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Temporal variation of Q_{10} values in response to changes in soil physiochemical properties caused by fairy rings

Chao Yang, Yingjun Zhang, Yuping Rong, Yixian Bei, Yuqi Wei, Nan Liu*

Key Laboratory of Grassland Management and Rational Utilization, The Ministry of Agriculture, College of Animal Science and Technology, China Agricultural University, Beijing 100193, China

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ABSTRACT

The temperature sensitivity (Q_{10} values) of soil respiration (Rs) has been a source of much debate given the potential feedbacks between soil carbon pools and global warming. Many studies have been conducted to investigate monthly variations in Q_{10} values. However, few studies have focused on the underlying causes of the variations, and it no clear how seasonal variation in soil physicochemical properties could affect Q_{10}. The fairy rings (FRs) caused by basidiomycete fungi can change soil physiochemical properties. Therefore, we collected a series of soils over five months (June–October) from three zones impacted by FRs: outside (OUT), on (ON) and inside (IN) the rings to explore the relationship between soil physicochemical properties and Q_{10} values. We observed significantly higher plant biomass, plant nitrogen content and soil available phosphorus (P) in the ON zone than the OUT and IN zones ($p < 0.05$). Soil total carbon, nitrogen and water content decreased significantly from the OUT zone to the IN zone. In contrast, soil pH increased significantly from the OUT zone to the IN zone. The Q_{10} values increased significantly as months passed, different zones followed the order IN > OUT > ON ($p < 0.05$), and the response of Rs to the zones and progression through the months was the opposite to that of Q_{10} values. Our study suggest that soil available P and water content were two dominant factors influencing temporal patterns in Q_{10}, and that soil pH was closely related to Rs, which can also affect Q_{10} indirectly.

1. Introduction

Global mean temperature is predicted to increase by at least another 0.3 °C by the end of this century [1]. One of the greatest challenges in predicting the global climate change caused by human activities is understanding how soil respiration (Rs) will change with warming [2]. Increases in temperature can induce exponential increases in Rs [3–6]. The temperature sensitivity of Rs (Q_{10} values) is a critical parameter that reflects the associated relationship between the carbon cycle in terrestrial ecosystems and climate change [7–9]. In addition, a small variation in Q_{10} values can cause a large bias in estimating soil CO_2 release into the atmosphere [10]. Recent investigations of Q_{10} values have focused on the elevation gradient [11], vegetation type [12–14], land-use types [5], fertilizer addition [15,16] and carbon addition [6]. Most empirical models rely on the correlation between seasonal patterns of Rs and temperature [5]. However, they usually have constant Q_{10} values [17]. In addition, many studies have indicated that Q_{10} exhibited strong seasonal variation patterns [17–19]. However, these studies have ignored changes within seasons; accordingly, analysis at a finer temporal resolution could be a step forward [17].

The Q_{10} values estimated from annual data sets not only reflect temperature responses, but also seasonal changes [20], and could be influenced by several soil physiochemical properties including soil carbon (C) and nitrogen (N) concentration [21], soil water content [18], soil pH [21–23] and soil available phosphorus (P), which is the nutrient indicator most closely related to soil pH [24]. The seasonal evolution of soil physiochemical properties may vary from year to year or from stand to stand, thereby changing the value of Q_{10} [25]. For example, seasonal changes in Q_{10} were negatively correlated with temperature and positively correlated with soil moisture [17], and many study suggests that the vegetation phenology can also controlling seasonal Q_{10} changes [20,26]. However, although there is abundant evidence showing the seasonal changes in Q_{10}, previous studies have not succeeded at establishing which environmental variable determines the spatial variation of the apparent Q_{10} [26]. Moreover, we still lack an understanding of soil microbes to determine seasonal changes in soil physiochemical properties and Q_{10} values.

Fairy rings (FRs) are caused by basidiomycete fungi, which grow

* Corresponding author.
E-mail address: liunan@cau.edu.cn (N. Liu).

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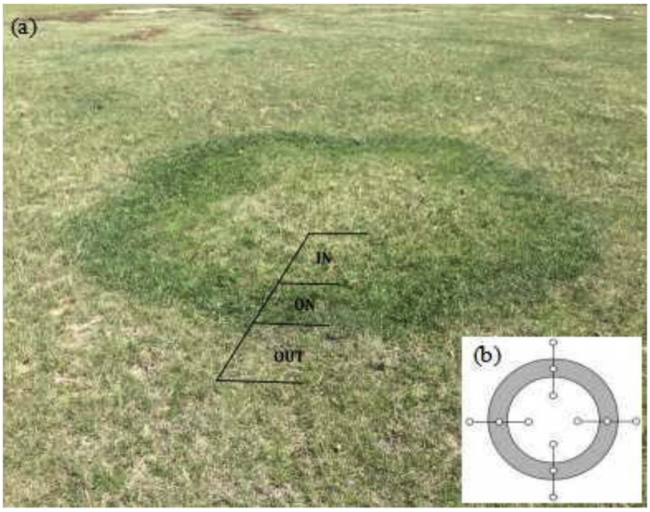

Fig. 1. Basidiomycete fungus develops a fairy ring as evidenced by the green vegetation boundary. (a) Indicates the three zones: (OUT) outside the rings, (ON) on the rings, and (IN) inside the rings. (b) Soil samples were collected from the topsoil (0–15 cm) from three zones and four positions at each sampling period.

radially through the soil and produce fruiting bodies near the outer edge of the ring [27]. Previous research has suggested that FR fungi grow on dead soil organic matter and release nutrients into the soil, resulting in higher P availability within the dense vegetation area of the ring, in contrast to the outside of the ring [27,28]. Therefore, the soil physiochemical properties are changed in this small area, providing a unique environment for testing temporal variations in soil Q_{10} values in response to changes in soil physiochemical properties.

