Acta Ecologica Sinica 37 (2017) 298–306

Contents lists available at ScienceDirect

Acta Ecologica Sinica

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

Adaption of two grasses to soil thickness variation under different water treatments in a karst region

Zhou Li, Jinchun Liu *, Yajie Zhao, Haiyan Song, Qianhui Liang, Jianping Tao

Key Laboratory of Eco-environments in Three Gorges Reservoir Region (Ministry of Education), Chongqing Key Laboratory of Plant Ecology and Resources Research in Three Gorges Reservoir Region, School of Life Sciences, Southwest University, Chongqing 400715, China

ARTICLE INFO

Article history:
Received 23 June 2016
Received in revised form 30 November 2016
Accepted 3 January 2017

Keywords:
Karst
Precipitation change
Soil thickness
Morphology
Biomass accumulation and allocation

ABSTRACT

Properties of soil in karst regions are discontinuous and highly heterogeneous due to the adverse conditions of exposed rocks, tattered land form, steep slopes, and severe soil erosion. Uneven distribution of karst soil also leads to obvious spatial heterogeneity of moisture. Global precipitation changes might aggravate heterogeneity of soil moisture in soils with different thickness. Thus, exploring the responses of plants to water availability and soil heterogeneity in karst regions is necessary for the understanding of how precipitation changes might affect plant growth in soils with different thickness. Herbaceous plants especially grasses in karst regions are most easily to be affected by soil heterogeneity and water availability, considering they mainly utilize water and nutrients from the surface soil through their fibrous root system. Therefore, two graminaceous perennial grasses, *Lolium perenne* L. and *Festuca arundinacea* Schreb. were chosen for the present study. In addition, these two species are often chosen as pioneer plants for ecological restoration and reconstruction in karst regions because of their attributes of fast growth, strong adaptive ability, and high yield, which can effectively promote economic development and help to alleviate rural poverty in the harsh karst region. In our study, three water treatments (CK: 40 ml/day, D1: 20 ml/day and D2: 12 ml/day) were combined with three levels of soil thickness [shallow soil (S_S; 5 cm), control (S_{CK}; 15 cm) and deep soil (S_D; 30 cm)] in a factorial randomized design and measurements were obtained of above- and below-ground growth, and biomass accumulation and allocation. The following results were obtained: (1) In CK water treatment, the total biomass, above-ground biomass, plant height and leaf area of both species were suppressed in S_S as compared with those of S_{CK}, and showed a decline to differing degrees, whereas these parameters were promoted in S_D. The root biomass of *L. perenne*, and root length and surface area of both species in S_S and S_D were not significantly different to those of plants in S_{CK}. The root biomass of *F. arundinacea* increased significantly in S_S, but the observed values did not differ from those of the control (S_{CK}). The specific root lengths of the two species decreased, and the ratio of root mass increased significantly in S_S compared to S_{CK}; but in S_D, there was no difference compared to the control (S_{CK}). (2) In D1 and D2 water treatments, there was a decrease in total biomass, above- and below-ground growth and biomass of both species in S_S, and as water was reduced, the difference in plant height and leaf area between S_S and S_{CK} decreased in both species, and the difference in root length and root surface area between S_S and S_{CK} increased. In the S_D treatment, apart from an increase in root length of *F. arundinacea*, there was no significant difference in other parameters of both species compared to S_{CK}. The ratio of root mass of *L. perenne* in S_S was still higher than S_{CK} in D1 and D2 water treatments, but as water availability decreased from D1 to D2, the difference between S_S and S_{CK} decreased, and there was no significant difference between S_D and S_{CK}. There was no significant difference in the ratio root mass of *F. arundinacea* in both SS and S_D compared to S_{CK} under either D1 or D2 water treatments. The results of this study indicate that when water is sufficient, plant growth is restrained in shallow soil and promoted in deep soil, and as water decreases, plants in shallow and deep soil are both subjected to drought stress with resulting growth suppression, but the drought stress has a greater effect in shallow soil, and the drought conditions induced plant root depth increasing in deep soil. *F. arundinacea*, with a greater root depth, shows stronger adaptability to deep soil compared to *L. perenne*.

1. Introduction

Karst is a distinctive ecological environment system in the geographical environment, with the slow soil forming rate leading to the

* Corresponding author.
E-mail address: jinchun@swu.edu.cn (J. Liu).

https://doi.org/10.1016/j.chnaes.2017.09.001
1872-2032/

congenital lack of soil resources in karst area, and the broken and undulating terrain resulting in discontinuous soil distribution and strong heterogeneity [1]. For karst depression, basins and valleys, the soil is thick and soil distribution is continuous. For hilly area and slopes, the soil is rock soil or missing [2]. Spatial heterogeneity of soil distribution also leads to a high degree of heterogeneity in water distribution [3]. Soil moisture is mainly determined by precipitation and soil water storage, and soil thickness is the key to soil moisture conservation [4]. In many shallow soil regions of karst, the lack of soil mass, poor soil quality and strong permeability lead to poor water storage capacity [5], resulted in karst region-specific karst drought. After sufficient rainfall, the field water holding capacity of soil conservation is only available for plant transpiration demand in 7–14 days [6,7]. Therefore, even in the rainy season, plants are often subjected to drought stress [8]. However, for many deep soil area, strong water storage capacity of the soil layer can be utilized to retain part of the water for plant growth from the evaporation and rock leakage process, and then the drought stress plant suffered can be relieved [9,10]. According to the IPCC forecast, with the global climate changing, rainfall in Chinese karst region (subtropical area) will be reduced, the frequency of rainstorm events will increase, and the interval between precipitations will be extended [11–13]. This prediction has also been confirmed by a lot of domestic scholars [14–16]. A decrease in precipitation and rainfall frequency may increase the frequency and intensity of karst drought, which would lead to further deterioration of the karst habitat which is highly dependent and sensitive to the external environment, and the discontinuous soil distribution would exacerbate the complexity of the impact of rainfall changes on karst ecosystem.

