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Short communication

Effects of increasing precipitation on soil microbial community composition and soil respiration in a temperate desert, Northwestern China

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ABSTRACT

Soil microbial communities play a critical role in soil carbon cycling and influence soil carbon–climate feedbacks. However, little information exists regarding the response of soil microbial communities in temperate desert ecosystems to projected increases in precipitation and the resulting effects on soil carbon emissions. A three-year precipitation addition experiment was conducted to explore the responses of soil respiration (R_s), microbial respiration (R_m) and microbial community composition to low (extra 15%) and medium (extra 30%) precipitation increases in a temperate desert ecosystem. R_s, R_m, microbial biomass carbon (MBC) and nitrogen (MBN), and microbial PLFAs consistently increased with increasing precipitation. R_s and R_m were positively correlated with MBC and microbial PLFAs. However, precipitation addition had no impacts on microbial community composition and fungal to bacterial PLFAs ratio. These results suggest that projected precipitation increase may synergistically increase bacterial and fungal abundance, and stimulation of microbial biomass can increase soil carbon release in desert ecosystems.

Global climate models predict the precipitation pattern will change in future, especially, with an increasing precipitation in mid-latitude regions (IPCC, 2007). Changes in the precipitation pattern are expected to impact ecosystem structure and function, especially in arid and semiarid ecosystems where water availability is the major limiting factor for both plants and soil organisms. However, only a few studies have concentrated on the impacts of increased precipitation on soil microbial organisms which are responsible for the major carbon release in sparse vegetation regions (Lal, 2004). The mosaic pattern of vegetation distribution is accompanied with the resource heterogeneity in arid and semiarid regions. “Shrub islands” effects have been found to exert the variations of water availability and vegetation growth between beneath shrubs and interplant soil (Jackson and Caldwell, 1993; Aguiar and Sala, 1999). To determine the effects of increasing precipitation on microbial activity and community structure, and the consequences on soil carbon cycling, a manipulative field experiment with 15% and 30% increase in precipitation was conducted from 2011 to 2013 in a temperate desert (the Gurbantunggut Desert). We hypothesized that 1) increased precipitation would alleviate the water-limitation of soil microbes and consequently increase heterotrophic respiration and soil carbon release; 2) soil microbial biomass, activity and carbon release would be significantly higher beneath shrubs than interplant soil because of the ‘fertile islands’ effects; 3) increasing precipitation may differentially impact activity patterns of microbial communities and exert indirect effects on soil carbon release.

The experiments were conducted in the vicinity of the southeastern Gurbantunggut Desert (44°17′N, 87°56′E, and 475 m a.s.l.). *Haloxylon ammodendron* is the dominant shrub. Soil organic carbon, total nitrogen and total phosphorus at 0–5 cm soil layer are significantly higher beneath *H. ammodendron* than those in interplant. The total precipitation in the site was 167.4 mm for 2011, 102 mm for 2012 and 133.7 mm for 2013, with 5.3%, 9.5% and 8.9% falling as snow, respectively. A complete random block design was applied (Fig. S1). Three precipitation treatments, with six

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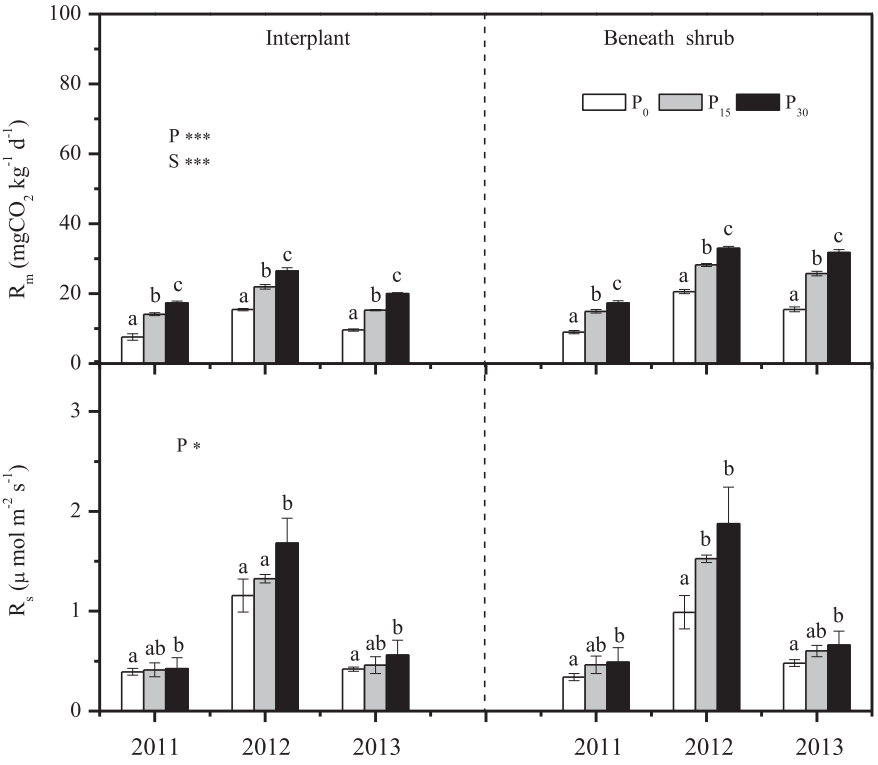

