Components of Soil Respiration and Its Temperature Sensitivity in Four Reconstructed Soils

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Components of soil respiration and its temperature sensitivity in four reconstructed soils

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Abstract: seasonal changes characteristics in the respiration of four reconstructed soil masses in a barren gravel land were monitored using soil carbon flux measurement system. The results showed that (1) The seasonal changes in soil respiration and heterotrophic respiration of four reconstructed soils of meteorite, shale, sand and soft rock were the same as the seasonal change in soil temperature. Soil respiration and heterotrophic respiration increased with soil temperature. It was gradually increasing, reaching the maximum in summer and decreasing to the minimum in winter. Among the four reconstructed soils, the average annual soil respiration of reconstructed soil with sand was $4.87 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, which was significantly higher than the other reconstructed soils ($p<0.05$). (2) The autotrophic respiration of four reconstructed soils showed obvious seasonal dynamic changes. The maximum and minimum values appeared in August 2018 and January 2018, respectively. In the whole year, The variation range of the annual average soil autotrophic respiration in the total respiration of the reconstituted soil with addition of meteorite, shale, sand and soft rock were 12.5-38.0%, 9.5-42.0%, 7.7-41.2%, and 5.0-39.3%, respectively. (3) Soil temperature was the main factor

affecting soil respiration. The four reconstructed respiration had a very significant correlation with soil temperature ($p < 0.01$). The relationship between reconstructed soils respiration and soil temperature can be indexed function characterization. The 90% to 93% changes in soil respiration of reconstructed soils were caused by soil temperature. The order of Q_{10} in soils respiration of four reconstructed was as follows: Sand > shale > soft rock > meteorite.

Keywords: seasonal changes, soil respiration, temperature sensitivity, soil temperature, ecosystems

1. Introduction

Soil respiration was the main way of the terrestrial ecosystems to release CO_2 to the atmosphere [1, 2]. The annual CO_2 released into the atmosphere by soil respiration was more than 10 times that of fossil fuel combustion [3]. The temperature sensitivity of soil respiration was the main factor that the response of terrestrial ecosystems to global warming, and it also determined the feedback of soil respiration to atmospheric CO_2 concentration [4]. In the context of continuous global warming, researching the temperature sensitivity of soil respiration has always been the focus of scholars [5, 6]. The mainstream view was that soil respiration had strong temperature sensitivity [7, 8]. Temperature and moisture were the main influencing factors of soil respiration [9, 10], but in reality, the soil respiration rate was the result of the joint action and mutual influence of many influencing factors such as temperature, humidity and organic carbon, Which complicated the response of soil respiration to temperature changes [11, 12]. The response of soil respiration to temperature changes had spatio-temporal variability [13], which undoubtedly increased the complexity of the research on the temperature sensitivity of soil respiration.

Soil respiration was composed of autotrophic respiration and heterotrophic respiration, and the contribution of each component to temperature sensitivity was not clear [14]. Clarifying the response of soil respiration process to temperature changes, it is necessary to accurately grasp the proportions of autotrophic respiration and heterotrophic respiration in total soil respiration. The biological and ecological processes involved in different components were different, and the response to temperature changes was also different [15], so the division of soil respiration into different components was the key to understanding the response of soil respiration to temperature changes from a mechanism [16]. The research results of temperature sensitivity of soil respiration and its components were quite different. Some studies believed that the temperature sensitivity of autotrophic respiration was greater than that of heterotrophic respiration [17, 18], but there were also studies have found that the temperature sensitivity of autotrophic respiration was less than that of heterotrophic respiration [19, 20], and the mechanism of soil respiration on temperature sensitivity was still unclear.

