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Impact of artificially simulated precipitation patterns change on the growth and morphology of *Reaumuria soongarica* seedlings in Hexi Corridor of China

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Abstract: Climate change has altered the existing pattern of precipitation and has an important impact on the resistance and adaptability of desert plants. However, the interactive impact and the main characteristics of changes in precipitation amount and precipitation frequency on desert plants are unclear. *Reaumuria soongarica* seedlings were treated by artificially simulating changes in precipitation (30% reduction and 30% increase) and its frequency (50% reduction). We first introduced three morphological indicators (i.e., main root length/plant height ratio (*RHR*), above-ground radial density (*ARD*), and below−ground radial density (*BRD*)) and drew an abstract figure of seedling growth. This experiment confirmed the following: (1) The increase in precipitation noticeably increased the plant height, above-ground biomass, and total biomass of seedlings. (2) The plant height and the biomass of seedlings were more affected by precipitation amount than by precipitation frequency. No interaction was found between precipitation amount and precipitation frequency on the growth of seedlings. (3) The response of *RHR* to precipitation changes was extremely significant, increasing with decreasing precipitation and vice versa. (4) The *ARD* first increased then remained constant as precipitation increased, while *ARD* first decreased and then increased with decreasing precipitation. When precipitation increases, the *BRD* increases and the root system becomes relatively thicker and shorter, and vice versa. In this regard, *R. soongarica* seedlings mainly adapt to their resource supply by adjusting plant height, root length, thickness and biomass.

Keywords: climate change; desert ecosystems; precipitation patterns; growth and morphology; *Reaumuria soongarica*

1. Introduction

Climate change is altering existing precipitation patterns [1,2]. The time and intensity of precipitation may change [3]. In the arid and semi-arid regions of northwestern China, precipitation will increase by 30 to 100 mm in the next 100 years [2]. At the same time, it will be accompanied by a trend of increasing precipitation intervals, decreasing small precipitation events and increasing extreme precipitation events [2]. Globally, the proportion of land surface under extreme drought is predicted to increase from 1%–3% at present to 30% by the end of 2090 [4]. The change of existing pattern of precipitation affects the amount and distribution of many physical, chemical, and biological factors inducing an alteration of available resources and a consequent destabilization of the ecological successions [5]. However, the interactive impact and the main characteristics of changes in precipitation amount and precipitation frequency to desert ecological are unclear. Due to their morphological and functional characteristics, plants show their conservation or alteration status in every moment. Therefore, plants can be considered general biological indicators of the environment where they develop, especially in largescale plant communities [5]. This makes it possible that artificial simulated precipitation patterns change, as the anthropogenic disturbance was used to predict the possible impact of precipitation pattern changes in the future on desert plants and can be observed at different scales and grains of definition.

It is generally believed that the increase in precipitation will increase the above-ground biomass of desert shrubs [6–8] and decrease that of herbaceous plants [9], a decrease in precipitation increases the underground biomass of desert shrubs [6], which may be related to the lifestyle of the plants. However, other studies have also shown that the below−ground biomass of shrubs seedlings decreases with increased precipitation [8], and the biomass of herbaceous plants increases with increased precipitation [10], precipitation increases from 95 to 283 mm, which may be differently sensitive to ecosystem disturbance in different growth stages [11,12]. Some researchers have determined that the frequency of precipitation is also a key factor affecting plant growth [11,13,14]. The main change in precipitation will likely be in the intensity, frequency, and duration of events, but these characteristics are seldomly analyzed in observations or models [15]. Moreover, many scholars only study the impact of precipitation, but few compare the frequency and interactive impacts on individual plant growth by multiple dimensions of precipitation pattern changes (such as precipitation amount and precipitation frequency).

Reaumuria soongarica is an ultra-drought shrub of the Tamaricaceae family. It is the main dominant species and founder species of plant communities in arid and semi-arid desert areas. It has a large distribution area, strong stress resistance, barren resistance, drought resistance, and strong sand collection capacity. It is widely distributed in Central Asia, Western Asia, Southern Europe, and North Africa and is mainly distributed in the northwest region in China. It plays an important role in maintaining the ecological stability of the desert. Seeding is a young plant that is grown from a seed, rather than from a cutting or bulb, for example [16]. The seedling stage of a plant is the core of plant population renewal [17]. It also has a more fragile development stage during plant growth and it is extremely sensitive to ecosystem disturbance [11,12]. At present, research on the impact of precipitation and changes in precipitation frequency on the morphology of *R. soongarica* seedlings has been reported [18–20], but has only studied annual *R. soongarica* seedlings. The complete life cycle of *R. soongarica* is several decades, so it is necessary to study the seedlings for a longer time. We take *R. soongarica* seedlings as the research object and analyze the deviations in their morphological characteristics by artificially controlling the precipitation amount (increase or decrease by 30%) and precipitation frequency (F) (decrease by 50%), in order to reveal the response and adaptation strategies of *R. soongarica* seedlings to precipitation pattern changes. We aim to answer the following questions: (1) What is the impact of precipitation pattern changes on the morphological characteristics of *R. soongarica* seedlings? (2) Can increasing precipitation and decreasing precipitation frequency promote the growth of *R. soongarica* seedlings? (3) What is the adaptive strategy of *R. soongarica* seedlings to precipitation pattern changes?

2. Materials and Methods

2.1. Study Area

The research area was selected at the National Field Observation and Research Station of the Linze Farmland Ecosystem in Gansu Province. This station is located in the middle stream of the Heihe River and the southern edge of the Badain Jaran Desert. Its geographical coordinates are 39°21′N and 100°07′E (Figure 1). The terrain is flat, with an altitude of 1382 m. The main climatic characteristics are drought, high temperature, and windy, which belong to a typical temperate continental desert climate. The annual average precipitation is 119.16 mm, mostly concentrated in May–October, accounting for about 85% of the whole year. The relative humidity of the air is 46% and the annual evaporation is as high as 2390 mm, which is about 20 times that of precipitation [21] (Figure 2a,b). Wind and sand activities are strong and plant growth depends entirely on natural precipitation. The zonal soil is gray-brown desert soil, sandy loam soil, and sandy soil. The landform types are mainly fixed sandy land, semi-fixed sand dune, and mobile sand dune.

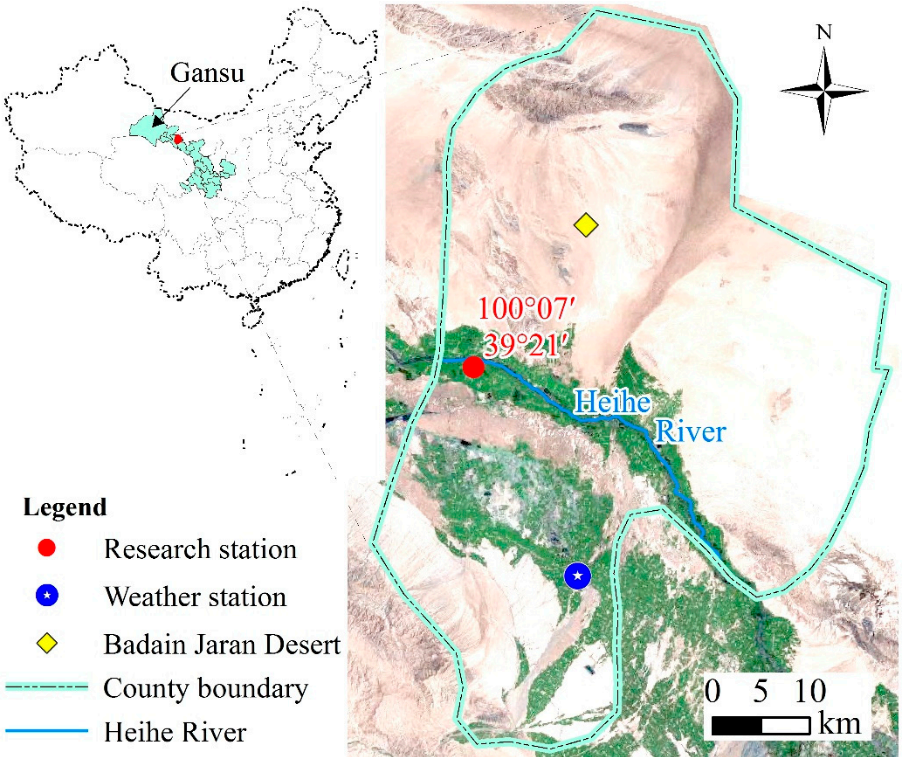

Figure 1. Location map of the study area.

