



# Seasonal pattern of soil respiration and gradual changing effects of nitrogen addition in a soil of the Gurbantunggut Desert, northwestern China



Xiaobing Zhou, Yuanming Zhang\*

Xinjiang Institute of Ecology and Geography, Key Laboratory of Biogeography and Bioresource in Arid Land, Chinese Academy of Sciences, South Beijing Road, Urumqi 830011, China

## HIGHLIGHTS

- High midday temperatures in the summer could repress soil respiration.
- Precipitation could dramatically increase soil respiration.
- C sequestration was affected by the rate of N added and number of exposed years.

## ARTICLE INFO

### Article history:

Received 4 September 2013

Accepted 16 December 2013

### Keywords:

Carbon production  
Fine root biomass  
N deposition  
Soil moisture  
Soil temperature

## ABSTRACT

Evaluating the responses of soil respiration in desert ecosystems to varying rates of added N is of great significance for understanding their carbon (C) budgets under increasing nitrogen (N) deposition. In this study, the diel and seasonal patterns of soil respiration through out the growing season were examined over a three-year period after adding a gradient of N to soil in the Gurbantunggut Desert. N was added at five rates: 0.5, 1.0, 3.0, 6.0 and 24.0 g N m<sup>-2</sup> y<sup>-1</sup> (denoted as N0.5, N1, N3, N6 and N24, respectively), plus a control without N addition: N0. Soil respiration showed both a distinct diel and seasonal dynamics. Soil temperature was the dominant factor influencing diel changes in soil respiration. High summer temperatures could reduce soil respiration due to the probable decrease of microbial respiration. Soil moisture was the driving factor that affected the soil respiration seasonal pattern. Precipitation pulses elicited an intense CO<sub>2</sub> release after the pulse ceased. Although soil respiration showed an increase with enhancing N rates in the first year, the positive effects of N24 treatments weakened in the second year and became negative, and effectively toxic in the third. The total carbon production in the growing seasons among different N treatments in 2010 and 2011 also followed this model. In addition, soil respiration was also consistent with fine root biomass in the growing seasons. The results indicated that as soil temperature interacted with soil moisture, it affected temporal changes in the soil surface C flux and C sequestration, with C sequestration being affected differently based on the rate of N added and number of exposed years.

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## 1. Introduction

With over 1500 Pg of carbon stored in soil carbon sinks, the soil can host twice the carbon storage of that found in the atmosphere (IPCC, 2001). The mean annual global soil respiration has been estimated to be 80.4 Pg C, which is more than 1/20 of the total carbon storage (Raich et al., 2002). Arid land ecosystems occupy

41% of the land globally, hosting 241 Pg of soil organic C, a rate that is twice that of temperate forest ecosystems, and 750–950 Pg of soil inorganic C (Lal, 2004). The belowground of semiarid short grass steppe ecosystem alone may account for approximately 99% of the carbon stored in this ecosystem (Burke et al., 2008). In light of their high C storage, arid ecosystems play an essential role in the C balance of terrestrial ecosystems and their responses to global change. Carbon fluxes of soil surfaces and their varying magnitude under environmental changes are vital indices to assess the C balance in arid ecosystems.

Soil respiration is an integrative measure of ecosystem function representing both biotic and physical controls over the C balance

\* Corresponding author. Tel.: +86 991 7823158; fax: +86 991 7885320.

E-mail addresses: [zhouxb@ms.xjb.ac.cn](mailto:zhouxb@ms.xjb.ac.cn) (X. Zhou), [zhangym@ms.xjb.ac.cn](mailto:zhangym@ms.xjb.ac.cn) (Y. Zhang).

(Ball et al., 2009). Two types of factors can affect the soil respiration of arid ecosystems: Abiotic factors, such as soil moisture, temperature, context, organic matter, nitrogen (N) availability, etc., and biotic factors, which includes measurements like the microbial biomasses or root systems. In general, soil temperature primarily drives the daily respiration variation. In both mesic and arid ecosystems, low soil temperatures repress respiration, or respiration could increase exponentially with increases in soil temperature (Fang and Moncrieff, 2001; Lloyd and Taylor, 1994). The same significant and positive correlation to soil surface temperatures has been found in three desert communities in northwestern China (Zhang et al., 2009b).

Water is the primary limitation in arid lands, so even minor precipitation pulses can trigger dramatic biological responses via soil moisture (Noy-Meir, 1973). By increasing soil moisture in the 0–5 cm soil depth where microbes and new liable carbon are abundant, even light rain in short duration can potentially alter soil carbon flux (Sponseller, 2007). In arid ecosystems, soil moisture often interacts with soil temperatures to influence soil respiration, which can be inhibited in high or low extremes of environmental factors. That is to say, even at optimal temperatures, low soil respiration rates can exist in the absence of sufficient soil moisture (Noy-Meir, 1973). Decomposition rates depend on soil temperature and moisture ranges in the cold desert. When soil temperatures were between 10 and 16 °C and volumetric soil moisture was greater than 10%, high CO<sub>2</sub> fluxes occurred (Fernandez et al., 2006). Soil moisture availability can also be influenced by soil texture, which modulates soil respiration and microbial decomposition (Cable et al., 2008).