Currently, land consolidation in China has developed from oversimplified land leveling and construction of supporting facilities to soil reconstruction, aiming to create high-quality cultivated land with high nutrient content and good soil structure [21, 22]. In Baoji, Huayin and other places where there are a large number of barren rock beach areas, the project of soil reconstruction has been carried out by adding different soil forming materials and improved materials, soil reconstruction will become the main direction of land consolidation in the future, it is also an important means to supplement cultivated land resources [23]. Soil reconfiguration alters the underlying surface conditions of the region, leading to transform in

the soil respiration of newly formed soils, in turn affecting the regional climate. However, up to now, there are few studies on the soil respiration components of reconstructed soils and their temperature sensibility.

In this study, four reconstructed soils added with meteorite, shale, sand and soft rock were selected as research objects. Use the soil carbon flux measurement system to observe soil respiration and its components, in order to detect the seasonal changes of soil respiration and its components and the temperature sensitivity of soil respiration in 4 different types of reconstructed soils, so as to accurately predict environmental changes the relationship with soil respiration provides a theoretical basis.

2. Materials and methods

2.1 Overview of test plots

The test plot is located in Shangwang Village, Tangyu Town, Meixian County, Baoji City, Shaanxi Province (107°53'50"E, 34°8'33"N), and a demonstration area for the barren gravel land remediation project. The total area is 8.00 hm², and the newly added cultivated land is 6.80 hm². Four materials of soft rock, sand, shale, and meteorite were selected, crushed through a 10 mm sieve, disinfected, sterilized, and mixed with the constructed soil source to form a mixed layer (30 cm) of meteorite, shale, sand and meteorite, and soil. Lou soil, which was the local common soil type, was used for construction. Finally, four reconstituted soils were formed, i.e., gravel + meteorite + lou, gravel + shale + lou, gravel + sand + lou, and gravel + soft rock + lou soil types (hereinafter referred to as meteorite, shale, sand, and soft rock reconstituted soil masses) long-term positioning test. The dosage of meteorite, shale, sand, and soft rock was $1 \times 10^{-3} \text{ m}^3/\text{m}^2$. The dimensions of all test plots were $20 \times 30 \text{ m}^2$ [24].

Three soil respiration rings (inner diameter 10 cm) were buried in each of the four test plots, ensuring that the tops of the rings were 2 cm above the ground. At the same time, three small rectangular plots (2×2 m) were randomly set up as root exclusion treatment plots. A soil respiration ring of the same specification was buried in each of root exclusion treatment plots. A small trench with a depth of 40 cm was excavated around the root exclusion treatment plots. The excavated ditches were partitioned with as oards, and the soil was backfilled according to the profile level. The vegetation on the ground was cut off in soil respiration rings, ensuring that no vegetation grew in soil respiration rings during the observation period[24].

2.2 Research methods

From November 2017 to October 2018, all the soil respiration rings of four test plots were measured on the three typical days each month. The measurement time per typical day was from 9:30 am to 11:00 am, and the time interval was basically 6~8 days. Soil respiration measurements were performed using a soil carbon flux measurement system (LI-8100, LI-COR Biosciences, Lincoln, NE, USA) to measure soil carbon flux, soil temperature at 5 m and water content at 10 cm. Each soil respiration ring was measured 3 times and the measurement time was 4 min. Autotrophic respiration was obtained by subtraction, that is, soil autotrophic respiration should be the difference between soil total respiration sinus heterotrophic respirations[24].

2.3 Data Analyses

One-way ANOVA was used to analyze differences in soil respiration of the four reconstructed soils. All statistical tests were carried out using SPSS software (version 16.0; SPSS Inc., Chicago, IL, USA). Nonlinear regression was used to assess the relationship

between soil respiration and hydrothermal influence factors of the four reconstructed soils, and Q_{10} was estimated. The relationship between soil respiration and soil temperature was fitted by an exponential model (Eq.1) [24]:

$$R_s = a e^{bT}, Q_{10} = e^{10b} \quad (\text{Eq.1})$$

Where R_s is the soil respiration rate ($\mu\text{mol m}^{-2} \text{s}^{-1}$); T is the soil temperature ($^{\circ}\text{C}$); a and b are the model parameters, and Q_{10} is the sensitivity coefficient of soil respiration, which refers to the change in entropy of soil respiration rate when the soil temperature rises by 10°C .