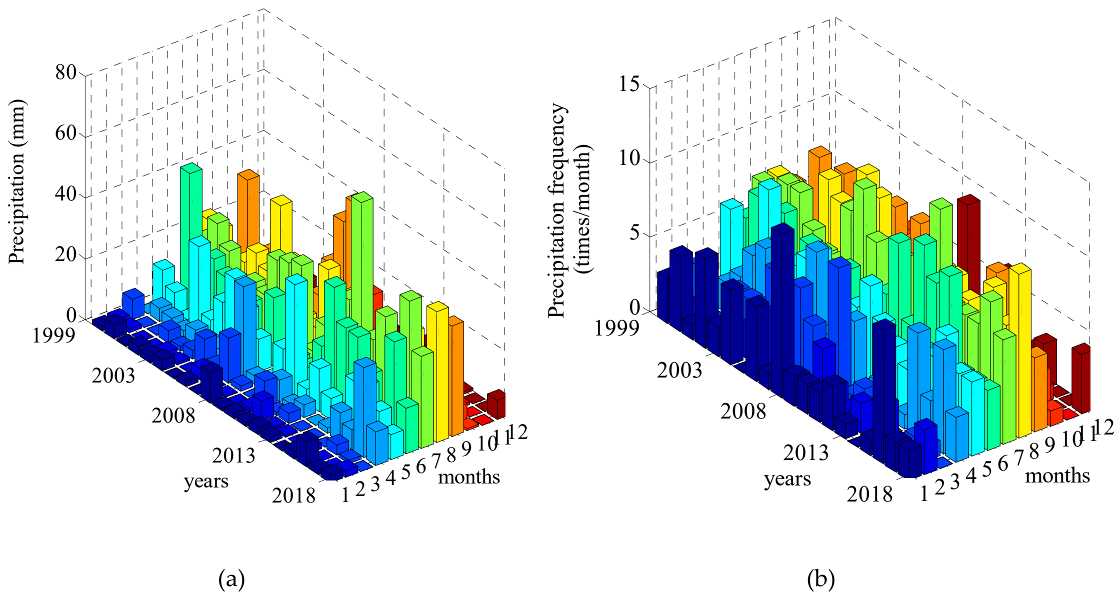

Figure 2. (**a**) Distribution of precipitation in Linze from 1999 to 2018; (**b**) precipitation frequency in Linze from 1999 to 2018.

2.2. Research Methods

2.2.1. Study Site and Experimental Design

The test site in the experimental field was relatively flat, well ventilated, and the soil was uniform in the same place with natural temperature. Before the experiment started, we measured the initial soil condition (nutrients, moisture et al.).The content of organic matter in the 0–30 cm soil layer is less than 0.5%, the total N and P content is relatively low and less than 0.05%, the total K content is less than 2.0%, the pH is about 9, and the water content of soil is relatively low, less than 4% on average. In early May 2017, we selected healthy seeds with uniform size and full grains for sowing, which were collected and stored from the previous year. *R. soongarica* seeds were soaked continuously in hot water at a temperature of 25 °C for 24 hours before being planted. Seeds were sown in rows at intervals of 0.3 m and a depth of 0.5–1.0 cm. After that, adequate irrigation was performed to ensure a certain emergence rate. In early June 2017, after the seedlings were well established, precipitation treatment began in 2018 while precipitation treatment began in late May.

The average annual precipitation in Linze has been 119.2 mm for many years. From 1999 to 2018, the overall precipitation remained stable, but the annual precipitation amount and precipitation frequency changed significantly (Figure 2a,b). The maximum and minimum annual precipitation is 186.3 mm (2010) and 71.1 mm (1999), which is 156.34% and 59.67% of the average annual rainfall of 119.2 mm. Except individual extreme years, in 90% of the past 20 years, annual precipitation is within the range of 70–130% of the average annual precipitation. The maximum and minimum monthly precipitation frequencies from July to October in the last 20 years were 9.3 times per month (2007) and 4 times per month (2004). From July to October, for many years, the average monthly precipitation frequency was 5.6 times per month. Therefore, in this experiment, three precipitation gradients, W (annual average precipitation), W− (W decreased by 30%), and W+ (W increased by 30%), were set with 119.16 mm as the control; two precipitation frequencies gradients were set, F (6 times per month) and F− (3 times per month); giving a total of 6 precipitation treatments: W−F, W− F− WF, WF−, W+F, and W+F−. The plot area was 3 × 2 m for each precipitation treatment, six plots for one block and three replicated blocks, with a total of one hundred and forty-four rows and about seven thousand and five hundred seeds (Figure 3).

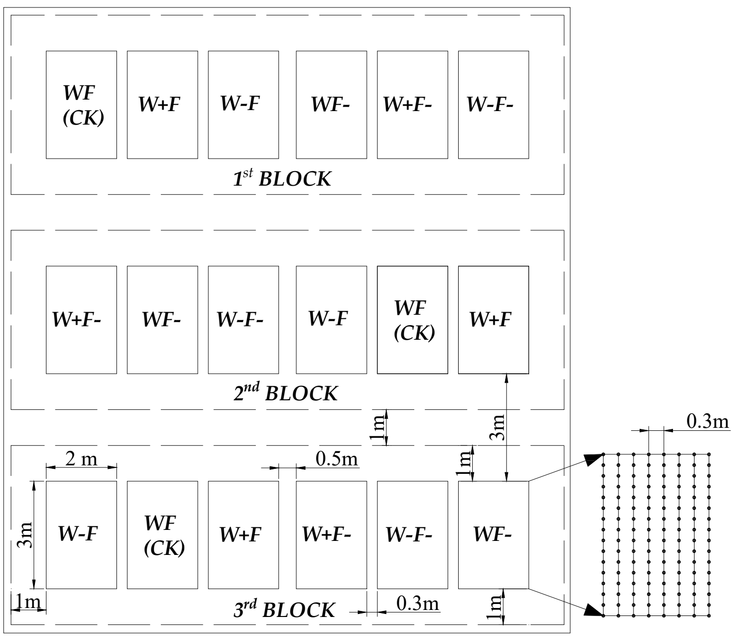

Figure 3. Diagram of experimental design for the seedling growth study. W, annual average precipitation; W+, 30% increase in precipitation; W−, 30% decrease in precipitation; F, annual average precipitation frequency (6 times per month); F−, 50% decrease in precipitation frequency (3 times per month). Black dots represent the random distribution of seedlings.