Fig. 1. Mean by year (mean ± S.E., n = 6, main panels) of microbial respiration (R_m) and soil respiration (R_s) in interplant (IP) and beneath shrub of *H. ammodendron* (BS). Significant results of the repeated-measures ANOVA on the effects of year (Y), precipitation addition (P), site (S), and their interactions on microbial respiration (R_m) and soil respiration (R_s) are shown. Significance: $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$ and $\wedge p < 0.1$. Bars with different letters within years represent significant differences based on post hoc two-way ANOVA testing with Bonferroni corrections at $p < 0.05$. IP: interplant, BS: beneath shrubs, P_0: control, P_{15}: 15% increase in precipitation, P_{30}: 30% increase in precipitation.

replications, were randomly distributed in six blocks across six interlands between sandy dune belts. Each plot was 10 × 10 m, with at least a 10 m buffer between adjacent plots. Two subplots of 'interplant' and 'beneath shrubs of *H. ammodendron*' were set up in each plot.

Precipitation was increased by 15% (P_{15}) and 30% (P_{30}) based on predictions for northern China over the next 30 years (Liu et al., 2010), and the third precipitation treatment was a control (P_0). The extra 15% and 30% precipitation was collected using precipitation collection pans. Immediately after a precipitation event, the collected rain was evenly sprayed into the plots. Given the ecological significance of snow in this site (Fan et al., 2014), collected snow was also evenly added before snow melting.

On August 10th in 2011, 2012 and 2013, soil respiration (R_s) was measured using the LI-6400-09 soil chamber (Li-Cor, Inc., Lincoln, Nebraska, USA). In each plot, three polyvinyl chloride collars (inner diameter: 10.4 cm; height: 5.8 cm) were randomly placed beneath *H. ammodendron* and in interplant soils, and then permanently installed 2 cm into the soil. For each measurement, the chamber was placed on each collar. R_s was measured between 9:00 h and 12:00 h and each subplot was repeated three times and averaged for data analysis. R_s measurement was accompanied by soil volumetric water content (SVWC) measurement at the top 5 cm using a portable TDR (HH_2-Delta T Device moisture meter, UK). On the same day of R_s measurement, five soil cores (5 cm in diameter, 5 cm in depth) were taken in each plot and mixed as a composite sample, yielding a total of 18 soil samples in interplant soil and beneath *H. ammodendron* for all treatments. After removing plant roots and large stones using a 2-mm sieve, soil samples were packed into a portable refrigerated box and transported to the laboratory for microbial measurements. Soil microbial biomass carbon (MBC) and nitrogen (MBN) were measured using the chloroform fumigation extraction method (Brookes et al., 1985). Microbial respiration (R_m) was measured using alkali absorption method (Page et al., 1982). Microbial community composition was evaluated using phospholipid fatty acid (PLFA) analysis (Bossio and Scow, 1998; Liu et al., 2013).

