Geoderma 269 (2016) 91–98

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Soil and ecosystem respiration responses to grazing, watering and experimental warming chamber treatments across topographical gradients in northern Mongolia

Anarmaa Sharkhuu [a,b], Alain F. Plante [a,*], Orsoo Enkhmandal [b], Cédric Gonneau [c], Brenda B. Casper [c], Bazartseren Boldgiv [b], Peter S. Petraitis [c]

[a] Department of Earth & Environmental Science, University of Pennsylvania, Philadelphia, PA 19104-6316, USA
[b] Department of Biology, National University of Mongolia, Ulaanbaatar 14201, Mongolia
[c] Department of Biology, University of Pennsylvania, Philadelphia, PA 19104-6018, USA

ARTICLE INFO

Article history:
Received 1 July 2015
Received in revised form 27 January 2016
Accepted 29 January 2016
Available online 4 February 2016

Keywords:
Soil respiration
Ecosystem respiration
Open-top chambers
Grazing
Watering
Topography
Mongolia

ABSTRACT

Globally, soil respiration is one of the largest fluxes of carbon to the atmosphere and is known to be sensitive to climate change, representing a potential positive feedback. We conducted a number of field experiments to study independent and combined impacts of topography, watering, grazing and climate manipulations on bare soil and vegetated soil (i.e., ecosystem) respiration in northern Mongolia, an area known to be highly vulnerable to climate change and overgrazing. Our results indicated that soil moisture is the most important driving factor for carbon fluxes in this semi-arid ecosystem, based on smaller carbon fluxes under drier conditions. Warmer conditions did not result in increased respiration. Although the system has local topographical gradients in terms of nutrient, moisture availability and plant species, soil respiration responses to OTC treatments were similar on the upper and lower slopes, implying that local heterogeneity may not be important for scaling up the results. In contrast, ecosystem respiration responses to OTCs differed between the upper and the lower slopes, implying that the response of vegetation to climate change may override microbial responses. Our results also showed that light grazing may actually enhance soil respiration while decreasing ecosystem respiration, and grazing impact may not depend on climate change. Overall, our results indicate that soil and ecosystem respiration in this semi-arid steppe are more sensitive to precipitation fluctuation and grazing pressure than to temperature change.

1. Introduction

Global soil respiration, that is the efflux of heterotrophic- and plant-respired carbon dioxide (CO_2) from the soil surface to the atmosphere, is the second largest C flux (98 ± 12 Pg C year^{-1}) in terrestrial carbon cycling (Bond-Lamberty and Thomson, 2010). A relatively minor disturbance could trigger the loss of significant amounts of CO_2 to the atmosphere and potentially create a positive feedback to climate change. Hence, understanding responses of the terrestrial carbon cycle to climate change and land-use at the landscape scale has become an important goal in terrestrial ecosystem ecology (Luo, 2007).

The net effects of climate and land-use changes on soil and ecosystem respiration will depend not only on independent effects of climate and land-use variables, but also their interactive effects. Results of experiments and modeling show that experimental treatments could have strong interactive effects on CO_2 effluxes (Luo et al., 2008; Selsted et al., 2012), while other experiments suggest that the interactive effects of warming and precipitation are minor compared to the independent main effects of treatments (Zhou et al., 2006). Hence, it is necessary to evaluate the interactive effects of climate change with changes in land-use and other environmental factors along with their main effects to accurately predict ecosystem responses.

For instance, in addition to altering vegetation composition (Frank et al., 1995), grazing removes live biomass, affects soil temperature and moisture (Klein et al., 2005), as well as a number of soil physical properties such as bulk density (Kölbl et al., 2011), all of which can indirectly or directly affect ecosystem and soil respiration. Soil respiration rates also vary across the landscape in response to spatial variation in microclimate, topography, soil and vegetation characteristics and disturbance regime (Luo and Zhou, 2006). Soil and ecosystem respiration typically respond positively to temperature increases (Rustad et al., 2001; Wu et al., 2011) and negatively to decreases in soil moisture under unsaturated conditions (Harper et al., 2005; Liu et al., 2002). Temperature and moisture vary with topographic gradients, resulting in spatial variability in CO_2 production and efflux (Pacific et al., 2008; Sotta et al., 2006). In addition, plant species diversity (Fu et al., 2004), productivity (Nippert et al., 2011) and nutrient availability (Casper et al., 2012; Fisk et al., 1998; Hook and Burke, 2000) also vary with