The temperature might be lower than 0°C before May, and sudden cooling might cause frostbite to the newly sprouted seedlings, thus affecting the experimental results. The research period was from May 2017 to October 2018. Except for the experimental precipitation treatment period, the seedlings were mainly irrigated by natural precipitation from the beginning of November 2017 to the end of April 2018. In the period of precipitation treatment, each block was provided with rain shelters, trenches, and ventilation around to keep other natural factors close to the natural conditions. The height of the canopy was 1.5 m and the sample plot extended around 1 m. It was fixed with wooden stakes. Shelters were removed on days without rain to minimize shelter effects on other environmental variables. During the whole experimental period, it was blocked at night, cloudy periods, and during precipitation to prevent natural precipitation from affecting the experiment. Artificial irrigation was performed according to the irrigation volume and irrigation frequency (Table 1) set in the experiment. Using a watering can, we evenly sprinkled the simulated precipitation amount set in the experiment in each plot. The irrigation time was from 19:00 to 20:00 on irrigation days (if the rain was absent for 1 day). From July to October, samples were taken on the 25th of each month, during which a total of 8 destructive sampling tests were performed. These selected data were for collecting samples from 2017 (25 July and 25 October) and 2018 (25 July and 25 October).

Table 1. Total number of precipitation events (treatments) in the *R. soongarica* growth experiments at two cycle levels from 2017 to 2018. W (annual average precipitation), W− (W decreased by 30%), and W+ (W increased by 30%).

Time	Average Monthly Precipitation (mm)	Event Size for Each Precipitation (mm)			Precipitation Cycle (d)	Precipitation Frequency (Times per Month)
		W−	W	W+		
July	26.7	3.1	4.5	5.8	5	6
		6.2	8.9	11.6	10	3
August	21.5	2.5	3.6	4.7	5	6
		5.0	7.2	9.3	10	3
September	18.0	2.1	3.0	3.9	5	6
		4.2	6.0	7.8	10	3
October	5.8	0.7	1.0	1.3	5	6
		1.4	1.9	2.5	10	3

2.2.2. Sampling Method

During sampling, we selected six healthy, uniform seedlings in each treatment. The seedling height was first measured with a steel tape measure; a vernier caliper was used to measure the base diameter, which was recorded. By using a spatula, the entire root system was carefully dug out and taken to the laboratory. The excess sand and soil were carefully removed; the length of the main root was measured with a tape measure. The above-ground and below−ground biomass were separated and dried in a 60 °C constant-temperature oven to obtain a constant weight. An electronic balance was used to weigh the above-ground biomass, below−ground biomass, and total biomass, the root/shoot ratio, the root/height ratio, the above-ground radial density, and the below−ground radial density.

2.2.3. Calculating the Root/Height Ratio, Above-Ground Radial Density, and Below−Ground Radial Density Parameters

Based on the fractal theory [22,23], we formulated the following morphological parameters and drew an abstract morphological figure of the seedlings (Figure 9):

$$RHR = \frac{H_R}{H_P}, \tag{1}$$

where RHR (main root/plant height ratio) is the root/height ratio; H_R is the main root length (cm); H_P is the plant height (cm);

$$ARD = \frac{M_A}{H_P}, \tag{2}$$

where ARD is the above-ground radial density (g·cm^{-1}); M_A is the above-ground biomass (g); and H_P is the plant height (cm);

$$BRD = \frac{M_B}{H_R}, \quad (3)$$

where BRD is the below−ground radial density (g·cm^{-1}); M_B is the below−ground biomass (g); and H_R is the main root length (cm).

2.2.4. Data Analysis

In different growth periods, two-factor analysis of variance distribution was used to evaluate the impacts of three precipitation treatments (W−, W, and W+), two precipitation frequency treatments (F and F−), and their interactions on plant height, basal diameter, main root length, above-ground biomass, below−ground biomass, total biomass, root/shoot ratio, root/height ratio, above-ground radial density, and below−ground radial density of *R. soongarica* seedlings. Least-significant difference (LSD) was used to test for significant differences between samples. All analyses were performed using SPSS 21.0 and plots were performed using Matlab R2014a and Excel 2010.

3. Results

3.1. Impact of Precipitation Pattern Changes on Plant Height of R. Soongarica Seedlings

The impact of precipitation on plant height was significant ($P < 0.001$, Table 2). At both precipitation frequencies, plant height increased at W+ (Figure 4). When the precipitation increased by 30% (W+) and the frequency of precipitation was three times per month (F−), the plant height was the highest (Figure 4). Plant height increased with increasing precipitation and decreasing precipitation frequency. In 2017 (July and October) and 2018 (July and October), the same precipitation frequency (F) with increased precipitation (W+) increased plant height by 12.50%, 59.01%, 55.42%, and 71.93%, respectively. With the same amount of precipitation (W−, W, and W+), the difference in plant height was not significant at the two precipitation frequencies (F and F−) ($P > 0.05$, Figure 4).

Table 2. (F−values) based on two-way ANOVA of the impacts of precipitation amount and precipitation frequency on the indexes of *R. soongarica* seedlings.

Source of variation	Precipitation (W)	Precipitation frequency (F)	Precipitation (W)×frequency (F)
Plant height	29.669 (0.0000) ***	2.646 (0.1298)	0.179 (0.8386)
Basal diameter	1.286 (0.3119)	0.278 (0.6075)	0.019 (0.9812)
Main root length	3.730 (0.0550)	0.069 (0.7974)	0.041 (0.9600)
Above-ground biomass	14.267 (0.0007) ***	2.746 (0.1234)	0.010 (0.9897)
below−ground biomass	10.358 (0.0024) **	0.012 (0.9154)	0.100 (0.9054)
Total biomass	13.157 (0.0009) ***	0.861 (0.3717)	0.010 (0.9896)
Root/shoot ratio	1.371 (0.2909)	14.135 (0.0027) **	1.588 (0.2444)
Main root length/Plant height ratio (RHR)	134.23 (0.0000) ***	2.562 (0.1354)	0.876 (0.4416)
Above-ground radial density (ARD)	10.516 (0.0023) **	0.925 (.03551)	0.250 (0.7825)
below−ground radial density (BRD)	92.207 (0.0000) ***	1.069 (0.3216)	0.055 (0.9470)

Note: The different levels of probability considered are ***$P < 0.001$, ** $P < 0.01$, * $P < 0.05$. W, precipitation; F, precipitation frequency. Replicate number = 3.

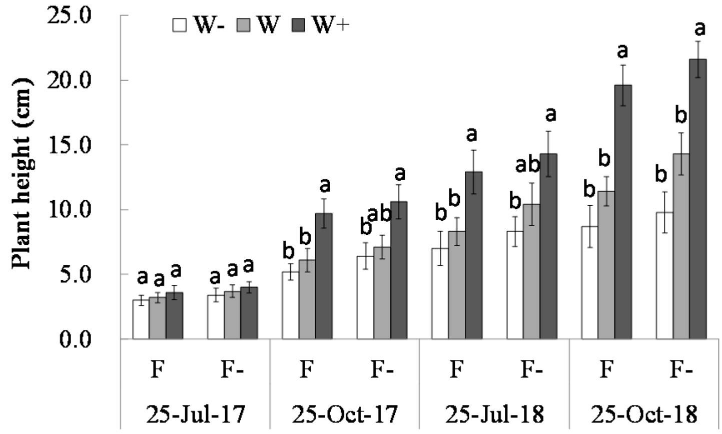

Figure 4. Dynamics of plant height of *R. soongarica* seedlings with different precipitation patterns from 2017 to 2018. For all plots, different lowercase letters are significantly different ($P < 0.05$) based on single-factor analysis of variance (ANOVA) with the same precipitation frequency. Bars indicate standard errors, n = 3.