3. Results and analysis

3.1 Respiration and heterotrophic respiration of reconstructed soils

The seasonal changes in the respiration and heterotrophic respiration of four reconstructed soils with the addition of meteorite, shale, sand, and soft rock were the same as the seasonal change in soil temperature. Soil respiration and heterotrophic respiration gradually increased with the increase of soil temperature. The trend was highest in summer and lowest in winter. In the whole year, The seasonal changes in the respiration of four reconstructed soils with the addition of meteorite, shale, sand, and soft rock ranged from 0.16 to $7.97 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$, 0.21 to $9.69 \mu \text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$, 0.26 to $10.87 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$, and 0.20 to $8.71 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$, respectively. the heterotrophic respiration rate varied from 0.14 to $4.94 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$. $0.19 \sim 5.62 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$, $0.24 \sim 6.39 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ and $0.19 \sim 5.42 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ (Figure1). Among four reconstructed soils, the annual average soil respiration of reconstructed soils with sand was $4.87 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$, which was significantly higher than the other three types of reconstructed soil ($p < 0.05$), but The difference between the other three

reconstructed soils were not significant.

Figure 1 Seasonal changes in soil respiration and heterotrophic respiration of four reconstructed soils (mean $\pm$ standard error)

2.2 Seasonal changes in the autotrophic respiration of four reconstructed soils

The autotrophic respiration of four reconstructed soils showed obvious seasonal dynamic changes. The highest and lowest values appeared in August 2018 and January 2018, respectively. The highest value in autotrophic respiration of four reconstructed soils with the addition of meteorite, shale, sand, and soft rock were 3.03, 4.07, 3.29, and 5.62 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, and the minimum values were 0.02, 0.02, 0.01 and 0.19 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, respectively (Figure 2). There were significant differences in soil autotrophic respiration among the three reconstructed soils with the addition of shale, sand, and soft rock ($p<0.05$), and significant differences in soil autotrophic respiration among the three reconstructed soil masses with the addition of meteorite, shale, and sand ($p<0.05$). There was no significant difference in soil autotrophic respiration between the reconstructed soil masses with the addition of meteorite and soft rock. In the whole year, the annual average soil autotrophic respiration of the reconstructed soil masses with the addition of meteorite, shale, sand, and soft rock accounted

for 12.5~38.0%, 9.5~42.0%, 7.7~41.2%, and 5.0~39.3% of the total respiration, respectively.

Figure 2 Seasonal changes in soil autotrophic respiration of four reconstructed soils (mean $\pm$ standard error)

2.3 The relationship between soil respiration and soil temperature, water content

The soil respiration of four reconstructed soils has a very significant correlation with soil temperature ($p < 0.01$), and there was no obvious correlation with the soil water content. The soil respiration components of four reconstructed soils have a very significant correlation with soil temperature ($p < 0.01$) (Table 1), soil temperature was the main factor affecting soil respiration. From the perspective of changes throughout the year, the relationship between

soil respiration and soil temperature of four reconstructed soils can be characterized by exponential functions (Table 2). The 90% to 93% changes in soil respiration of four reconstructed soils with the addition of meteorite, shale, sand, and soft rock were caused by soil temperature, the Q_{10} values were 3.23, 3.66, 3.89 and 3.50, respectively. The order of Q_{10} in soils respiration of four reconstructed was as follows: Sand> shale> soft rock > meteorite, the Q_{10} of reconstructed soils with sand was significantly higher than that of the other reconstructed soils, and the Q_{10} of the other three reconstructed soils have no difference significantly.

Table 1 Correlation between soil respiration and soil temperature (T), water content (W)

Respiration component	Meteorite		Shale		sand		soft rock	
	T	W	T	W	T	W	T	W
Total Respiration	0.952**	0.416	0.942**	0.566	0.937**	0.363	0.955**	0.487
heterotrophic respiration	0.960**	0.429	0.942**	0.571	0.944**	0.380	0.971**	0.493
autotrophic respiration	0.934**	0.491	0.913**	0.541	0.899**	0.323	0.914**	0.468

Note: **, $p < 0.01$ *, $p < 0.05$.

