European Journal of Soil Biology 56 (2013) 101–106

Contents lists available at SciVerse ScienceDirect

European Journal of Soil Biology

journal homepage: http://www.elsevier.com/locate/ejsobi

Original article

Responses of ecosystem respiration and its components to fertilization in an alpine meadow on the Tibetan Plateau

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ARTICLE INFO

Article history:
Received 17 July 2012
Received in revised form
5 March 2013
Accepted 5 March 2013
Available online 29 March 2013
Handling editor: Yakov Kuzyakov

Keywords:
Nutrient enrichment
Aboveground plant respiration
Soil respiration
Aboveground biomass
Soil temperature
Soil water content

ABSTRACT

Nitrogen (N) deposition alters composition and productivity of plant community, plant litter quality and quantity, composition and activity of soil microbial community. All these changes would influence ecosystem and soil CO_2 emissions. We established a fertilization experiment in an alpine meadow in hinterland of the Tibetan Plateau to detect the responses of ecosystem and soil respiration to fertilization and further explore forces driving changes of CO_2 fluxes. The fertilization experiment was conducted in 2008, in which five treatments were manipulated, i.e. three N levels of 0, 5, 10 g N m^{-2} yr^{-1} (coded as Control, LN and HN, respectively), and two N levels combined with constant level of 5 g phosphorus (P) m^{-2} yr^{-1}, respectively (coded as LN + P and HN + P, respectively). Ecosystem respiration (*Rec*), aboveground plant respiration (*Ra*), and soil respiration (*Rs*) were measured in growing season of 2010 the third year of the experiment. N addition alone did not affect *Rec*, *Ra* or *Rs*. However, combination of N and P increased *Rec*, *Ra* and *Rs* mainly in later period of the growing season. Similarly, N addition did not affect aboveground biomass, but combination of N and P increased aboveground biomass. *Rec*, *Ra* and *Rs* were positively correlated with aboveground biomass, but were not correlated with belowground biomass, indicates enhancement of aboveground biomass by nutrient enrichment could contribute a large part of variation of ecosystem and soil respiration, especially at the end of the growing season. It is suggested that apparent negative effect of soil temperature on ecosystem and soil respiration could be confounded by the effect of aboveground biomass, especially under nutrient enrichment.

1. Introduction

Nitrogen (N) and phosphorus (P) are common nutrient elements constraining plant productivity and microbial activity in most of terrestrial ecosystems [12,47]. Human activity has substantially modified N and P cycles [35]. For instance, the deposition of reactive N has been doubled over the last century primarily due to the increasing application of N fertilizer and burning of fossil fuels [14]. It is projected that N deposition would increase another two or threefold in the coming decades [24]. N and P enrichment can alter composition of soil microbial and plant communities and thus may alter ecosystem and soil respirations (*Rec*, *Rs*) [20,26]. *Rec* contributes to a large part of atmospheric carbon concentration and its dynamic is important in mediating the feedback of terrestrial ecosystems to global changes [16,17,21]. Therefore, knowledge on responses of *Rec* and *Rs* to N and P enrichment and the driving factors is crucial for accurate estimation on ecosystem carbon input and output.

N enrichment generally increases aboveground biomass in most terrestrial ecosystems in Europe [6,41] and North America [11,50], but there still exists some arguments on responses of ecosystem and soil respiration to N enrichment. For instance, studies have showed significant positive [8,15], negative [29,30] and neutral effects [25,34] of N input on soil respiration. Moreover, little is known about the forces driving these responses. In addition, N and P are usually co-limiting nutrient for plant growth in most of ecosystems, and N enrichment could aggravate plant P limitation [7]. Therefore, the effects of combination of N and P on ecosystem and soil respiration should be concerned, especially in nutrient-limiting alpine ecosystems.

Ecosystem and soil respiration are controlled by both abiotic and biotic factors. Soil temperature and moisture are the most

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http://dx.doi.org/10.1016/j.ejsobi.2013.03.001

important abiotic factors controlling respiration [13,28,32,53]. The significant correlations of soil temperature and moisture with respiration have been widely recognized, and soil temperature has been included in many models to predict global patterns of carbon (C) cycle [33,56]. However, recent studies suggest the linkage between photosynthetic assimilate supply and soil respiration could confound the dependence of soil respiration on soil temperature across multiple spatial and temporal scales [36,43]. Furthermore, the modulation of photosynthetic assimilate supply to soil respiration has been used to explain the inconsistent relationship between soil respiration and temperature in some ecosystems [4,19,49]. In nutrient-limited ecosystems, nutrient enrichment generally increases plant aboveground productivity (photosynthetic C fixed by plants). If carbohydrate supply to the belowground increases with increasing photosynthetic C [37,48], *R*ec and *R*s might be enhanced due to increasing photosynthetic assimilate supply. In herbaceous community dynamics of aboveground biomass may reflect dynamics of photosynthetic C fixed by the community during plant growing season. Therefore, in nutrient-limiting ecosystems *R*ec and *R*s might be enhanced by increasing plant aboveground biomass in the face of nutrient enrichment.