3.2. Impact of Precipitation Pattern Changes on Above-Ground and Below−Ground Biomass and Total Biomass Accumulation

The impact of precipitation on the accumulation of above-ground, below−ground, and total biomass was significantly different ($P < 0.01$, Table 2). At both precipitation frequencies, above-ground and below−ground biomass and total biomass increased at W+ (Figure 5a–c). When the precipitation increased by 30% (W+) and the frequency of precipitation was three times a month (F−), the above-ground biomass and total biomass were the highest (Figure 5a,c). At the same precipitation frequency (F), an increase in precipitation (W+) promoted the accumulation of above-ground biomass, which increased by 94.59%, 101.38%, 54.93%, and 71.95%, respectively, during the growing season. The impact of increased precipitation (W+) on below−ground biomass was only significant in the growth of seedlings in July 2017 and October 2018 ($P < 0.01$, Figure 5), which were 108.04% and 68.53%, respectively, and the other growth periods were not significant ($P > 0.05$, Figure 5). The same amount of precipitation (W) with a reduction in precipitation frequency (F−) had a significant difference in seedling above-ground biomass with an increase of 33.06% in July 2018. There were no significant differences in other growth stages ($P > 0.05$). Changes in precipitation amount and precipitation frequency had significant impacts on the total biomass of *R. soongarica* seedlings; the trends were the same as those for the above-ground biomass. There was no significant difference in the impact of precipitation reduction (W−) on the below−ground biomass at the two frequencies (F and F−) ($P > 0.05$).

3.3. Impact of Precipitation Pattern Changes on The Root/Shoot Ratio

There was a significant difference in the impact of precipitation increasing on root/shoot ratio ($P < 0.05$) in October 2017 and July 2018, which decreased by 34.77% and 36.89%, respectively. There were not significant ($P > 0.05$, Table 2 and Figure 6) in other periods. While, there was not significantly different in the impact of precipitation decreasing on root/shoot ratio ($P > 0.05$) (except for July 2017). W+F treatmen decreased by 34.77% in October 2017 and W+F treatmen decreased by 36.89% in July 2018, respectively. The effect of precipitation frequency on root/shoot ratio was significantly different ($P < 0.01$, Table 2). Decrease in precipitation frequency (F−), W−F− treatment decreased by 60.15% in July 2017. W−F− treatment decreased by 24.60%, WF− treatment decreased by 26.47%, W+F− treatment decreased by 28.55% in October 2017, W+F− treatment increased by 28.57% in July 2018, and WF− treatment decreased by 31.75% in October 2018, respectively.

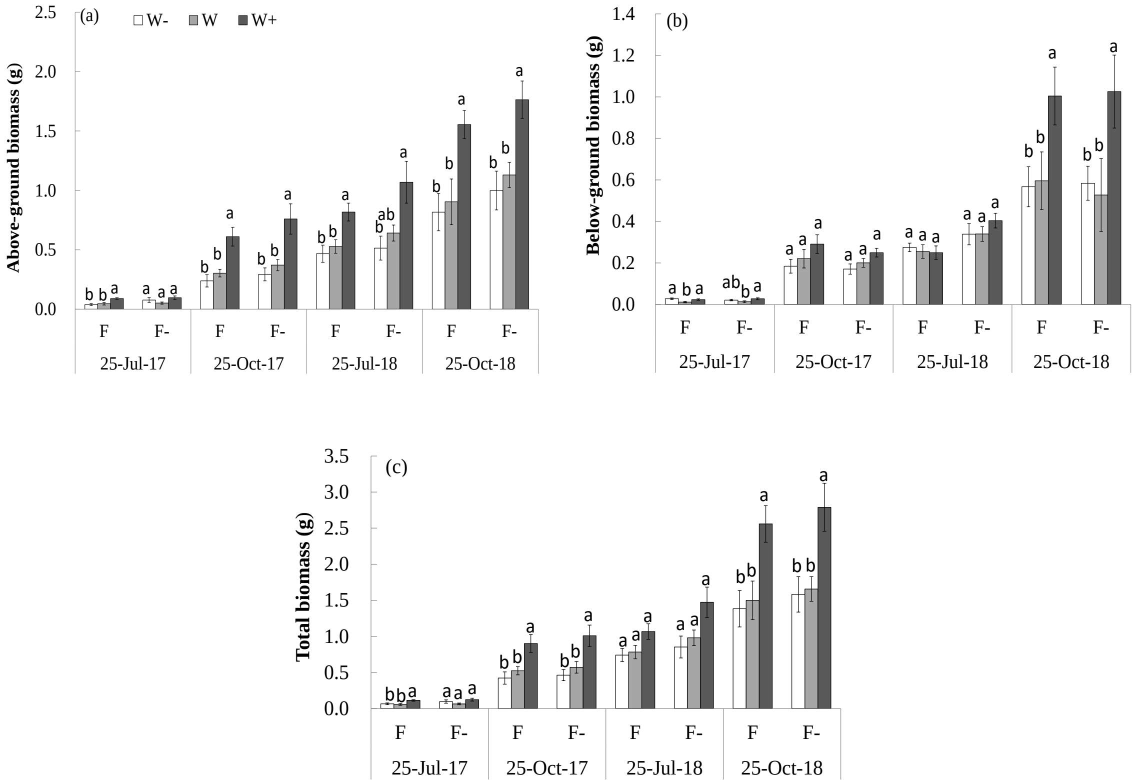

Figure 5. Dynamics of above-ground biomass (**a**), below−ground biomass (**b**) and total biomass (**c**) of *R. soongarica* seedlings with different precipitation patterns from 2017 to 2018. Different lowercase letters are significantly different ($P < 0.05$) based on single-factor analysis of variance (ANOVA) with the same precipitation frequency. Bars indicate standard errors, n = 3.

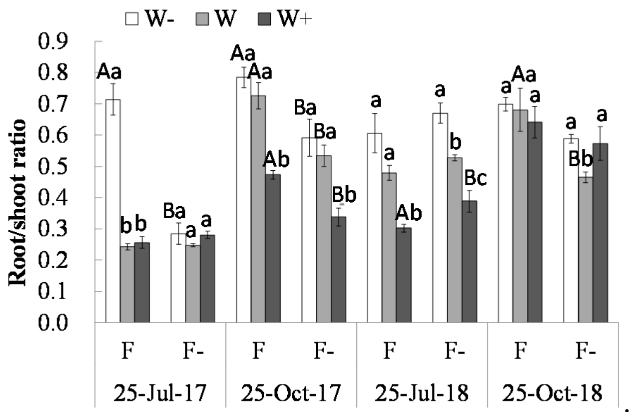

Figure 6. Dynamics of the root/shoot ratio of *R. soongarica* seedlings with different precipitation patterns from 2017 to 2018. Different capital letters indicate that in the same precipitation, the difference between the change of precipitation frequency and the control is significant ($P < 0.05$), and different small letters indicate that the difference between the change of precipitation and the control is significant ($P < 0.05$).

3.4. Impact of Precipitation Pattern Changes on the Root/Height Ratio

The impact of precipitation change on the root-to-height ratio is extremely significant ($P < 0.001$, Table 2 and Figure 7). From October 2017, the root-to-height ratio stabilized under various precipitation treatments. The main root/height ratio (RHR) was 5.435–6.639 under W− treatment, 2.750–3.694 under W treatment, and 1.676–2.439 under W+ treatment. When precipitation frequency (F) was constant, with an increase in precipitation (W+), seedling growth in July and October 2017 was not significantly different ($P > 0.05$), but it was significantly different in July and October 2018 ($P < 0.05$), decreasing by 37.96% and 50.01%, respectively. When the precipitation decreased (W−), the root/height ratio showed significant differences in each period ($P < 0.001$), increasing by 67.44%, 79.70%, 42.78%, and 74.80%, respectively. When the amount of precipitation was constant (W) with decreasing precipitation frequency (F−), the growth stage of the seedlings was not significantly different ($P > 0.05$).

