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Precipitation alters temperature effects on ecosystem respiration in Tibetan alpine meadows

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ABSTRACT

There is scant evidence for the interactive effect of warming and precipitation change on ecosystem respiration (Re), particularly regarding for alpine meadow ecosystems where there are high belowground biomass and soil organic carbon stocks. Such knowledge is crucial for predicting terrestrial carbon cycling under climate change. We transplanted meadow blocks reciprocally among three altitudes (4650 m, 4950 m and 5200 m) in the central Tibetan Plateau and examined the controls on Re in 1.5 and 2.5 years after the transplantation. Under the same degree of experimental warming by the downward transplantation, the Re increased and decreased significantly when the precipitation was higher and lower at destination sites than at the home sites, respectively. However, the experimental cooling by the upward transplantation consistently reduced the Re regardless of the precipitation change. Further analysis showed that the increase of Re under the experimental warming was closely related to the increase of aboveground biomass, whereas the reduction of Re under the cooling was highly correlated with the decrease of soil temperature. Moreover, the temperature sensitivity of the Re was decreased by the experimental warming but increased by the experimental cooling. These results suggest that effects of climate warming on the ecosystem respiration are highly associated with precipitation changes in the temperature-limited meadow ecosystems.

1. Introduction

Global mean temperature is expected to increase with concomitant changes in precipitation in the 21st century (IPCC, 2014). The changes of temperature and precipitation will affect the carbon fluxes between terrestrial ecosystems and atmosphere (Heimann and Reichstein, 2008; Wu et al., 2012). Alpine meadows, covering extensive areas in the high-altitude ecosystems, have long been regarded as one of the most vulnerable ecosystems to climate change. First, some studies found that recent climate warming is generally faster at higher altitudes (Beniston et al. 1997; Mountain Research Initiative EDW Working Group, 2015). Secondly, alpine meadows often have high proportion of belowground biomass and/or high soil organic carbon stocks. There is thus growing concern that the ecosystem respiration (Re) in particular the soil respiration will be accelerated under the fast temperature elevation in alpine meadows (Chen et al., 2016b; Bosch et al., 2017). Recent studies have perceived that the potential change of the Re with warming is highly associated with other climatic factors (Lu et al., 2013; Wang et al., 2014). Most of these studies, however, have focused only on the effect of either temperature or precipitation (Wu et al., 2011; Liu et al., 2016). Knowledge of interactive effects of temperature and precipitation on Re is needed for understanding the carbon cycle of alpine meadow ecosystems in response to climate changes.

Changes of ecosystem respiration depend greatly on environmental temperature and precipitation (Davidson et al., 1998; Wu et al., 2011; Liu et al., 2016). Experimental warming generally increases the Re due to increasing plant biomass, litter decomposition and microbial activity (Rustad et al., 2001; Lu et al., 2013; Wang et al., 2014). Increasing precipitation can also increases the Re in general in water-limited ecosystems (Wu et al., 2011; Liu et al., 2016). It is noticed that warming

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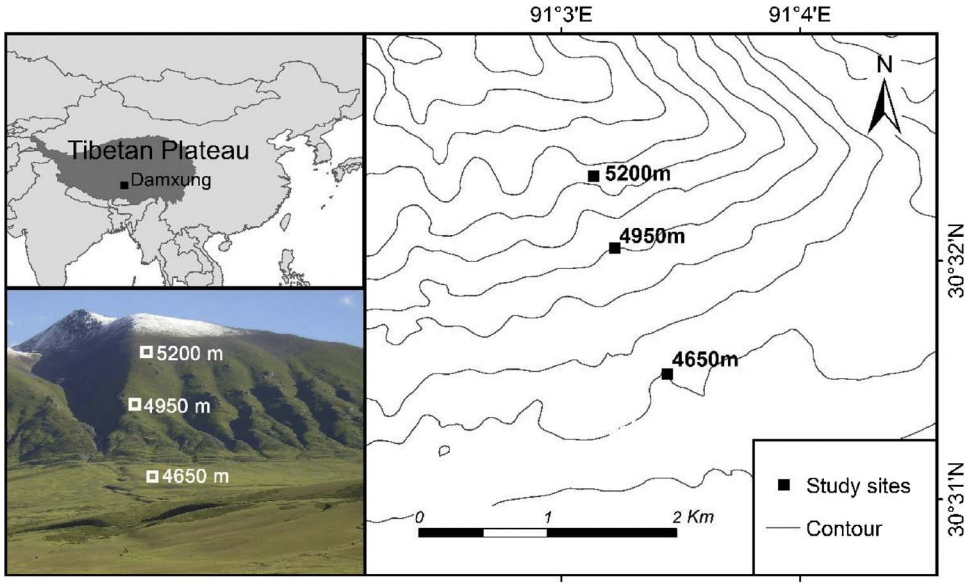

Fig. 1. Diagram of the landscape and experimental sites along the south-facing slope of Nyaiqentanglha Mountains on the Tibetan Plateau.

