may directly and indirectly affect Rs and subsequently terrestrial ecosystem carbon cycle (Jia et al., 2013). The Loess Plateau is facing more severe water stress in the context of global climate change (Sun et al., 2010), with the adjustment of national policies, artificial grasslands have been established in this area, and growing forages such as alfalfa keep expanding.

The time interval between the last cutting time of alfalfa and the frost period is called the overwintering preparation period (Ren et al., 2008). The preparation period for overwintering of alfalfa on the Loess Plateau is more than 30 days before it can survive the winter safely, which is an important part of the whole growing period (Ren et al., 2008). However, the response of soil respiration of alfalfa grassland during the preparation period for overwintering is not clear. Therefore, this study explores the relationship between Rs and Ts under different precipitation variation conditions on alfalfa grassland in a shelter simulating precipitation variation, to provide a theoretical basis for accurate estimation of soil respiration and the carbon cycle in alfalfa grasslands of the Loess plateau.

Materials and Methods

The experiment was conducted at Qingyang, the Loess Plateau Experimental Research Station of Lanzhou University (35.67°N, 107.85°E, 1297 m a.s.l.). The alfalfa was established in late September, 2018, to varying precipitation of 30% precipitation reduction (P-30), normal precipitation (CK) and 30% precipitation increase (P+30). The variation of the precipitation on the experimental plots was achieved using rain fall shelter, which trap 30 % of the precipitation (P-30), and the trapped rainfall is channeled to P+30. Continuous measurements of Rs were made in situ using an automated soil respiration system (model LI-8100A fitted with an LI-8150 multiplexer, LI-COR, Nebraska, USA). Hourly Rs was continuously measured from September 20th to November 8th, 2019, which was the preparation period for the over-wintering of alfalfa. Hourly Ts and VWC at 10 cm depth were measured outside of each chamber using the 8150-203 soil temperature sensor and EC_{H2O} soil moisture sensor (LI-COR, Nebraska, USA). We performed a non-linear regression analysis of Rs against Ts:

$$Rs=ae^{bTs} \quad (1)$$

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

where a and b are the fitting parameters, and Q_{10} is the temperature sensitivity of Rs (Li et al., 2008).

Results and discussion

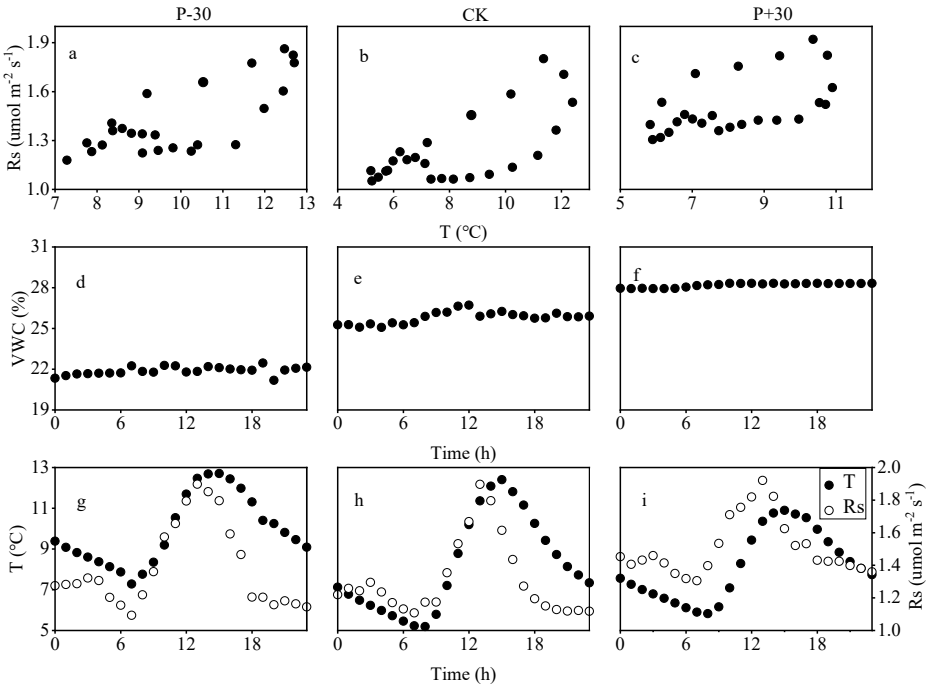

Fig 1. Daily averages of soil respiration (Rs), volumetric water content (VWC) and soil temperature (Ts) during the preparation period for overwintering