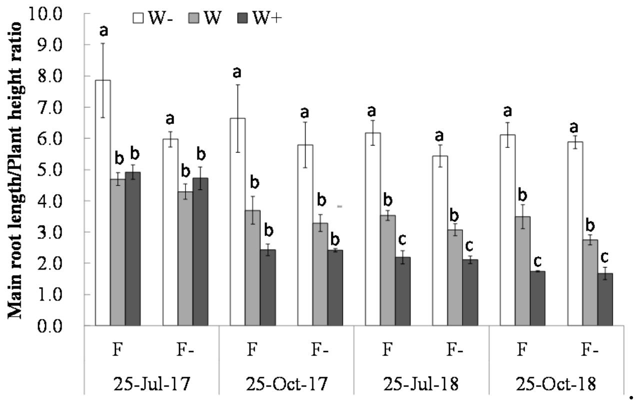

Figure 7. Dynamics of the main root length/plant height ratio of *R. soongarica* seedlings with different precipitation patterns from 2017 to 2018. Different lowercase letters are significantly different ($P < 0.05$) based on single-factor analysis of variance (ANOVA) with the same precipitation frequency. Bars indicate standard errors, n = 3.

3.5. Impact of Changes in Precipitation Patterns on Above-Ground Radial Density and Below−Ground Radial Density

The impact of precipitation changes on the above-ground and below−ground radial density was significantly different ($P < 0.01$, Table 2). The overall above-ground radial density showed an increase when precipitation increased in July and October 2017, but the difference was not significant in July 2018. The density increased when precipitation decreased in October 2018. When precipitation frequency (F) was constant, an increase of precipitation (W+) caused a significant difference in above-ground radial density in July and October 2017 ($P < 0.001$, Figure 8a), increasing by 72.96% and 26.64%, respectively. The difference between July and October was not significant ($P > 0.05$, Figure 8a). When precipitation decreased (W−), the above-ground radial density was significantly different in October 2018 ($P < 0.001$, Figure 8a), showing an increase of 74.80%.

When precipitation frequency (F) was constant, an increase in precipitation (W+) had a significant effect on the below−ground radial density of seedlings between July 2017 and October 2018 ($P < 0.01$), which increased by 82.51% and 93.12%, respectively. When precipitation decreased (W−), the differences in the below−ground radial density of seedlings between July and October 2017 and July 2018 were significant ($P < 0.01$, Figure 8b), which increased by 67.36%, and decreased by 45.65% and 24.28%, respectively. When precipitation was constant (W), a decrease in precipitation frequency (F−) had a significant effect on below−ground radial density in July 2018 ($P < 0.01$, Figure 8b), with an increase of 23.18%, and no significant difference at other times ($P > 0.05$, Figure 8b).

3.6. Abstract Morphological Figure of The Impact of Different Precipitation Patterns on the Growth of R. Soongarica Seedlings

When the precipitation increased by 30%, the plant height, aboveground biomass, and below−ground radial density (BRD) increased, and the root system was relatively thicker and shorter. However, when the precipitation decreased by 30%, the plant height, above-ground biomass, and below−ground radial density (BRD) decreased, and the whole root system was relatively thinner and longer. The maximum above-ground biomass was obtained in W+F− treatment (Figure 9).

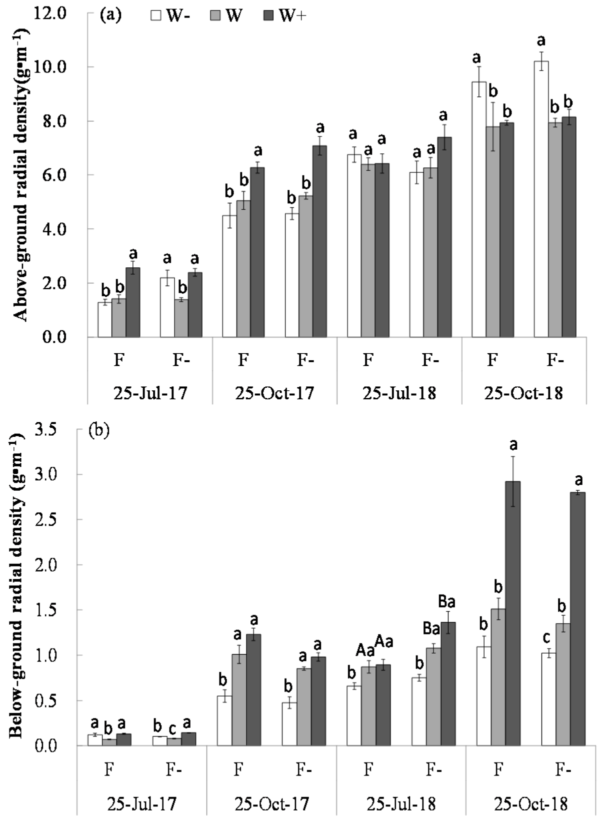

Figure 8. Dynamics of above-ground radial density (ARD) (**a**) and below−ground radial density (BRD) (**b**) of *R. soongarica* seedlings with different precipitation patterns from 2017 to 2018. Different lowercase letters are significantly different ($P < 0.05$) based on single-factor analysis of variance (ANOVA) with the same precipitation frequency. Bars indicate standard errors, n = 3.

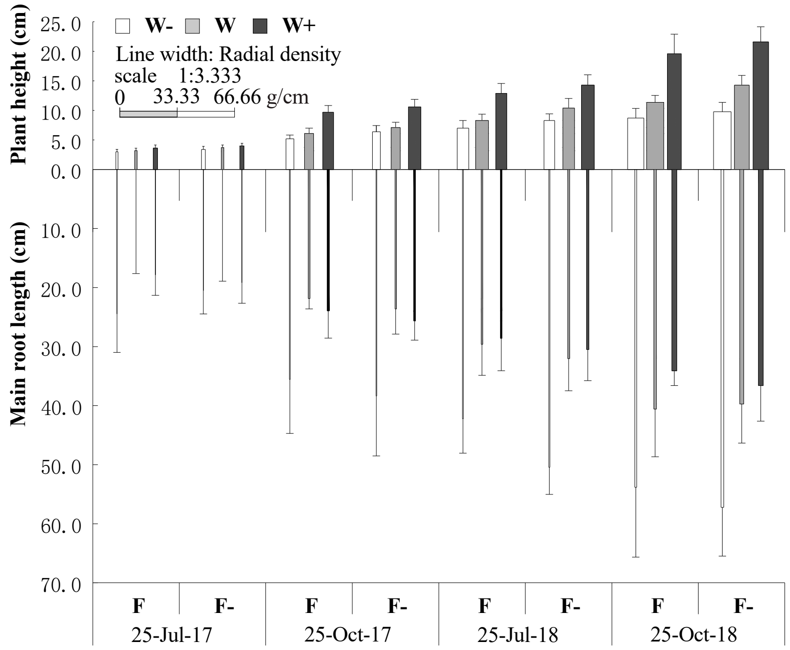

Figure 9. Abstract morphological figure of the impacts of different precipitation patterns on the growth of *R. soongarica* seedlings from 2017 to 2018. The radial density is expressed by the width of the line. The above-ground biomass is expressed by the rectangular area of the line width and height. The scale on the figure is only meaningful for the line width (radial density) and has no constraint on the plant height and the main root length.

4. Discussion

Climate change has changed the existing precipitation pattern and had a profound impact on ecosystems, especially in arid and semi-arid ecosystems where precipitation resources are scarce. The distribution of plant biomass in various organs can reflect the plant's adaptability to the environment and its growth strategy. The response of plants to changes in precipitation amount and frequency affects the future of desert ecosystems and regional sustainable development.