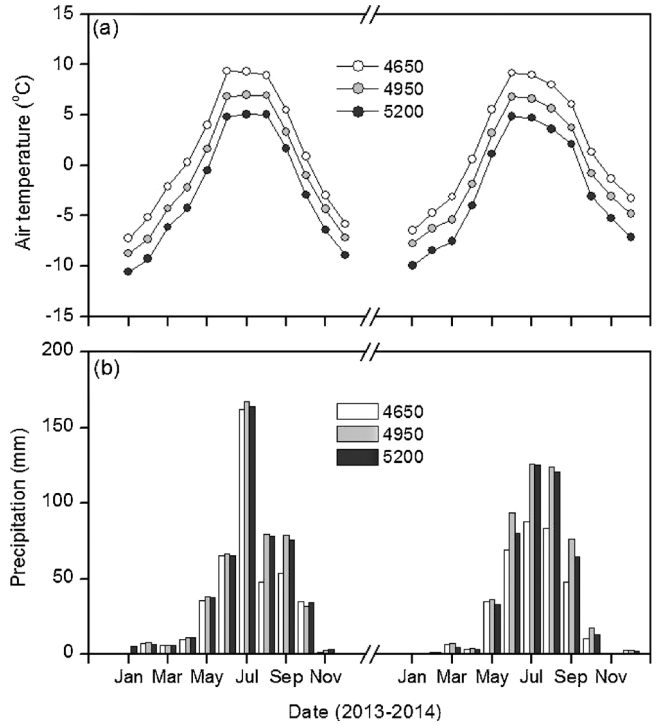

Fig. 2. Seasonal changes in (a) monthly mean air temperature and (b) monthly precipitation at 4650 m, 4950 m and 5200 m during 2013 and 2014.

effects on Re depend strongly on temperature-moisture interactions or on precipitation in grassland ecosystems (Flanagan and Johnson, 2005). A combination of warming and decreased precipitation may largely reduce soil organic carbon (Angert et al., 2005; Ciais et al., 2005). However, very little information is available for evaluating temperature and precipitation interactions on the Re in alpine meadow ecosystems.

The alpine meadow on the Tibetan Plateau has been considered to be sensitive to global warming (Cao et al., 2004; Yang et al., 2008). The plateau has become warmer and wetter in recent decades, and the warming magnitude is much larger than surrounding areas (Liu and Chen, 2000). Temperature elevation on the plateau is often accompanied by precipitation change (Li et al., 2004; Hu et al., 2016). Some studies have already paid attention to the possible consequences of climate warming on the carbon cycle in the alpine meadow ecosystem, but evidences are inconsistent. Fu et al. (2013) found that experimental warming decreases Re due to warming-induced drying, while other studies report different effects of warming on Re (Lin et al., 2011; Hu et al. 2016). No evidence exists to clarify the interactive effect of warming and precipitation change on the Re in the alpine meadow ecosystem on the Tibetan Plateau.

To examine the combined effect of changes in temperature and precipitation on Re, we transplanted meadow blocks reciprocally along an altitude gradient of Nyaiqentanglha Mountains in the central Tibetan Plateau. Previous studies have provided basic ecological information for the altitude gradient including plant phenology, species distribution, biomass production, soil properties and even the Re observed under natural conditions (Li et al., 2013b, 2016; Wang et al., 2013; Zhao et al., 2016). In this study, we focused our attention only on the *Kobresia pygmaea* meadows, which is one of the meadow vegetation types distributed most extensively in the high mountains on the plateau. Our objectives were: 1) to determine the effects of experimental warming and cooling on Re; 2) to evaluate the combination effects of altered temperature and precipitation on Re; and 3) to assess the relationship of warming and cooling with the temperature sensitivity of Re (Q_{10}).

2. Materials and methods

2.1. Study sites

The experiment was conducted on the south-facing slope of Nyaiqentanglha Mountains (30°30′–30°32′ N, 91°03′ E; 4650–5200 m a.s.l, Fig. 1), central Tibetan Plateau. This region has a semi-arid climate, characterized by Indian monsoon in summer and the westerlies in winter. According to meteorological observations from 1963 to 2010 at Damxung station (4288 m, ca. 4 km from the study site), annual precipitation was 479 mm and annual mean air temperature was 1.8 °C. During 1963–2010, annual mean air temperature has increased by 1.6 °C, but the trend of annual precipitation varies with timescales, with a decreasing trend from 1963 to 1990 and an increasing trend from 1991 to 2010 (Wang et al., 2013).

Along the slope, the typical alpine meadow dominated by *Kobresia pygmaea* is found in altitudes between 4650 m (lower limit) and 5200 m (upper limit), with a distribution center at ca. 4950 m (Wang et al., 2013). Other coexisting species mainly include *Androsace tapete*, *Kobresia humilis*, *Kobresia humilis*, *Polygonum macrophyllum*, *Potentilla saundersiana*, *Thalictrum alpinum* etc. The vegetation cover is about