Variations in Rs and Q_{10} under different precipitation conditions

Rs under P-30 and P+30 treatment were 1.43 and 1.51 umol m^{-2} s^{-1}, respectively, which is significantly higher than CK treatment by 12.3% and 21.8% (P<0.05, Table 1). This is mainly due to high soil temperature (Fig. 1a) and soil moisture (Fig. 1f) caused by P-30 and P+30 respectively (Table 1). The sensitivity of Rs to Ts (Q_{10}) in CK, P-30 and P+30 were 1.58, 1.87

and 1.44, respectively, likely explained that the variability of microbial activity causes Q_{10} to be positively correlated with Ts and negatively correlated with VWC (Liu et al., 2009).

Table 1. The average value of soil respiration (Rs), soil temperature (Ts), volumetric water content (VWC), Q_{10} (temperature sensitivity of soil respiration) and lag times during the preparation period for overwintering

Treatments	Rs	Ts	VWC	Q_{10}	Lag time
P-30	1.43±0.22a	9.90±1.71a	21.89±0.31c	1.87±0.09a	2h
CK	1.24±0.22b	8.19±2.37b	25.80±0.45b	1.58±0.12ab	2h
P+30	1.51±0.17a	8.16±1.72b	28.19±0.16a	1.44±0.21b	2h

All regressions were significant at the 0.05 level, Values are means ± SD of each index of alfalfa during the overwintering preparation period.

Hysteresis between Rs and Ts

Our results showed a significant phase hysteresis from Rs to Ts under precipitation variation at 10 cm depth (Fig. 1g-i). The mean time lag between Rs and Ts was 2 hrs for three treatments (Table 1), with Rs peaking earlier than Ts. The difference between Rs and Ts measurement interface should be one of the causes for hysteresis (Zhang et al., 2015). Previous studies have reported that diurnal hysteresis between soil CO_2 and soil temperature is mostly due to the balance (or imbalance in wet soils) between production and diffusion (Riveros-Iregui et al., 2007).

Conclusions

This study found that the Q_{10} decreases with increasing soil water content, and Rs increases with increase in temperature during the overwintering preparation period of alfalfa. The mean time lag between Rs and Ts was 2 hrs. The effects of precipitation variation on Rs, will facilitate the assessment and simulation of ecosystem carbon cycling of alfalfa grassland on the rainfed region.

Acknowledgments

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References

Jia, X., Zha, T., Wu, B., et al. 2013. Temperature response of soil respiration in a Chinese pine plantation: hysteresis and seasonal vs. diel Q10. *PLoS One.*, 8(2), e57858.

Li, H.-j., Yan, J.-x., Yue, X.-f., & Wang, M.-b. 2008. Significance of soil temperature and moisture for soil respiration in a Chinese mountain area. *Agric. For. Meteorol.*, 148(3), 490-503.

Liu, W., Zhang, Z. H. E., & Wan, S. 2009. Predominant role of water in regulating soil and microbial respiration and their responses to climate change in a semiarid grassland. *Global Change Biol.*, 15(1), 184-195.

Luo, Y., & Zhou, X. 2006. Soil respiration and the environment. San Diego: Elsevier Academic Press.

O'Gorman, P. A. 2015. Precipitation Extremes Under Climate Change. Curr Clim Change Rep., 1(2), 49-59.

Ren, W. B., Chen, L. B., Guo, H. Q., Zhu, X. U., & Xie, J. H. 2008. Progress in Winter Hardiness and Survival of Alfalfa. *Chin J Grassland*., (02), 104-108.

Riveros-Iregui, D. A., Emanuel, R. E., Muth, D. J., et al. 2007. Diurnal hysteresis between soil CO2and soil temperature is controlled by soil water content. *Geophys. Res. Lett*., 34(17).

Sun, H., Shen, Y., Yu, Q., et al. 2010. Effect of precipitation change on water balance and WUE of the winter wheat–summer maize rotation in the North China Plain. *Agric. Water Manage*., 97(8), 1139-1145.

Zhang, Q., Katul, G. G., Oren, R., Daly, E., Manzoni, S., & Yang, D. 2015. The hysteresis response of soil CO2 concentration and soil respiration to soil temperature. *J. Geophys. Res. Biogeosci*., 120(8), 1605-1618.