* Corresponding author at: Department of Earth & Environmental Science, University of Pennsylvania, Hayden Hall, 240 South 33rd Street, Philadelphia, PA 19104-6316, USA.
E-mail address: aplante@sas.upenn.edu (A.F. Plante).

http://dx.doi.org/10.1016/j.geoderma.2016.01.041
0016-7061/

topography, with possible consequences for ecosystem and soil respiration (Bardgett et al., 2009; Chapin et al., 2009). Variations in these landscape features can directly impact respiration by regulating substrate supply, or indirectly by altering the temporal dynamics of soil moisture (Liancourt et al., 2012). Thus, topographically-induced conditions may either exacerbate or negate effects of climate change and land-use.

The numerous studies that have been designed to test the response of carbon fluxes to climate change and land-use are predominantly centered on temperate areas of North America and Europe, while colder, drier areas are underrepresented (as are also tropical areas). Northern Mongolia lies in the transition zone between the Siberian boreal forest and the Eurasian steppe, where boreal forest and semi-arid steppe co-exists within close proximity. Northern Mongolia currently acts as a net carbon sink (Lu et al., 2009), but the balance may shift due to climate change and land-use. Over the last 40 years, the area has experienced a significant increase (1.8 °C) in mean annual temperature (Nandintsetseg et al., 2007), greater than the global average temperature increase (IPCC, 2007). In the future, air temperature in this region is projected to increase by 2–3 °C by the end of 2070–2080 (Sato and Kimura, 2006), and simultaneously, soil moisture is predicted to decrease due to the temperature increase and precipitation decrease (Sato et al., 2007; but see IPCC, 2007). Moreover, livestock numbers in this region (Khankh soum) have increased from 13.7 thousand sheep units in 1972 to 32.8 thousand sheep units in 2014 (National Statistical Office of Mongolia, 2015), thereby increasing grazing pressure. It is uncertain, and important to assess, how the ecosystem- and landscape-scale carbon balance of this area might change in response to climate change and intensification of grazing pressure.

Few experiments have been conducted in northern Mongolia to address the response of carbon efflux to direct and interactive effects of grazing and climate change despite its substantial land area. Otgonsuren et al. (2008) used multiple valleys along the shore of Lake Hövsgöl as a means of assessing the effect of grazing intensity and topography on soil CO_2 fluxes, though the experimental design was less than optimal due to confounded variables. We conducted a number of simultaneous field experiments to determine how ecosystem and soil respiration might respond to independent and interactive effects of soil temperature and soil moisture, grazing manipulations, and topographic position on a single slope in a single valley. Climate was manipulated using passive open-top chambers (OTCs) similar to those used in the International Tundra Experiment (Marion et al., 1997). Experimental blocks with OTCs and control plots were installed on opposite ends of a topographic gradient. Grazing was manipulated by fencing and crossed with OTC treatments on the lower slope. Soil moisture was altered by weekly watering and crossed with OTC treatments on the upper slope. In this study, we aimed to answer: (1) how do topography, watering, grazing and climate manipulation affect soil and ecosystem respiration through changes in soil temperature and moisture, and (2) how does climate manipulation interact with topography, watering and grazing to affect soil temperature, moisture and these same measures of respiration?

2. Methods

2.1. Study site

The study site is located in the Dalbay valley, in the Lake Hövsgöl International Long-Term Ecological Research (ILTER) site, in northern Mongolia (51° 01.405′ N, 100° 45.600′ E; 1670 m a.s.l.). The mean annual temperature of this region is −4.5 °C, with the coldest average temperature of −21 °C in January and the warmest average temperature of 12 °C in July (Nandintsetseg et al., 2007). Mean annual rainfall ranges between 290 and 300 mm in lower altitudes (Namkhaijantsan, 2006). The study area is located on the southern fringe of Siberian continuous permafrost. Forests on north-facing slopes and riparian areas in valley bottoms are underlain by permafrost, but steppe areas on south-facing slopes are permafrost free. The dominant soil texture in the steppe is sandy loam, and steppe soils are classified as non-calcareous dark Kastanozems (Aridic Borolls or Typic Ustolls) (Batkhishig, 2006).