All statistical analyses were performed using R software version 3.0.2 (http://www.r-project.org). Due to the significant effects of year on tested parameters, a two-way ANOVA was performed to analyse the yearly impacts of the increased precipitation and site on soil microbial biomass, the ratio of MBC:MBN, R_m, R_s and total PLFAs, fungal and bacterial PLFAs, and Fungal:bacterial PLFAs ratio (F:B ratio). Multiple comparisons of treatments were performed to test for differences in soil properties among precipitation treatments. The default 'cor.test' function (Pearson correlation) was used to test the significance of correlations between MBC, MBC:MBN, total PLFAs and F:B ratio with R_s and R_m. Multivariate comparisons of microbial community composition were conducted from 2011 to 2013. Nonmetric multidimensional scaling (NMDS, 'metaMDS' function of vegan package) analysis was used to analyse changes in microbial community composition. The PLFAs using presence–absence of PLFAs as response variables were considered present only when >0.5 mol% (individual lipid percentage of total lipids) was detected, for the purpose of reducing noise in the ordination analysis.

Increasing precipitation led to a greater R_m (24.3 ± 0.6 $mgCO_2\ kg^{-1}\ d^{-1}$) and R_s (0.9 ± 0.2 μmol $m^{-2}\ s^{-1}$) in P_{30} compared to the control (R_m: 12.9 ± 0.5 $mgCO_2\ kg^{-1}\ d^{-1}$; R_s: 0.6 ± 0.1μ mol $m^{-2}\ s^{-1}$), with intermediate values of, R_m and R_s were 20.0 ± 0.4 $mgCO_2\ kg^{-1}\ d^{-1}$ and 0.8 ± 0.1μ mol $m^{-2}\ s^{-1}$ in P_{15} (Fig. 1, R_m: $p < 0.001$, R_s: $p < 0.05$). These results are consistent with other desert ecosystems (Gallardo and Schlesinger, 1992, 1995; Schwinning and Sala, 2004). The close relations between R_m and

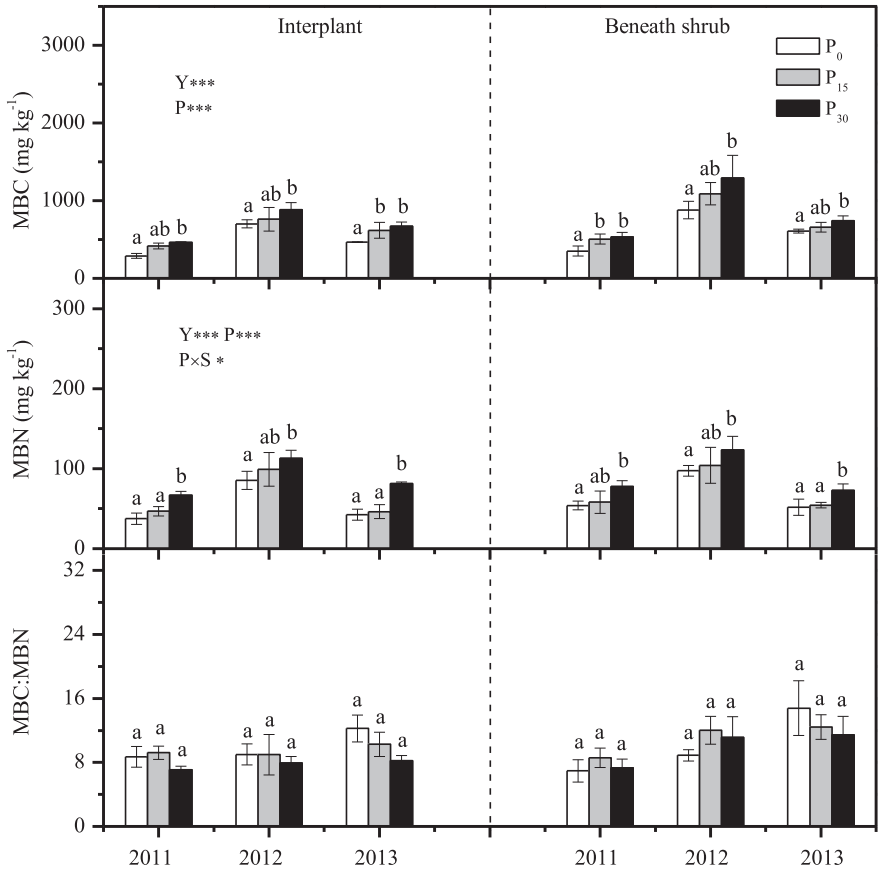

Fig. 2. Mean by year (mean ± S.E., n = 6, main panels) of microbial biomass carbon (MBC) and nitrogen (MBN), the ratio of microbial biomass carbon to nitrogen (MBC:MBN). Significant results of the repeated-measures ANOVA on the effects of year (Y), precipitation addition (P), site (S), and their interactions on MBC, MBN and MBC: MBN are shown. Significance: $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$ and $\wedge p < 0.1$. Bars with different letters within years represent significant differences based on post hoc two-way ANOVA testing with Bonferroni corrections at $p < 0.05$. IP: interplant, BS: beneath shrub, P_0: control, P_{15}: 15% increase in precipitation, P_{30}: 30% increase in precipitation.