4.1. Impact of Precipitation on the Growth of R. Soongarica Seedlings

In desert ecosystems, water is a key factor for plant growth and survival [24]. Plant growth and development are the results of a combination of genetic factors and environmental conditions [25]. It is generally accepted that increased precipitation has a significant positive impact on plant growth in research on responses to increasing precipitation [26]. This study found that the increase of 30% in precipitation significantly increased the plant height, above-ground biomass, and total biomass of *R. soongarica*. This result is similar to that of Duan et al. and Shan et al. [18,20]. However, some studies have suggested that increasing precipitation does not significantly promote the growth of desert plants [10]. The results of this study are different from those of Sun [10], indicating that the *R. soongarica* seedlings are more sensitive to ecosystem disturbance than adults, especially in plant height. Rapid height growth in this species may have low net costs (and thus a high internal use efficiency) and would seem to favor minimizing allocation to lateral branches during juvenile stages. Li and Zhao [27] concluded that with an increase in precipitation, the plant height of *R. soongarica* seedlings decreased significantly, and the change in precipitation did not significantly affect their biomass and biomass allocation. This is different from the results of this study possibly because the precipitation and research objects of the two experimental settings are different. Li and Zhao [27] studied the seedlings that only grow for 20 days and the irrigation amount was 0.49–1.96 mm·d^{-1}, so that the water basically cannot effectively infiltrate. Our results are different because we studied 1-year and 2-year-old seedlings and had a higher irrigation frequency. There is a positive relationship between disturbance size or intensity and the availability of resources for plant growth. Whole plant growth should be strongly influenced by the factors such as the uptake of water and nutrients, the interception of light, and the allocation of carbon to the maintenance of roots and shoots.

This research found that the impact of precipitation changes on the *R. soongarica* below−ground biomass is different from the above-ground biomass. When precipitation is sufficient, water promotes the synthesis and transportation of auxin, which results in increased plant height, increased biomass, inhibited growth of the main roots below−ground, vigorous growth of lateral roots, and increased biomass. In the absence of precipitation, inhibition of auxin synthesis and transportation will slow plant growth, decrease above-ground biomass, cause vigorous growth of the main roots, and increase the below−ground biomass. Desert plants show different response strategies to different water conditions [28]. As a result of natural selection, physiological activities such as the distribution of plant roots in the arid zone have reached the level of maximum use of precipitation [29].

Studies have shown that both an increase and decrease in precipitation contribute to the below−ground biomass accumulation of desert plants [6]. This study found that the increase and decrease of precipitation in July 2017 (2 months of seedling growth) promoted the growth of the below−ground part (Figure 5). This result supports previous findings. However, the increase and decrease of water in October 2017 and July 2018 had no significant impact on the growth of the subsurface, which is basically the same as the result of Shan's study [20]. The increase in precipitation in October 2018 significantly promoted the accumulation of below−ground biomass and changed significantly from previous trends. This may be due to the fact that after rapid growth during the growing period, the plant has accumulated a large amount of biomass, while the water in October is relatively rare. Therefore, it is necessary to meet the water demand by inhibiting growth above ground (even becoming deciduous) and increasing the growth of the main roots in order to achieve a new water balance. Zhang's research found that the leaves of *R. soongarica* seedlings fell off early in the late stage of seedling growth (October), it was considered that the seedlings entered the dormant phase early, shortening the growth period [19]. This may be due to the lack of water, the adaptive mechanism of falling leaves in *R. soongarica* seedlings, and reducing evaporation, not necessarily entering the dormant period early. *R. soongarica* seedings adapt their resource supply mode by adjusting the changes of the above-ground parts mainly through the plant height and biomass.

4.2. Impact of Precipitation Frequency on the Growth of R. Soongarica Seedlings

In addition to total precipitation, water availability is also affected by soil characteristics, the temporal distribution of precipitation, such as the frequency, and the season of events [13]. Disturbance events frequency may be an important characteristic able to influence individuals' life cycles, the ecology and distribution of populations and of entire species, the structure and dynamics of community and of ecological processes [5]. Research has shown that in arid regions, reducing the frequency of precipitation and decreasing the amount of precipitation show a slight mutual inhibition [13]. However, the results of this study did not find that there was an interaction between precipitation amount and frequency of *R. soongarica* seedling growth (Table 2). During the whole growing season, the seedling plant height, above-ground biomass, and total biomass increased with the increase of precipitation. The treatment of decreasing precipitation frequency was slightly larger than the treatment of constant frequency, but the difference was not significant (Figures 4 and 5). The maximum plant height, above-ground biomass, and total biomass were obtained when the precipitation was increased by 30% and the frequency of precipitation was reduced by 50% (lower frequency, but individual precipitation is larger) (Figures 4 and 5). This shows that reducing the frequency of precipitation is better than the frequency-invariant treatment, but the impact is slight. The results are consistent with those of Schneider and Shan [13,20]. Gao et al. [11] believed that the values of all nutritional and reproductive traits in plants increase with increasing precipitation frequency. Our study found that the below−ground biomass of *R. soongarica* seedlings did not differ significantly at the two frequency levels. This is different from the results of Gao et al. [11], which may be because of different adaptation strategies. Gao et al.'s research object was one-year-old herbs and the net growth rates of herbs to an increase in water is different from that of shrubs [9].

4.3. Impact of the Interaction Between Precipitation Amount and Frequency on the Growth of R. Soongarica Seedlings

A series of complex factors such as precipitation, precipitation frequency, atmospheric evaporation, and soil structure characteristics control the interaction between precipitation amount and precipitation frequency to seeding, as well as their impacts on soil moisture content, and plant growth and recovery. These factors mean that there cannot be a universal law for large-scale precipitation time and plant water use [30]. Related research has also presented diversity. Some research [31] shows that the interaction between precipitation amount and precipitation frequency affects the main root length of (Nitraria spp), seedlings, above-ground biomass of *R. soongarica* seedlings [19], below−ground biomass, and total biomass [18]. There is an interaction between growth rates [20]. However, the results of this research did not find that there was an interaction between precipitation amount and frequency on *R. soongarica* seedling growth (Table 2), possibly because of different research objects. The research objects in this article were 1-year and 2-year-old *R. soongarica* seedlings, while the previous studies used 1-year-old *R. soongarica* seedlings, and even seedlings with a growth period of about 100 days. There are different growth strategies for different levels of water availability.

4.4. Abstract Morphological Figure of the Impacts of Different Precipitation Patterns on the Growth of R. Soongarica Seedlings