Soil moisture and soil depth gradients exist on the south-facing slope, where our experimental plots were located because of natural topographical variation. The upper slope (elevation 1800 m a.s.l. and incline ~20°) has a shallower A horizon and less soil moisture (mean summer soil volumetric water content was 8.4%) compared to the lower slope (elevation 1670 m a.s.l. and gentle to flat slope), a deeper A horizon, and mean summer soil volumetric water content of 14%. These gradients drive nutrient availability, vegetation composition and plant cover percentage (Casper et al., 2012). Vegetation cover is semi-arid steppe characterized by grasses (e.g., *Festuca lenensis*, *Helictotrichon schellianum*, *Koeleria macrantha*, *Agropyron cristatum*), sedges (e.g., *Carex pediformis*, *Carex dichroa*) and forbs (*Potentilla acaulis*, *Aster alpinus*, *Artemisia commutata*). The upper slope has less total plant cover (64%), which is dominated by *P. acaulis*, while the lower slope is characterized by greater total plant cover (78%) dominated by *Carex* spp.

Since the study area is a part of the Hövsgöl National Park, grazing is not as intensive as in other valleys in the region. Still, the steppe on the south-facing slope is used as pasture, particularly in autumn and winter, by two herder families, and vegetation in some parts of the riparian area are harvested for hay. The number of livestock in the immediate area is equivalent to approximately 300 sheep-head. Cattle, yaks, and horses are the main grazers on the lower slope, while sheep and goats forage mainly on the upper slope.

2.2. Experimental design and measurements

Experimental treatments were grouped in fifteen blocks on the south-facing slope of the Dalbay valley. Eight 9 × 13 m blocks, spaced approximately 40 m apart, were located on the lower slope. Each was divided into a 9 × 4 m section, which was exposed to fall/winter grazing, and a 9 × 9 m section with year-round fencing. Seven 9 × 9 m blocks, fenced year round and likewise approximately 40 m apart, were located

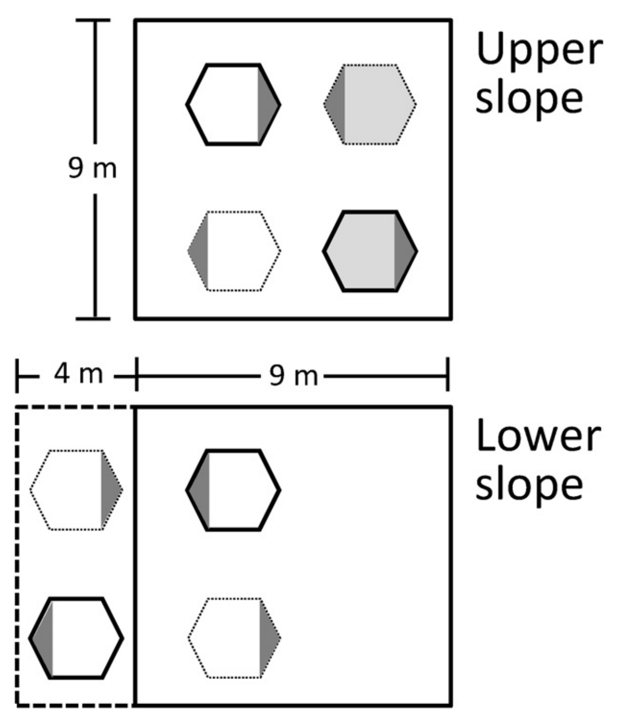

Fig. 1. Schematic of experimental plot design in the upper and lower slope positions showing open-top chambers (solid outline hexagons), watering (shaded hexagons), grazing (dashed outline block) and control treatments (dotted outline hexagons). Bare soil areas are represented by the darkly shaded triangular areas.