The Tibetan Plateau covers about 2.5 million km^2 with average altitude more than 4000 m. 35% of this area is occupied by alpine meadows [55]. In alpine meadow ecosystem processes strongly depend on temperature and precipitation owing to the severe climatic conditions. For instance, slow decomposition rate of soil organic matter is mainly constrained by low temperature, which leads to the trapping of nutrient in forms unavailable to plant [9]. As a result, plant growth is limited by soil nutrient availability [57]. Thus nutrient enrichment may increase plant biomass after release of limiting nutrient elements, and enhance ecosystem and soil CO_2 effluxes. Although effect of soil temperature and moisture on soil respiration has been examined in an alpine meadow ecosystem [20], little is known about effect of nutrient enrichment on ecosystem and soil respiration. Here a field N and N + P fertilization experiment was carried out in an alpine meadow on hinterland of the Tibetan Plateau. In this study, we used opaque chamber-based CO_2 efflux (measured by Li-Cor 8100) to represent ecosystem respiration (with aboveground plants) and soil respiration (without aboveground plants) in order to explore effect of N and P fertilization on ecosystem respiration and soil respiration. We aim (i) to test responses of *R*ec, *R*a and *R*s to N and P enrichment during the growing season in the third year of the fertilization treatment, (ii) to detect the relationships of *R*ec, *R*a and *R*s with biotic (aboveground biomass) and abiotic (soil temperature and soil water content) factors during the growing season.

2. Materials and methods

2.1. Study site

Field fertilization experiment was conducted in an alpine meadow in Damxung County (30°51′N, 91°05′E) located in the mid-south of the Tibetan Plateau. The average altitude of this area is 4320 m a.s.l. Climate is continental semiarid with dry and frigid winter and spring. Mean annual temperature is 1.3 °C with the lowest mean temperature of −10.4 °C in January and the highest mean temperature of 10.7 °C in July. The length of plant growing reason is about 100 days. Annual precipitation is 470 mm, and about 85% falls in summer monsoon from June through August. The vegetation is dominated by perennial sedge *Kobresia pygmaea*, *Carex montis-everestii*, and gramineous *Stipa capillacea Keng*, and accompanied by herbs such as *Anaphalis xylorhiza*, *Potentilla bifurca*. In summer average height of canopy is less than 10 cm and vegetation cover ranges from 50 to 80% depending on annual precipitation [38].

2.2. Experiment design

In 2008, we selected 40 m × 40 m area with uniform vegetation coverage for fertilization experiment, in which the vegetation had never been fertilized. Complete randomized block design was used for fertilization manipulation. We established five blocks, and five 5 m × 5 m split plots were set up in each block. Plots were separated from each other by 2 m aisle as buffer zone. The five plots in each block were assigned randomly for the following five treatments, i.e. three levels of N and two levels of N combined with the constant level of phosphorous (P). The three N levels are 0, 5, 10 g N m^{-2} yr^{-1} (hereafter as coded as Control: without N addition; LN: low N; and HN: high N, respectively). Level of P is constant 5 g P m^{-2} yr^{-1}, which was combined with the low and high N treatments, hereafter coded as LN + P and HN + P, respectively. The fertilizer $CO(NH_2)_2$ and $(NH_4)_2HPO_4$ was applied at the beginning of growing season (in middle June) each year. For each treatment four out of five replicate plots were randomly selected for the measurements of respiration and biomass in 2010.

2.3. Field sampling and measurements

Ecosystem (*R*ec) and soil respiration (*R*s) were measured three times about 10 days interval for each month from July to September. Previous studies indicated that respiration rate measured at about 9:00 am (local time) was similar to the average respiration rate during the whole day in the same alpine meadow [54]. Therefore, *R*ec and *R*s measurements in this study were made between 09:00 and 11:00 am (local time).

*R*ec and *R*s were directly measured using opaque chamber of Li-Cor-8100 103 automatic soil CO_2 efflux measurement system (LI-COR Inc., Lincoln NE, USA). The CO_2 efflux with aboveground vegetation measured in dark chamber was considered as ecosystem respiration [10,39], and CO_2 efflux without aboveground vegetation as soil respiration. At beginning of each measurement, one cylindrical PVC collar with 20 cm in diameter and 5 cm in height was inserted into the soil to a depth of 3 cm in each plot for measurement of respiration rates. All the collars were installed at least 12 h prior to the measurements in order to reduce disturbance. The chamber was mounted on collar in each plot for respiration measurement. The internal height of the chamber was approximately 25 cm so the chamber is high enough to enclose all the plants within it. The vegetation in the collar was left intact so that the measurement represents ecosystem respiration (soil plus above-ground vegetation). Each measurement lasted 120 s. The respiration rate was calculated based on CO_2 concentration in the chamber during the measurement. *R*ec was measured in the first day. After *R*ec measurement, the plants within those collars were clipped to the ground level and collected in the envelopes. *R*s was measured 24 h later after aboveground plant clipping. Finally belowground root samples (0–15 cm) were taken by core in 7 cm diameter for five spots in each collar. Aboveground and belowground plant samples from each collar were oven-dried at 65 °C for over 48 h. The dry matter weight was calculated (±0.01 g) and expressed on a per square meter basis. Here we consider aboveground biomass approximately as aboveground net primary productivity (ANPP) at the specific measuring date during the growing season, and presume dynamics of aboveground biomass reflect dynamics of photosynthetic C fixed by community.

Daily precipitation, soil temperature and soil water content in 5 cm depth were measured with a FLUXNET station within 200 m distance from the experimental site. *R*a was calculated by subtracting *R*s from *R*ec.