At present, scholars generally use plane graphics to accurately reflect the change range and trend of a single indicator, which is convenient for analysis and statistics. However, it is often difficult for a single indicator to reflect the overall and comprehensive traits of the research object, and it is impossible to comprehensively describe the correlation between plant morphological characteristics and plant growth. This paper introduces three morphological indicators: the main root length/plant height ratio (RHR), the above-ground radial density (ARD), and the below−ground radial density (BRD), combined with the plant height and main root length to draw an abstract figure of *R. soongarica* (Figure 9). The root/shoot ratio not only reflects the growth and coordination of the crops above and below the ground, but is also an important indicator of whether the crop can adapt to environmental factors (such as nutrients and water) [32]. However, the root/shoot ratio has limitations in reflecting plant morphology and evaluating environmental adaptability. This limitation is reflected in the fact that the root/shoot ratio can only reflect the distribution and coordination of the above-ground and below−ground crops from the biomass dimension, but cannot reflect the specific allocation patterns of above-ground and below−ground biomass. Ratios of dry mass fractions (e.g., root/shoot ratio; RMF) do not account for the more plastic response of tissue morphology, architecture, and physiology [33]. This is crucial because dry mass fractions can mask shifts in morphology or architecture by remaining constant [34]. The introduction of root/height ratio ((RHR) main root length to plant height ratio), above-ground radial density (ARD), and below−ground radial density (BRD) has expanded the research dimension, and it is possible to study how the plant biomass is distributed from the morphological dimension. The root system mainly absorbs water and nutrients from the soil for the growth and development of the entire plant. Current research generally believes that plants often increase the root/shoot ratio when water is scarce in order to use deep soil water to sustain growth [35]. With less water, the inhibition of root growth in shallow soils is enhanced, while the promotion in deep soils increases. The drier, the inhibition and promotion were stronger [36]. This study found that the root/shoot ratio decreased as precipitation increased overall, the root/shoot ratio did not increase significantly when water was reduced (except for July 2017) (Figure 6). This is inconsistent with general research results. However, this study found that the root-to-height ratio of seedlings responded significantly differently to water changes (Figure 7). The root/height ratio (RHR) increases with decreasing water content and decreases with increasing water content. This study found that the increase of precipitation in different periods had different effects on root-to-height ratio, the decrease of precipitation had no significant difference on root/shoot ratio ($P > 0.05$), and the decrease of precipitation frequency had significant difference on root/height ratio (RHR) ($P < 0.01$, Figure 7). This is inconsistent with the result of Duan et al. [18] where low rainfall promotes the increase of root/shoot ratio. It may be because there are differences in the research objects selected by Duan et al. [18]. The growth period was about 3 months, and the seedlings in the vigorous growth period were selected, while the research objects selected in this experiment were 1 year and 2 years from July 2017 to October 2018. The water condition and the performance of each growth stage were also different during this period. In addition, the root/shoot ratio was affected by multiple factors, and there was different performance in different growth periods. This study also found that the response of root/height ratio of seedlings to water changes was very significant (Figure 7). The root height ratio (RHR) increases with decreasing water content, decreases with increasing water content, and remains relatively stable. This is consistent with the results of studies by Kage, Xu, and Chen [37–39], where drought-tolerant plants increased root length/plant height ratio and reduced transpiration resistance to absorb water and adapt to a water deficit. The experimental data showed that the range of the root/height ratio of W−treatment is 5.435–6.639, W treatment is 2.750–3.694, and W + treatment is 1.676–2.439. This has showed that the root/height ratio of *R. soongarica* seedlings is more stable in characterizing the relationship between water and plant morphology.

Much research has been done on moisture in desert plants [7,20]. However, these research indicators (such as plant height, biomass, root/shoot ratio, root branch number, specific root length, etc.) are isolated from each other due to lack of connection, and cannot form a relatively comprehensive and systematic evaluation system. The introduction of above-ground radial density (ARD) and below−ground radial density (BRD) expands the traditional research dimension and helps to grasp and describe the plant morphology as a whole.

Above-ground radial density is the ratio of above-ground biomass to plant height and characterizes the general form of above-ground biomass distribution. When the water is sufficient, both the above-ground and below−ground plant can fully grow. The biomass is accumulated on the ground with high growth and increased leaves. The biomass accumulation rate is faster than the plant height growth rate and the above-ground radial density increases. The below−ground biomass accumulation rate is greater than the main root length growth rate and the below−ground radial density increases. When the water is insufficient, the growth of the above-ground plant is suppressed and the biomass is reduced. When the above-ground biomass accumulation rate is less than the plant height growth rate, the above-ground radial density decreases (the lower part mainly grows and absorbs water through the main root) and the below−ground biomass accumulates. When the growth rate is less than the main root, the below−ground radial density decreases and vice versa. This study found that firstly, above-ground radial density increased then remained constant as precipitation increased, while above-ground radial density decreased first and then increased with decreasing precipitation. This indicates that the above-ground bioaccumulation rate is greater than the plant height growth rate and less than the plant height growth rate as the precipitation increases, while the above-ground bioaccumulation rate is less than the main root length growth rate and greater than the main root length growth rate as the precipitation decreases.

Diversity in root morphology has declined sharply; the roots have become thinner across the sequence of tropical, temperate, and desert biomes, presumably owing to changes in resource supply caused by seasonally inhospitable abiotic conditions [40]. Comas et al. [34] found that in an environment with water deficits, small xylem diameters in seminal roots save soil water deep in the soil profile and capacity for deep root growth, and large xylem diameters in deep roots may also improve root acquisition of water when ample water at depth is available. The below−ground radial density is the ratio of the below−ground biomass to the length of the main root, and represents the general shape of the below−ground unit length biomass distribution. The results of this study found that when the precipitation increased, the below−ground radial density increased, and the root system was relatively thicker and shorter, while when the precipitation decreased, the below−ground radial density decreased, and the overall root system became finer and longer (Figures 8 and 9). This has enabled them to markedly improve their efficiency of soil exploration per unit of carbon invested and to reduce their dependence on symbiotic mycorrhizal fungi [40]. This is the same result as Comas and Ma [34,40]. Some results suggest that root traits have evolved along a spectrum bounded by two contrasting strategies of root life: an ancestral 'conservative' strategy in which plants with thick roots depend on symbiosis with mycorrhizal fungi for soil resources and a more-derived 'opportunistic' strategy in which thin roots enable plants to more efficiently leverage photosynthetic carbon for soil exploration [40]. The results of this study indicate that the *R. soongarica* seedlings' root adaptive strategy manifests as an obvious 'opportunistic' strategy.

5. Conclusions

Our findings suggest that in the context of climate change, the derivation of morphological traits has been important for preparing plants to colonize new habitats and for the rich generation of biodiversity within and across biomes; to the degree that a particular set of morphological and physiological traits will result in high growth efficiency for only a limited range of disturbance sizes or resource availability. The traits that determine *R. soongarica* growth appear to be more specialized in their response to disturbance. *R. soongarica* seedings adapt their resource supply mode by adjusting the changes of the above-ground parts mainly through the plant height and biomass and the length and thickness of the root system of the below−ground part. An improved functional understanding of morphological traits is critical for comprehending the distribution of plant life, and may help to predict the risk of species extinction and to conserve biodiversity, and to improve regional sustainable development capabilities in the face of environmental change.