The temperate steppe of China, which is mainly distributed in Inner Mongolia, constitutes a large part of the Eurasian steppe [29]. The FRs regions evaluated in the present investigation are close to the south-eastern part of Inner Mongolia. In this study, we incubated soil taken from three different zones (Fig. 1) of the FRs for five months under different temperature conditions according to the meteorological data of the sampling site (Fig. 2). The specific goals of our study were: (1) to confirm how the soil physiochemical properties change as a result of FRs and (2) to examine the effects of soil physiochemical properties on the Rs and Q_{10} values. Our initial hypotheses were as follows: (1) there are different physiochemical properties of soil in three zones of FRs that affect the Rs and the Q_{10} values, and (2) soil available P and water content can regulate the temporal variation in the Rs and Q_{10} values.

2. Materials and methods

2.1. Study sites

This study was conducted at the National Field Station for Grassland Ecosystems (41°46′ N, 115°41′ E, elevation 1380 m), which is close to the southeastern part of Inner Mongolia, China. This area is a typical temperate zone characterized by a mean annual temperature of 1.4 °C and a mean annual precipitation of 430 mm. The minimum monthly mean air temperature in the study area is −18.6 °C in January, while the maximum of 21.1 °C occurs in July. Precipitation mainly occurs during the growing season (June through August), which coincides with the highest temperatures. The plant community is dominated by *Leymus chinensis* (Trin.) Tzvel. The site has a calcic-orthic Aridisol soil with a loamy-sand texture according to the ISSS Working Group RB (1998) [30].

2.2. Plant and soil samples collection

Three regular shaped FRs with an internal radius of ~5 m were investigated (3 replicates). In addition, three different zones were identified across transects, proceeding from the outer to the inner areas of rings as follows: OUT, outside the rings; ON, on the rings; and IN, inside the rings (Fig. 1a).

Plant and soil samples were collected during five sampling months (June–October 2016), and we carefully minimize the damage near the sampling area. The samples of the next month were collected from the sample adjacent to the previous month in the same rings. At each sampling period, the soil samples were collected from the topsoil (0–15 cm soil depth and 5 cm diameter) in four different directions for each ring (Fig. 1b), with a total of 36 original soil samples (three rings, three zones and four directions) being collected. We mixed the four direction samples into a repeated sample, and obtained a representative fairy ring data point. Finally, 9 soil samples (three rings and three zones) were obtained from each sampling period. Therefore, 45 soil samples (three rings, three zones and five months) were taken for incubation and analysis over the study period. All of the fresh soil samples were stored at 4 °C for chemical analysis and incubation. To reduce the damage caused to the FRs, one quadrat (20 × 20 cm) was established in only one direction to determine the aboveground biomass of the community. In addition, 9 vegetation samples (three rings and three zones) were collected during each sampling period. The aboveground biomass was cut at the soil surface, then oven dried at 65 °C for 72 h before calculating the aboveground biomass.

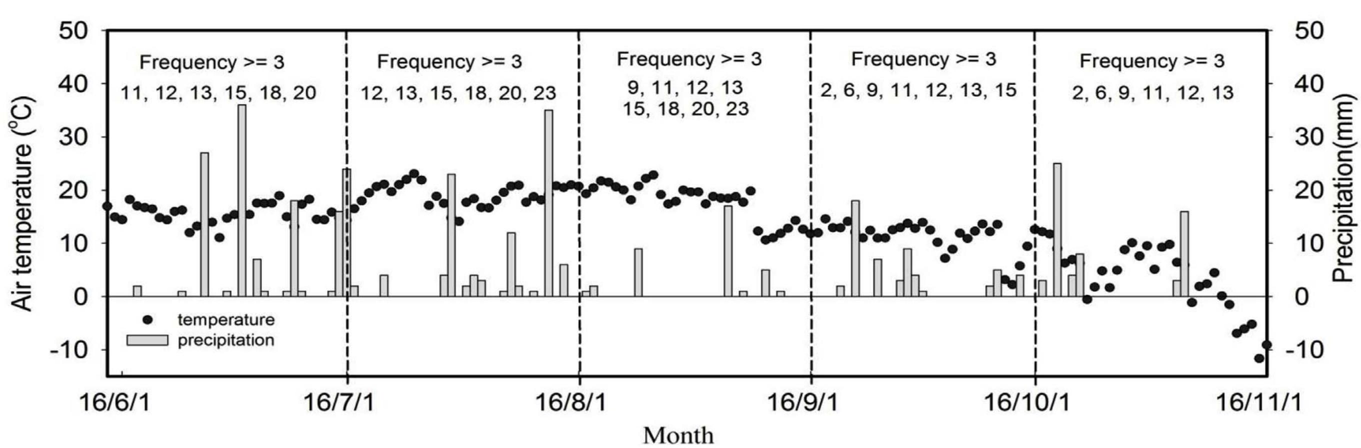

Fig. 2. Monthly dynamics of air temperature and precipitation from June 1 to October 1, 2016. We selected the same daily mean temperature frequency ≥3 as the incubation temperature of the month. The incubation temperatures were 11 °C, 12 °C, 13 °C, 15 °C, 18 °C and 20 °C in June; 12 °C, 13 °C, 15 °C, 18 °C, 20 °C and 23 °C in July; 9 °C, 11 °C, 12 °C, 13 °C, 15 °C, 18 °C, 20 °C and 23 °C in August, 2 °C, 6 °C, 9 °C, 11 °C, 12 °C, 13 °C and 15 °C in September and 2 °C, 6 °C, 9 °C, 11 °C, 12 °C and 13 °C in October.