

Editorial

Plant Adaptation to Extreme Environments in Drylands—Series II: Studies from Northwest China

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Arid and semi-arid lands cover more than one-third of the Earth's terrestrial area [1]. The environmental conditions in these areas are very harsh, characterized by scarce rainfall, high temperatures and evaporation, soil salinization, poor soil nutrition, and low vegetation coverage [2]. Affected by global climate change, these regions will face more frequent and intense extreme weather events, such as prolonged droughts and extreme summer heatwaves, which will pose major challenges to local ecosystems and biodiversity. Revealing strategies and mechanisms of plant adaptation to extreme environments (such as drought, salinity, and high temperatures) in arid zones has become one of the research hotspots, which is of great relevance for taking appropriate measures to protect and manage local vegetation and ecosystems. Despite the efforts of academic researchers, differences in adaptation strategies between species and changes in plant adaptation across environmental gradients require more thorough and accurate research. This will provide practical solutions to the ecological challenges faced by arid and semi-arid regions.

We gathered research from all relevant areas, including water uptake and use mechanisms, physiological and biochemical adaptation strategies of plants, plant–soil microbial interactions, and ecosystem services, in the Special Issue titled “Plant Adaptation to Extreme Environments in Drylands—Series II: Studies from Northwest China”. By bringing together these findings, we aim to deepen our understanding of how plants in arid regions adapt to the more widespread and frequent stresses of environmental change in the future. This Special Issue includes twelve innovative research papers covering diverse ecosystems such as desert sparse shrublands, natural forests, and artificial forests. Among them, 11 papers are located in Northwest China, while the remaining papers are based on published data using bibliometric methods to cover the global scope. We are fortunate that most of the research in the Special Issue is located in the Ebinur Wetland Nature Reserve. This reserve is an ideal site for studying biodiversity and ecological adaptability in arid and semi-arid areas of Northwest China due to its unique biodiversity and extremely arid environment [3]. This gathering of papers at the research site allows our papers to logically form a cohesive whole. The articles in this Special Issue reveal the complex interactions and adaptation differences between different ecosystems in arid areas in a multidimensional way, showing the rich results of biodiversity and ecological adaptation, as well as representing the latest advances in research on a wide range of adaptations of plants in arid areas to extreme environments.

In an arid environment, the survival and reproduction of plants are severely challenged due to the extreme lack of water. In order to adapt to this water-limited environment, plants have evolved a series of unique water absorption and regulation mechanisms, such as adjusting leaf stomata to absorb water and changing their structure to store water more effectively. Li et al. [4] first discussed the foliar water uptake (FWU) of male and female *Populus euphratica* Oliv. in different growing seasons and its relationship with photosynthetic capacity and anatomical structure from a gender perspective. The results showed



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that the FWU capacity of both male and female plants increased with the growing period. Although the FWU capacity of female plants was better than that of males due to their developed water storage structure, the male plant was better than the female plant in alleviating the leaf water deficit and carbon benefit. An in situ wetting experiment also found that in the middle of the growing season, wetting treatment significantly improved the pre-dawn water potential and photosynthetic capacity of *P. euphratica*. This study revealed the different water use strategies of male and female *P. euphratica* under drought conditions, providing a new perspective for understanding the foliar water uptake adaptation of plants to extreme environments. By measuring the contact angle, FWU parameters, and hydraulic parameters, Wang et al. [5] explored the differences among six desert species' FWU capacity and the effects of leaf wettability and hydraulic parameters on FWU capacity. The results suggested that all six species had FWU capacity and emphasized that stomatal regulation played a more important role in the FWU than leaf wettability and leaf structure. This study provides a theoretical basis for understanding the water utilization mechanisms of plants in arid areas.