Although microbial and root biomasses are important biotic controls for soil respiration, abiotic factors predominantly affect respiration by affecting soil microbial activity. For example, when soil temperatures exceed the threshold for microbial activity, these high temperatures suppress soil microbial activity, thus soil respiration decreases. The lack of a significant linear correlation between soil temperature and respiration might due to the temperature staying within the appropriate range for microbes (La Scala et al., 2006). However, the increase of microbial biomasses might not lead to soil respiration growth in temperate forests (Micks et al., 2004). Furthermore, 28–70% of CO<sub>2</sub> from the soil surface to the atmosphere is attributed to root respiration, which controls the plant's normal growth and physiological activity (Raich and Schlesinger, 1992). Soil respiration is positively related to root biomass and mycorrhizal associations (Haynes and Gower, 1995; Vose et al., 1997). In addition, fine roots have been reported to respire more than coarse roots per unit mass (Wang et al., 2005). Some abiotic factors, such as substrate availability and C input, might affect soil respiration more significantly than soil temperature by influencing the plant productivity in both natural and managed ecosystems (Sheng et al., 2010).

Soil respiration in desert ecosystems may be playing a much larger role in global C cycling and in modulating atmospheric CO<sub>2</sub> levels than previously assumed (Wohlfahrt et al., 2008). Although soil respiration has been extensively studied in many arid ecosystems, few studies have focused on the seasonal pattern of soil respiration in desert ecosystems, especially under increasing N deposition. The concentration of N deposition has increased due to the development of agriculture and industry adjacent to the deserts (Fenn et al., 2003), making nitrogen the second driving factor behind water in arid ecosystems. Nitrogen enrichment can stimulate the growth of plants, influence microbial activity and alter microbial community structure (Brooks, 2003; Clark et al., 2009; Zhou et al., 2012), but whether the effects of N deposition on soil respiration are positive or negative in desert ecosystems have yet to be determined. In many grassland and forest ecosystems, both

stimulating and depressing effects of chronic N deposition have been found (Burton et al., 2004; Fang et al., 2012).

Precipitation, total N pools might be identified as determinants of soil CO<sub>2</sub> loss in desert ecosystems. Soil processes in desert ecosystems are strongly controlled by precipitation inputs via changing soil water moisture. Following wetting treatments, soil respiration was positively correlated with N deposition (McCrackin et al., 2008). For the total N pools, C sequestration in N-limited sandy grassland soils of North America may have sharply increased due to high N deposition (Reid et al., 2012).

Effects of N addition on soil respiration might vary with time (in terms of years) and soil water conditions. After N addition in forest ecosystems, soil respiration increased in the first year and then decreased (Bowden et al., 2004). Increases in water and N supplies promoted ecosystem respiration 47–70% during the growing season in a degraded semiarid steppe of Inner Mongolia, China (Chen et al., 2013). However, contrasting effects of low and high N additions on soil CO<sub>2</sub> flux components have also been found, which calls for further studies of the quantitative relations among N addition rates (Hasselquist et al., 2012).

To elucidate the seasonal pattern of soil respiration and evaluate deposition effects of various N concentrations, a gradient of simulated N additions over the course of three growing seasons was used to determine the effect on soil respiration. The driving factors for the changes in respiration were also of value. We hypothesized that soil respiration would be lower in summer than other seasons due to relatively low moisture, and experience a mid-day reduction due to heat suppression on microbial activity. Due to toxicity in plots of high N added levels (Zhou et al., 2012), we further hypothesized that these levels would repress soil respiration due to their toxicity.

## 2. Materials and methods

### 2.1. Site description

The Gurbantunggut Desert is located in the center of the Junggar Basin in northwestern China. The desert is the largest fixed/semi-fixed desert in China, with an area of  $4.88 \times 10^4$  km<sup>2</sup> and altitude 300–600 m. The mean annual temperature is between 6 and 10 °C. Annual precipitation, of which 47.6% falls from April to July reaches a mere 70–150 mm, while the annual evaporation exceeds 2000 mm. In the winter, about 20 cm of snow covers the desert, with stable snow coverage lasting about 100–160 days. The precipitation distribution pattern and spring snowmelt could be the cause of abundant soil moisture in spring, which creates favorable conditions for the growth and development of ephemeral (short vegetative annual) plants, such as *Erodium oxyrrhynchum*. Some long vegetative annual plants, such as *Ceratocarpus arenarius* and *Horanowia ulicina* reach their largest biomasses in August. *Haloxylon persicum* is the most dominant species, appearing mainly in the middle to upper range of dunes.

### 2.2. Experimental treatments

In October 2008, sixty 8 × 8 m plots were established at the study site. Five different concentrations of N were randomly applied to selected plots in addition to a control with no N added, in a total of 10 replicates. The N levels of the six treatments were 0, 0.5, 1.0, 3.0, 6.0 and 24.0 g N m<sup>-2</sup> y<sup>-1</sup> and will henceforth be denoted as N0, N0.5, N1, N3, N6 and N24, respectively. N0.5 was considered low, N1–N3 as medium, and N6–N24 as high. The N treatments were applied each year in March in equal amounts after the snow had thawed and again in October before the first snowfall. N was diluted with water and applied as a spray for even dispersment.

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