Faced with complex environmental variation, plants have the ability to adjust the allocation pattern, morphology and physiology [17], minimizing the impact of unfavorable factors on themselves [18]. Plant root growth is very sensitive to the size of root proliferation space [19]. The narrow underground space of shallow soil could stimulate roots secreting chemical substances to inhibit the growth, and with more restriction in confined space, the roots' auto-inhibitory effect will get larger [20]. While deep soil can provide more moisture, nutrients and available space for plant root growth, facilitating plant growth and producing more seed output [21]. Furthermore, in arid habitats, plants can adaptively alter the ratio of investment in shoots and roots to increase water and nutrient use efficiency [22,23]. For example, leaf area reduction is considered to be one of the initial responses of seedlings to drought stress [24], and root depth can also reflect the response of plants to arid habitats. In addition, plants can make compensation for soil moisture deficiencies by increasing root depth [25].

At present, harsh karst habitat and fragile ecosystems have received wide attention from academia, and it is generally accepted that water is the most critical limiting factor in the recovery process of karst ecosystem. Accordingly, a large number of studies on adaptability of karst plants to drought stress have been carried out. However, the root cause of karst drought is the lack of soil resources in karst regions. The collective effect of karst drought and the lack of soil resources (thickness) has a serious influence on plant growth, reproduction and distribution in the region.

At present, the adaptability of plant to soil resources (thickness) under karst drought is seldom studied. *Lolium perenne* L. and *Festuca arundinacea* Schreb. are perennial grass of Poaceae family with shallow roots. They mainly utilize water and nutrients from the surface soil through their fibrous root system, unlike shrubs and trees with deeper roots, which can root deeply into the interstices and utilize the moisture and nutrients in the deep interstitial rocks [3]. Therefore, the growth of herbaceous plants especially grasses in karst area is most susceptible to the effects of soil thickness.

In addition, both *L. perenne* and *F. arundinacea* have strong adaptability and can respond to environmental changes quickly, and they can grow well in karst harsh terrain and have a high yield, so they are widely used in karst ecological restoration [26,27].

Therefore, we chose these two species to study their responses to soil thickness under different water treatments by pot experiment to verify the following hypotheses:

(1) Under well-watered conditions, the two species grow well in deep soil, while if soil thickness decreases, plant growth in shallow soil may be inhibited due to the restriction of nutrient and space;
(2) When water is scarce, growth of the two plants is inhibited in different thickness of soil, but in deep soil, the drought conditions would induce the increase of plant root depth to obtain more water and nutrients, thus mitigating the negative impact of drought and the decrease of soil resources on plants.

2. Materials and methods

2.1. Test materials

Lolium perenne L. and *Festuca arundinacea* Schreb. were used as the experimental materials. Experimental soil was yellow limestone soil, taken from Zhongliang mountain located in Shapingba, Chongqing, China. The physicochemical properties were as follows: pH was 7.4 ± 0.14, content of organic matter was $0.34 \pm 0.02\%$, total nitrogen was 0.28 ± 0.03 g/kg, total phosphorus was 0.39 ± 0.02 g/kg and total potassium was 23.7 ± 3.22 g/kg.

2.2. Experiment design

Three levels of soil thickness were set by three self-made rectangular containers with the same basal area and different heights. Five holes were drilled on the bottom of each container which could make the excess water out. Because *L. perenne* and *F. arundinacea* are with fibrous root system, their roots are mainly distributed in the topsoil layer within 15 cm [28]. Therefore, we defined soil thickness of 15 cm as control (S_{CK}), 5 cm as shallow soil (S_S) and 30 cm as deep soil (S_D). Three containers had a same basal area of 0.01 m^2, filled with 500 g, 1500 g and 3000 g of dry soil, respectively. On January 14, 2015, seeds of *F. arundinacea* and *L. perenne* were sowed in the ecological garden of Southwest University. On April 4, 2015, we selected the two species' seedlings with the uniform growth, and transferred them to the designed containers. Each container had two plants. All containers were placed and managed with same light condition in the ecological garden of Southwest University with the altitude being 245 m. After planting, keep the soil moist. Until all seedlings survived and adapted to grow after a period of time, we randomly selected five containers to measure the initial values of plant growth parameters. From each container, one plant was selected.

On April 14, 2015, three water treatments were set. The water treatment levels were determined based on the monthly rainfall (119.58 mm/m^2) from April to June over 30 years from 1981 to 2011 in Chongqing area. According to the basal area of the containers (0.01 m^2), we calculated the average daily rainfall per 0.01 m^2 area is 40 ml, and the height is 4 mm. We set 40 ml daily rainfall as the control (CK), while 20 ml (50% reduction) was water reduction group 1 (D1), 12 ml (70% reduction) was the water reduction group 2 (D2). Each container was watered once every three days and CK, D1 and D2 were watered 120 ml, 60 ml, and 30 ml every time, respectively.

In addition, for each watering and soil thickness condition, three blank controls were set without plant independently. The same water treatments were performed synchronously with the above experiment to measure the soil water content by weighting method. The specific process of soil sample collection is as follows: before every water treatment, we collected mixed soil sample by five-point sampling with different soil depths on the four corners of the container and at an intermediate locations, put the mixed soil sample into an aluminum box, and took them back to lab. Soil moisture storage was calculated