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References

1. Qin, D.H. Climate change science and sustainable development. *Prog. Geogr.* **2014**, *33*, 874–883. (In Chinese)
2. Westra, S.; Fowler, H.J.; Evans, J.P.; Alexander, L.V.; Berg, P.; Johnson, F.; Kendon, E.J.; Lenderink, G.; Roberts, N.M. Future changes to the intensity and frequency of short-duration extreme rainfall. *Rev. Geophys.* **2014**, *52*, 522–555. [CrossRef]
3. Densmore-Mcculloch, J.A.; Thompson, D.L.; Fraser, L.H. Short-term effects of changing precipitation patterns on shrub-steppe grasslands: Seasonal watering is more important than frequency of watering events. *PLoS ONE* **2016**, *11*, e0168663. [CrossRef] [PubMed]
4. Burke, E.J.; Brown, S.J.; Christidis, N. Modeling the Recent Evolution of Global Drought and Projections for the Twenty-First Century with the Hadley Centre Climate Model. *J. Hydrometeorol.* **2006**, *7*, 1113–1125. [CrossRef]
5. Battisti, C.; Poeta, G.; Fanelli, G. *An Introduction to Disturbance Ecology*, 1st ed.; Springer Nature Switzerland AG: Zug, Switzerland, 2016; pp. 13–136.
6. Zhang, L.M.; Liu, X.P.; Zhao, X.Y.; Zhang, T.H.; Yue, X.F.; Yun, J.Y. Response of sandy vegetation characteristics to precipitation change in Horqin sandy land. *Acta Ecol. Sin.* **2014**, *34*, 2737–2745. (In Chinese)
7. He, J. Eco-Physiology Responses and Adaptive Strategies of Desert Species *Nitraria tangutorum* to Simulated Rain Addition. Ph.D. Dissertation, Chinese Academy of Forestry, Beijing, China, 2015. (In Chinese).
8. Sun, B.; Qian, J.P.; Zhao, H.X. Response of biomass and root morphology of desert plants *Corispermum candelabrum* to precipitation change in northwest China. *Ecol. Environ. Sci.* **2018**, *27*, 1993–1999. (In Chinese)
9. Gherardi, L.A.; Sala, O.E. Enhanced precipitation variability decreases grass- and increases shrub-productivity. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 12735–12740. [CrossRef]
10. Sun, Y.; He, M.Z.; Wang, L. Effects of precipitation control on plant diversity and biomass in a desert region. *Acta Ecol. Sin.* **2018**, *38*, 2425–2433. (In Chinese)
11. Gao, R.; Yang, X.; Liu, G.; Huang, Z.; Walck, J.L. Effects of rainfall pattern on the growth and fecundity of a dominant dune annual in a semi-arid ecosystem. *Plant Soil* **2014**, *389*, 335–347. [CrossRef]
12. Zeppel, M.J.B.; Wilks, J.V.; Lewis, J.D. Impacts of extreme precipitation and seasonal changes in precipitation on plants. *Biogeosciences* **2014**, *11*, 3083–3093. [CrossRef]
13. Schneider, A.C.; Lee, T.D.; Kreiser, M.A.; Nelson, G.T. Comparative and interactive effects of reduced precipitation frequency and volume on the growth and function of two perennial grassland species. *Int. J. Plant Sci.* **2014**, *175*, 702–712. [CrossRef]
14. Gibson-Forty, E.V.J.; Barnett, K.L.; Tissue, D.T.; Power, S.A. Reducing rainfall amount has a greater negative effect on the productivity of grassland plant species than reducing rainfall frequency. *Funct. Plant Biol.* **2016**, *43*, 380–391. [CrossRef]
15. Trenberth, K.E.; Dai, A.; Rasmussen, R.M. The changing character of precipitation. *Bull. Am. Meteorol. Soc.* **2003**, *84*, 1205–1218. [CrossRef]
16. The American Heritage Dictionary. Available online: https://www.thefreedictionary.com/Seedlings (accessed on 1 March 2020).
17. Fay, P.A.; Schultz, M.J. Germination, survival, and growth of grass and forb seedlings: Effects of soil moisture variability. *Acta Oecologica* **2009**, *35*, 679–684. [CrossRef]
18. Duan, G.F.; Shan, L.S.; Li, Y.; Zhang, Z.Z.; Zhang, R. Effects of changing precipitation patterns on seedling growth of *Reaumuria soongorica*. *Acta Ecol. Sin.* **2016**, *36*, 6457–6464. (In Chinese)

19. Zhang, Z.Z.; Shan, L.S.; Li, Y. Prolonged dry periods between rainfall events shorten the growth period of the resurrection plant *Reaumuria soongorica*. *Ecol. Evol.* **2018**, *8*, 920–927. [CrossRef]
20. Shan, L.S.; Zhao, W.Z.; Li, Y.; Zhang, Z.Z.; Xie, T.T. Precipitation amount and frequency affect seedling emergence and growth of *reaumuria soongarica* in northwestern China. *J. Arid Land* **2018**, *10*, 574–587. [CrossRef]
21. Liu, B.; Zhao, W.Z. Ecological Adaptability of Photosynthesis and Water Metabolism for *Tamarix Ramosissima* and *Nitraria Sphaerocarpa* in Desert-Oasis Ecotone. *J. Desert Res.* **2009**, *29*, 101–107. (In Chinese)
22. Mandelbrot, B.B. *The Fractal Geometry of Nature/Revised and Enlarged Edition*; WH Freeman and Company: New York, NY, USA, 1982; p. 460.
23. Lin, Q.D. Architectural Form-Finding Based on Fractal Theory. Ph.D. Dissertation, Tsinghua University, Beijing, China, 2014. (In Chinese).
24. Wu, Y. Physiological Response of Desert Plants in the Southern Margin of Junggar Basin to Light Rainfall Events. Ph.D. Dissertation, Chinese Academy of Sciences University, Urumqi, China, 2014. (In Chinese).
25. Yin, M.H.; Li, Y.N.; Zhou, C.M. Compensation effects of regulated deficit irrigation and tillering interference to winter wheat. *J. Appl. Ecol.* **2015**, *26*, 3011–3019. (In Chinese)
26. Xiao, C.W.; Zhou, G.S.; Zhao, J.Z. Effect of different water conditions on growth and morphology of *Artemisia ordosica* Krasch. seedlings in Maowusu sandland. *Acta Ecol. Sin.* **2001**, *21*, 2136–2140. (In Chinese)
27. Li, Q.L.; Zhao, W.Z. Responses of seedlings of five desert species to simulated precipitation change. *J. Glaciol. Geocryol.* **2006**, *28*, 414–420. (In Chinese)
28. Zhou, H.; Zhao, W.Z.; He, Z.B. Water sources of *Nitraria sibirica* and response to precipitation in two desert habitats. *Chin. J. Appl. Ecol.* **2017**, *28*, 2083–2092. (In Chinese)
29. Fay, P.A.; Carlisle, J.D.; Knapp, A.K.; Blair, J.M.; Collins, S.L. Productivity responses to altered rainfall patterns in a C_4-dominated grassland. *Oecologia* **2003**, *137*, 245–251. [CrossRef] [PubMed]
30. Deng, W.P. Water Use Mechanism of Typical Tree Species in Beijing Mountainous Areas. Ph.D. Dissertation, Beijing Forestry University, Beijing, China, 2015. (In Chinese).
31. Zhang, R.; Shan, L.S.; Li, Y. Effect of change to simulated precipitation patterns on seedling growth of *Nitraria tangutorum*. *Acta Prataculturae Sin.* **2016**, *25*, 117–125. (In Chinese)
32. Xu, G.W.; Wang, H.Z.; Zhai, Z.H.; Sun, M.; Li, Y.J. Effect of water and nitrogen coupling on root morphology and physiology, yield and nutritionutilization for rice. *Trans. Chin. Soc. Agric. Eng.* **2015**, *31*, 132–141. (In Chinese)
33. Boot, R.G.A.; Mensink, M. Size and morphology of root systems of perennial grasses from contrasting habitats as affected by nitrogen supply. *Plant Soil* **1990**, *129*, 291–299. [CrossRef]
34. Comas, L.H.; Becker, S.R.; Cruz, V.M.V.; Byrne, P.F.; Dierig, D.A. Root traits contributing to plant productivity under drought. *Front. Plant Sci.* **2013**, *4*, 442. [CrossRef]
35. Guo, J.P.; Gao, S.H. Response of sandland plants growth to CO_2 enrichment and soil drought. *J. Soil Water Conserv.* **2004**, *18*, 174–176. (In Chinese)
36. Liang, Q. Response of Growth and Physiological Characteristics to Soil Depth Under Different Water Conditions on Lolium Perenne in Karst Region. Master's Dissertation, Southwest University, Chongqing, China, 2016. (In Chinese).
37. Kage, H.; Kochler, M.; Stützel, H. Root growth and dry matter partitioning of cauliflower under drought stress conditions: Measurement and simulation. *Eur. J. Agron.* **2004**, *20*, 379–394. [CrossRef]
38. Xu, B.; Shan, L. A Study comparing water use efficiency and root/ shoot ratio of alfalfa and *Astragalus adsurgens* at seedling stage. *Acta Agrestia Sin.* **2003**, *11*, 78–82. (In Chinese)
39. Chen, S.Y. Effect of Water Stress on the Growth and Quality of Alfalfa and Its Physiological Basis. Master's Dissertation, Shandong Agricultural University, Taian, China, 2006. (In Chinese).
40. Ma, Z.; Guo, D.; Xu, X.; Lu, M.; Bardgett, R.D. Evolutionary history resolves global organization of root functional traits. *Nature* **2018**, *555*, 94–97. [CrossRef] [PubMed]