R_s with soil moisture suggest the direct and critical role of soil water availability in regulating the soil carbon release (Fig. S2). Moreover, increased precipitation exerted a greater stimulation on R_m and R_s in the dry year (2011, 2013) than in the wet year (2012). This result implies that following rewetting of dry soils, soil can emit more carbon through lysis of living microbial cells, the release of cell solutes, and the exposure of protected organic matter to microbes (Fierer and Schimel, 2002; Schimel et al., 2007; Borken and

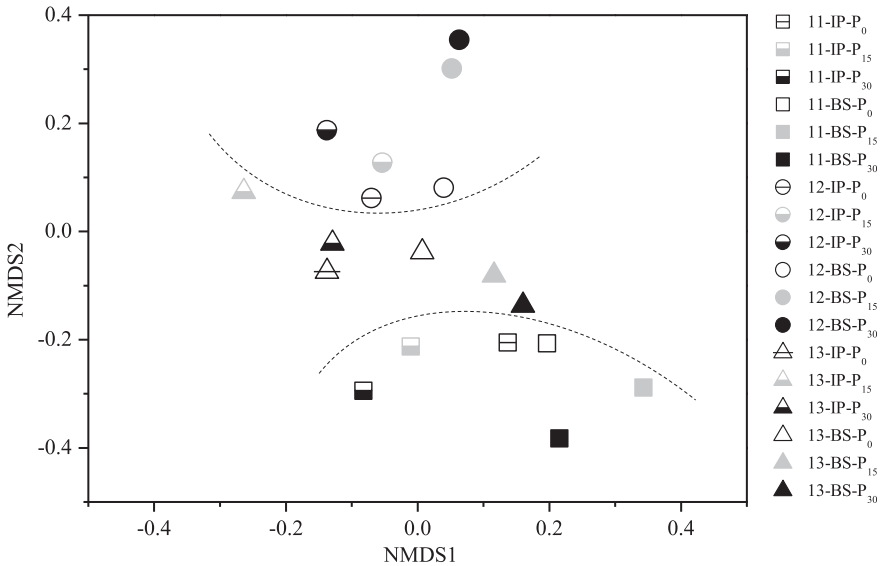

Fig. 3. Non-metric multidimensional scaling (NMDS) analysis on microbial community composition as measured by phospholipid fatty acid profiles. The label represents Year-Site-Treatment. IP: interplant, BS: beneath shrub, P_0: control, P_{15}: 15% increase in precipitation, P_{30}: 30% increase in precipitation.

Table 1
Effects of increased precipitation and site on the PLFAs of the main microbial groups (means ± S.E., n = 6). F and p values from repeated measures two-factor ANOVA (precipitation, site and interaction for main treatments). IP: interplant, BS: beneath shrubs, P_0: control, P_{15}: 15% increase in precipitation, P_{30}: 30% increase in precipitation. Different small letters indicate significant differences between precipitation treatments at $P < 0.05$.