Table 2 Relationship between annual soil respiration (R) rate and temperature (T)

Reconstituted soil mass types	relationship	Model types	R^2	Q_{10}
Meteorite	$R \& T$	$R=0.3021e^{0.1343T}$	0.90	3.23a
Shale	$R \& T$	$R=0.3593e^{0.1242T}$	0.92	3.66a
Sand	$R_S \& T$	$R=0.3838e^{0.1182T}$	0.92	3.89b
Soft rock	$R \& T$	$R=0.3194e^{0.1227T}$	0.93	3.50a

4. Discussion

4.1 Soil respiration and its components

The four reconstructed soils in respiration and its components were high in summer and low in winter, showing obvious seasonality. This was consistent with the conclusions obtained from previous studies on soil respiration changes in forest, grassland, and farmland

ecosystems in different regions [25, 26, 27], which was determined by suitable temperature and soil moisture conditions in summer [28]. Heterotrophic respiration is an important component of soil respiration. Organic carbon entered the atmosphere mainly through heterotrophic respiration, participated in the ecosystem carbon cycle process, and affected global climate change [29]. In this study, the changing trends in soil heterotrophic respiration and soil respiration of four reconstructed soils were consistent, and all showed a single-peak curve, which was consistent with the research conclusions of soil respiration obtained by Li et al. [30] in the Sanjiang Plain in Northeast China and Shi et al. [31] in semi-arid loess plateau China. The ratio of autotrophic to total respiration in varies from 5.0 to 42.0%. The study on the percentage of autotrophic respiration to total soil respiration showed that the ratio of autotrophic respiration to soil respiration was 13 to 94% [32], the proportion of autotrophic respiration in total soil respiration in cold zone was 50~93%, followed by 33~62% in temperate zone [33], which may be due to the proportion of autotrophic respiration was affected by vegetation, time, temperature, and measurement methods [34]. Various types of ecosystems have significant differences in different seasons. Autotrophic respiration show obvious changes with changes in climate, day and night, and seasons. The contribution of autotrophic respiration to total soil respiration was usually higher in the growing season, but the period was relatively low in the dormant year [32], which was why the soil autotrophic respiration was significantly higher in summer than in winter.

4.2 Reconstruct soils respiration with addtion of different materials

The production of mineral fertilizers and nutrient substrates using relevant miners materials at home and abroad was widely used to improve soil quality. The four additives selected meteorite,

shale, sand and soft rock in this study were all mineral materials with natural and unique crystal structure and good physical and chemical properties, which can improve soil structure, increase soil moisture retention capacity, increase soil fertility, adjust soil pH and repair heavy metal pollution, etc. [22, 35]. The addition of the improved materials changed the physical, chemical properties and the ecological environment of reconstructed soils in the study area [36, 37], causing changes in the gas and material cycle process to varying degrees, especially the changes in the underlying surface changed in soil temperature, moisture, etc., have an impact on the respiration of reconstructed soils. The order of Q_{10} values in soil respiration of four reconstructed soils in this study were all sand > shale > soft rock > meteorite. The Q_{10} values in soil respiration of reconstructed soils with sand was significantly higher than that of the other reconstructed soils. This was because the physical properties of different materials were different, and the effects on soil respiration after addition were also different. Sand has a small specific heat capacity, a faster heating, and a faster approach to the temperature of the environment, and at the same time a faster cooling. Meteorite has good water storage and moisture retention performance, a large specific heat capacity, and it takes a long time to raise the temperature.