The adaptability of plants to a drought environment is realized through a series of complex physiological and biochemical mechanisms, including not only the absorption and efficient use of water but also the adjustment of their internal physiological and biochemical traits under drought stress. In order to clarify the adaptation strategies of desert plants in different habitats, Yang et al. [6] focused on the interspecific integration of chemical traits in desert plant leaves with variations in soil water and salt habitats and found that the interspecific integration of plant leaf chemical traits in high water-salinity habitats was higher than that in low water-salinity habitats. Trait networks showed that C and Ca were the core leaf chemical traits for desert plant growth. Jiang et al. [7] compared the physiological traits of the leaves and roots of *Kalidium foliatum* (Pall.) Moq. under different saline habitats in a desert region and found that different salt environments had different effects on the leaf and root traits, including chlorophyll content, anatomical structure, nutrient composition, and the content of osmotic regulatory substances. *K. foliatum* adapts to different salt environments by regulating leaf and root structure, element allocation, ion balance, osmotic regulation, and antioxidant defense mechanisms, which provides insights into how plants respond to salt stress. Additionally, Jiang et al. [8] discussed the influence of intraspecific trait variation on plant functional diversity and community assembly processes in arid desert areas of northwest China. They pointed out that the effects of spatial and environmental factors on functional diversity varied across the different scales. Spatial factors have a greater impact on functional diversity at small scales, while environmental factors have a more significant impact at larger scales. Moreover, they emphasized the importance of intraspecific trait variation in understanding and predicting the response of plant communities to environmental change in arid regions. Zheng et al. [9] analyzed the distribution patterns of $\delta^{13}\text{C}$ and major nutrient elements in different organs of *Alhagi sparsifolia* Shap. and *Karelinia caspia* (Pall.) Less. across the growing seasons in the northern part of the Taklimakan Desert and their relationship with soil environmental factors. It was found that $\delta^{13}\text{C}$ and nutrient contents were significantly different between the different organs of the two species. Soil total phosphorus was the most important environmental factor affecting $\delta^{13}\text{C}$ and nutrient elements in the two species. They also demonstrated that these two species are able to effectively coordinate and regulate their water, N, and P use strategies in response to environmental stress. Khan et al. [10] compiled a dataset of a total of 1295 desert plant species from the literature and then used bibliometric analysis to explore whether plant adaptive strategies and ecosystem nutrient concentrations shifted across three desert ecosystems (e.g., desert, steppe desert, and temperate desert). They found that leaf N, P, and C concentrations were significantly different only from those of certain other growth forms and in certain desert ecosystems. In leaves, the C concentrations were always greater than the N and P concentrations and were greater than those in soils. The element concentrations and ratios were also greater in the organs than in the soils. Additionally, the values in the leaf versus the root N and P changed among the

three desert ecosystems. However, the conclusion reached in this study was different from previous macro-ecology studies in that the mean annual precipitation and mean annual temperature had no significant influences on the leaf elemental concentrations and ratios. This study deepened our understanding of resource-related adaptive strategies, indicating that plants adapt to drought-stressed environments via divergent element concentration changes, thus maintaining the stability of desert ecosystems. Aishan et al. [11] conducted a field survey of tree cavities (hollows) of *P. euphratica* in the Tarim River and found that water source was the main environmental factor affecting the formation of hollows. Moreover, the height and width of the hollows of *P. euphratica* were significantly positively correlated with the DBH, crown loss, average crown width, and the distance from trees to rivers. This study is of great significance for understanding the death and ecological adaptation mechanisms of *P. euphratica* and similar species.

Microbial activity plays a crucial role in maintaining the functional stability of vegetation–soil ecosystems [12]. Because arid zones soil is characterized by insufficient water, loose structure, and severe salinization, the interaction between plants and soil rhizosphere microorganisms is very important for plant adaptation to an arid environment. By conducting pot experiments to control the water and nitrogen sources of *Haloxylon ammodendron* (C.A.Mey.) Bunge seedlings, Zhu et al. [13] found that water deficit and nitrogen addition significantly changed the morphological traits and rhizosphere microbial diversity. They highlighted that rhizosphere microorganisms respond significantly to water deficits and nitrogen addition, thus promoting plant adaptation to environmental stress through symbiotic relationships. Wang et al. [14] studied the soil bacterial community structure and its influencing factors in an artificial *H. ammodendron* forest in the Sand Blocking and Fixing Belt of Minqin, China. It was found that *H. ammodendron* plantation significantly increased the principal nutrient contents and the diversity and richness of soil bacteria compared to the mobile dune soil. They also found that soil organic matter, total nitrogen, available potassium, pH, and electrical conductivity were the main environmental factors affecting the structure and function of the soil bacterial community. This study provides important insights into the underlying mechanism for explaining the changes in the structure and function of soil bacterial communities in artificial sand-fixation vegetation.

Biological systems in arid areas play a vital role in maintaining ecological balance and providing ecosystem services. Due to the unique climatic conditions and resource constraints, ecosystem services have become a core area of ecological research in arid areas, involving water resource management, the carbon cycle, and climate regulation. By using the InVEST model, Yao et al. [15] studied the spatial and temporal response of vegetation to runoff changes in the Ebinur Lake Basin by using remote sensing data. The results suggested that the spatial distribution of runoff was positively correlated with altitude. Vegetation coverage and types have an obvious spatial and temporal response to runoff changes. This is of great significance in terms of theoretical guidance for water resource management and ecological restoration in arid areas. Li et al. [16] explored the ecological functions of artificial shelterbelts (composed of *H. ammodendron*, *Calligonum mongolicum* Turcz., and *Tamarix chinensis* Lour.) along the Tarim Desert Highway. They found that the average daily net photosynthetic rate, carbon sequestration per unit leaf area, and oxygen release of *T. chinensis* were significantly higher than those of the other two species, but the carbon storage was the greatest in *H. ammodendron*. According to the net photosynthetic rate method and the biomass method, they obtained shelterbelts that contributed significantly to carbon storage and oxygen release. This study highlighted the role of these shelterbelts in promoting ecological restoration and sustainable development in arid desert areas.

It should be emphasized that the studies of plant adaptation to extreme environments in the arid region collected in our Special Issue are still in the preliminary exploration stage, although they provide profound insights and rich data. Further work is needed to systematically reveal plant adaptation to extreme environments, especially in the study of processes and mechanisms based on experimental, functional-based, and modeling methods.

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