		Total PLFAs		Bacterial PLFAs		Fungal PLFAs		F:B	
		IP	BS	IP	BS	IP	BS	IP	BS
2011	P_0	2.6 (0.2)a	8.1 (0.7)a	2.1 (0.1)a	8.0 (0.3)a	0.5 (0.0)a	0.1 (0.4)a	0.3 (0.1)a	0.1 (0.0)a
	P_{15}	6.5 (0.2)b	11.0 (0.4)b	5.4 (0.1)b	9.9 (0.3)a	1.1 (0.1)b	1.1 (0.0)b	0.2 (0.0)a	0.1 (0.0)a
	P_{30}	7.0 (0.4)b	10.6 (0.4)b	5.8 (0.1)b	9.5 (0.4)a	1.2 (0.3)b	1.2 (0.0)b	0.2 (0.0)a	0.1 (0.0)a
2012	P_0	18.0 (1.6)a	23.4 (0.6)a	14.8 (1.4)a	19.7 (0.6)a	3.2 (0.3)a	3.7 (0.1)a	0.2 (0.0)a	0.2 (0.0)a
	P_{15}	29.9 (6.7)b	29.5 (1.4)b	24.5 (5.5)b	24.7 (1.4)b	5.4 (1.2)b	4.8 (0.0)b	0.2 (0.0)a	0.2 (0.0)a
	P_{30}	35.5 (2.2)b	32.6 (2.8)c	28.3 (1.8)b	27.0 (2.3)b	7.2 (0.4)c	5.6 (0.5)b	0.3 (0.0)a	0.2 (0.0)a
2013	P_0	4.0 (0.4)a	14.6 (0.6)a	3.2 (0.3)a	12.1 (0.5)a	0.8 (0.1)a	2.5 (0.1)a	0.2 (0.0)a	0.2 (0.0)a
	P_{15}	6.4 (1.1)b	14.9 (0.2)a	5.2 (0.9)b	12.3 (0.2)a	1.2 (0.2)b	2.6 (0.0)a	0.2 (0.0)a	0.2 (0.0)a
	P_{30}	6.1 (0.3)b	17.0 (1.9)b	4.9 (0.2)b	14.1 (1.5)b	1.2 (0.1)b	2.8 (0.4)a	0.2 (0.0)a	0.2 (0.0)a
Repeated-ANOVA		F	*p*	F	*p*	F	*p*	F	*p*
Y		162.8	<0.001	687.2	<0.001	727.9	<0.001	22.6	<0.001
P		31.8	<0.001	66.4	<0.001	143.5	<0.001	1.1	0.346
S		65.5	<0.001	165.7	<0.001	27.2	<0.001	61.6	<0.001
P × S		4.3	0.039	8.0	0.006	24.9	<0.001	0.1	0.877

Matzner, 2009; Tiemann and Billings, 2011), and the carbon availability may contribute to the more carbon release.

MBC and MBN were promoted with the increasing precipitation across the three years (Fig. 2, MBC: $p = 0.001$, MBN: $p = 0.006$), which showed a synergistic changes with R_m and R_s. Increased precipitation had no impact on the ratio of MBC:MBN (Fig. 2, $p = 0.241$). As hypothesized, our results indicate that increased precipitation can stimulate microbial biomass; and changes in precipitation exert a subsequent effect on soil carbon release.

Soil microbial composition was investigated by PLFA profiles. Increased precipitation exerted no impacts on microbial community structure (Fig. 3, $p = 0.966$, MRPP test), which was consistent with the unchanged F:B ratio (Table 1, $p = 0.346$), this resulted from the synchronized increase in bacteria ($p < 0.05$) and fungi ($p < 0.05$) PLFAs under precipitation addition. Moreover, microbial composition showed a large interannual variation, and it differed significantly between dry and wet years, the large interannual variation of microbial structure may weaken the increased precipitation effects. One limitation of our study is the absence of seasonal microbial PLFAs investigation. Microbial PLFAs degrade rapidly and display high seasonal variation (Bossio and Scow, 1998), which cannot be captured by a single sampling during the year. In contrast to PLFAs, studies using phylogenetic sequence method showed different results. For instance, changed precipitation pattern altered fungal community and increased precipitation elevated the abundance of *Proteobacteria* while decreasing *Acidobacteria* using 16S rRNA and 28S rRNA genes (Castro et al., 2010). Using phylogenetic marker genes for bacterial (16S) and fungal (28S) RNA and DNA, Barnard et al. (2013) also found that fungal community showed no response to drying and rewetting, while *Actinobacteria* increased and *Acidobacteria* decreased with dry-down, and the reverse responses occurred to rewetting in bacterial community. In addition, a two-year delay of the positive microbial responses to seasonal precipitation increase has been observed in a Chihuahuan Desert