4.3 The relationship between soil respiration and hydrothermal factors

Among the environmental factors, water content and temperature were the main factors affecting soil respiration in Chinese farmland ecosystems, but soil respiration and its components responded differently to temperature and water content [38]. Many studies believed that soil temperature were the main factors affecting soil respiration. It can explain seasonal changes in soil respiration [39, 40]. In this study, the soil respiration and soil temperature of four reconstructed soils was exponentially correlated, which was consistent

with the research conclusions of most scholars [41, 42]. During the monitoring period, the soil volumetric water content was lower than the field water holding capacity, which did not inhibit soil respiration. This was also one of the important factors that reconstructed soils temperature can better explain the seasonal changes in soil respiration. Some scholars believed that soil moisture was the main factor affecting seasonal changes in soil respiration in tropical forests [43]. Through comparative analysis, this study believed that the correlation between soil respiration and soil volumetric water content was not significant, causing this difference the reason was that the influence of soil moisture on soil respiration was more complicated. Differences in precipitation changes, total annual precipitation and soil structure in the study area may cause changes in the relationship between the two both. There was a threshold for the influence of soil moisture on soil respiration, which only worked when the threshold was exceeded, but the moisture threshold was affected by factors such as soil texture and structure.

4.4 Temperature sensitivity of soil respiration

The temperature sensitivity of soil respiration was an important indicator for quantifying and predicting the response of ecosystems and global carbon cycles to climate change [44]. Although most scholars had shown that temperature and moisture were the main factors affecting soil respiration, soil respiration was actually the result of the combined effects of soil physics, chemistry, biology and other factors [45]. At the same time, soil respiration responded to temperature changes with spatiotemporal variability [46], which increased the temperature sensitivity of soil respiration complexity. Generally scholars believed that soil respiration was usually modeled by simple temperature, and temperature sensitivity was

expressed as a function of the basal rate of soil respiration and the respiration change rate under a temperature change of 10°C [47], which is Q_{10} , which was widely used to estimate the temperature sensitivity of soil respiration. The temperature sensitivity of soil respiration can vary for different soil and climatic conditions [48]. In this study, the soil respiration of four reconstructed soils had a strong sensitivity to temperature changes. Q_{10} show a strong seasonal and annual change pattern, which decreased with the increase of soil temperature, which was in agreement with the research of Chen et al. [49], Meyer et al. [41], Tian et al. [50] in the subalpine forest system of the Qinghai-Tibet Plateau in China, the wheat-corn rotation planting system, and the bamboo forest planting system in western China, respectively.

4. Conclusion

(1) The seasonal changes in soil respiration and heterotrophic respiration of four reconstructed soils of meteorite, shale, sand and soft rock were the same as the seasonal change in soil temperature. Soil respiration and heterotrophic respiration increased with soil temperature. It was gradually increasing, reaching the maximum in summer and decreasing to the minimum in winter. Among the four reconstructed soils, the average annual soil respiration of reconstructed soil with sand was $4.87 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, which was significantly higher than the other reconstructed soils ($p<0.05$).

(2) The autotrophic respiration of four reconstructed soils showed obvious seasonal dynamic changes. The maximum and minimum values appeared in August 2018 and January 2018, respectively. In the whole year, The variation range of the annual average soil autotrophic respiration in the total respiration of the reconstituted soil with addition of meteorite, shale, sand and soft rock were 12.5-38.0%, 9.5-42.0%, 7.7-41.2%, and 5.0-39.3%,

respectively.

(3) Soil temperature was the main factor affecting soil respiration. The four reconstructed respiration had a very significant correlation with soil temperature ($p < 0.01$), and there was no obvious correlation with soil water content. The relationship between reconstructed soils respiration and soil temperature can be indexed function characterization. the 90% to 93% changes in soil respiration of reconstructed soils were caused by soil temperature. The order of Q_{10} in soils respiration of four reconstructed was as follows: Sand > shale > soft rock > meteorite, the Q_{10} of reconstructed soils with sand was significantly higher than that of the other reconstructed soils.

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Author contributions

L.N. wrote the main manuscript, L.N. and W.H.Y conceived the study, experimentation and C.T.Q analyzed the data.

Additional Information

Competing interests: The authors declare no competing interests.

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