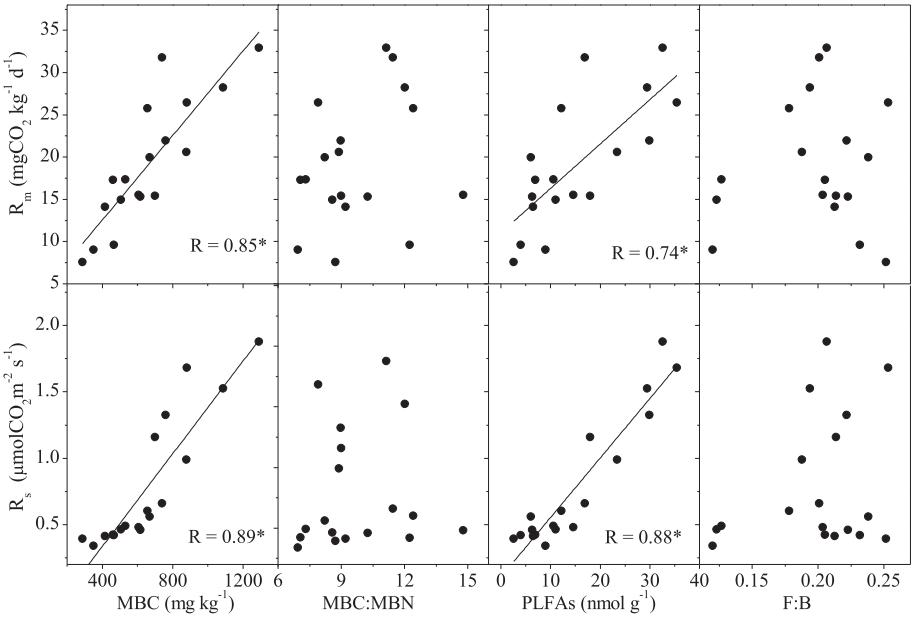

Fig. 4. Correlations of microbial biomass carbon (MBC), the ratio of microbial biomass carbon to nitrogen (MBC:MBN), total microbial PLFAs (PLFAs) and the ratio of fungal to bacterial PLFAs with microbial respiration (R_m, n = 18) and soil respiration (R_s, n = 18) from 2012 to 2013 for three precipitation treatments in two sites. Correlation coefficients and associated *p*-values were based on Pearson correlation tests.

grassland (Bell et al., 2014). Thus, the absent response of microbial community structure to increased precipitation might, to a large content, result from the limitation of PLFA method (Bird et al., 2011).

Taken together, given the positive correlations of R_s and R_m with MBC and total PLFAs (Fig. 4), the increase of soil microbial biomass to increasing precipitation implies that microbial biomass is the determining factor for R_s and R_m in desert ecosystems. But linking with the positive effects of precipitation increasing on NPP in this region, further studies integrating gross primary production and respiration are needed to better quantify the response of net carbon release to precipitation increasing in the temperate desert.

Both the two levels of precipitation addition consistently increased R_m beneath shrubs and in interplant throughout the three years. This result implies three dimensions of consistency in the responses of R_m to precipitation addition. First, in terms of temporal effects of precipitation, R_m was promoted under increased precipitation during three consecutive years with contrasting precipitation patterns, and the response did not weaken in the later stages of the experiment: this suggest that microbial communities did not acclimate to the increased precipitation regime. Second, the stimulation magnitude of R_m by increased precipitation was related to the amount of increased precipitation, showing a positive linear relation between R_m and precipitation. Given that a 30% increase in precipitation is normal in this region (Liu et al., 2010), it is rational to expect an increasing soil respiration under increasing precipitation in this desert. Third, although consistent with other microbial properties, R_m beneath shrub was significantly higher than that in interplant soil (Fig. 1, $p < 0.001$), the stimulation of R_m under increased precipitation showed consistent changes between beneath shrubs and interplant, suggesting the R_m response to increased precipitation is independent of soil resources. Combining the consistent increase between R_m and R_s with the comparable R_s between two microsites, we can deduce that the autotrophic respiration may be similar between beneath shrub and interplant and remains stable across the precipitation addition duration. Previous studies have proven that the promotion of R_s under increasing soil resources (water and N), to a great extent, is associated to soil autotrophic respiration (increases in root growth, mycorrhizal activity or root exudations). But our result might provide a different response mechanism of R_s under increased precipitation. The elevated R_s under precipitation addition might primarily result from the contribution of microbial heterotrophic respiration. This deduction could be explained by the root distribution of shrubs, phreatophytes have few lateral roots distributing in the surface soils, so, increased precipitation might not have stimulated root growth of *H. ammodendron*, leading to a slight response of autotrophic respiration to increased precipitation.

In conclusion, these results illustrate that precipitation increasing can enhance soil carbon release in this temperate desert, and the soil respiration increased linearly with the increase of precipitation. The synergistic increases of bacterial and fungal abundance under precipitation increasing are responsible for the enhancement of soil respiration. In the future, nucleic acid based methods should be used to elucidate microbial community changes under climate change.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.soilbio.2015.01.007.

References

Aguiar, M.R., Sala, O.E., 1999. Patch structure, dynamics and implications for the functioning of arid ecosystems. Trends in Ecology & Evolution 14, 273–277.
Barnard, R.L., Osborne, C.A., Firestone, M.K., 2013. Responses of soil bacterial and fungal communities to extreme desiccation and rewarding. ISME Journal 7, 2229–2241.
Bell, C.W., Tissue, D.T., Loik, M.E., Wallenstein, M.D., Acosta-Martinez, V., Erickson, R.A., Zak, J.C., 2014. Soil microbial and nutrient responses to 7 years of seasonally altered precipitation in a Chihuahuan Desert grassland. Global Change Biology 20, 1657–1673.
Bird, J.A., Herman, D.J., Firestone, M.K., 2011. Rhizosphere priming of soil organic matter by bacterial groups in a grassland soil. Soil Biology & Biochemistry 43, 718–725.
Borken, W., Matzner, E., 2009. Reappraisal of drying and wetting effects on C and N mineralization and fluxes in soils. Global Change Biology 15, 808–824.
Bossio, D.A., Scow, K.M., 1998. Impacts of carbon and flooding on soil microbial communities: phospholipid fatty acid profiles and substrate utilization patterns. Microbial Ecology 35, 265–278.
Brookes, P.C., Landman, A., Pruden, G., Jenkinson, D.S., 1985. Chloroform fumigation and the release of soil nitrogen-A rapid direct extraction method to measure microbial biomass nitrogen in soil. Soil Biology & Biochemistry 17, 837–842.
Castro, H.F., Classen, A.T., Austin, E.E., Norby, R.J., Schadt, C.W., 2010. Soil microbial community responses to multiple experimental climate change drivers. Applied and Environmental Microbiology 76, 999–1007.
Fan, L.L., Tang, L.S., Wu, L.F., Ma, J., Li, Y., 2014. The limited role of snow water in the growth and development of ephemeral plants in a cold desert. Journal of Vegetation Science 25, 681–690.
Fierer, N., Schimel, J.P., 2002. Effects of drying-rewetting frequency on soil carbon and nitrogen transformations. Soil Biology & Biochemistry 34, 777–787.
Gallardo, A., Schlesinger, W.H., 1992. Carbon and nitrogen limitations of soil microbial biomass in desert ecosystems. Biogeochemistry 18, 1–17.
Gallardo, A., Schlesinger, W.H., 1995. Factors determining soil microbial biomass and nutrient immobilization in desert soils. Biogeochemistry 28, 55–68.
IPCC, 2007. IPCC WGI Fourth Assessment Report. Climatic Change 2007: the Physical Science Basis. Intergovernmental Panel on Climate Change, Geneva.
Jackson, R.B., Caldwell, M.M., 1993. The scale of nutrient heterogeneity around individual plants and its quantification with geostatistics. Ecology 74, 612–614.
Lal, R., 2004. Carbon sequestration in dryland ecosystems. Environmental Management 33, 528–544.
Liu, Y.M., Li, X.R., Xing, Z.S., Zhao, X., Pan, Y.X., 2013. Responses of soil microbial biomass and community composition to biological soil crusts in the revegetated areas of the Tengger Desert. Applied Soil Ecology 65, 52–59.
Liu, Y.X., Li, X., Zhang, Q., Guo, Y.F., Gao, G., Wang, J.P., 2010. Simulation of regional temperature and precipitation in the past 50 years and the next 30 years over China. Quaternary International 212, 57–63.
Page, A., Miller, R., Keeney, D., 1982. Soil Respiration, Methods of Soil Analysis, pp. 143–156.
Schimel, J., Balser, T.C., Wallenstein, M., 2007. Microbial stress-response physiology and its implications for ecosystem function. Ecology 88, 1386–1394.
Schwinning, S., Sala, O.E., 2004. Hierarchy of responses to resource pulses in arid and semi-arid ecosystems. Oecologia 141, 211–220.
Tiemann, L.K., Billings, S.A., 2011. Changes in variability of soil moisture alter microbial community C and N resource use. Soil Biology & Biochemistry 43, 1837–1847.