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Original Research

Selection of Optimal Farmland Tree Species in Southern Xinjiang Oasis Based on the Process of Photosynthesis

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Abstract

This study aims to select the optimal field tree species based on the photosynthesis process at the leaf scale. Experimental results indicate that, in terms of average water use efficiency, the ranking from highest to lowest is as follows: *Populus tomentosa*, *Populus nigra*, *Salix matsudana*, *Elaeagnus angustifolia*, and *Populus euphratica*. In terms of daytime transpiration water consumption, the ranking from highest to lowest is: *Salix matsudana*, *Populus tomentosa*, *Populus euphratica*, *Elaeagnus angustifolia*, and *Populus nigra*. Regarding the response relationship between light intensity and transpiration rate, *Populus nigra* and *Elaeagnus angustifolia* show a high degree of consistency in the timing of changes in transpiration rate and light intensity. Based on these research results, *Populus nigra* is the most suitable field tree species. The commonly perceived drought-resistant tree, *Populus euphratica*, has high transpiration water consumption and significant groundwater competition with crops, making it unsuitable as a field shelterbelt species. This study provides theoretical support for the selection of shelterbelt tree species in the oasis farmlands of southern Xinjiang and offers guidance for the optimal configuration of field tree species.

Keywords: Field tree species, Oasis, Environmental adaptation, *Populus euphratica*, *Populus nigra*

Introduction

Drought and desertification are ecological problems faced by many regions in the mid-latitude regions [1]. To combat desertification, reduce natural disasters, and improve the ecological environment, the Chinese government began implementing the "Three-North Shelterbelt Program" in 1978. This program aims to improve the ecological environment quality in northern China by increasing forest cover, thereby providing windbreak and sand-fixation effects [2]. The Taklamakan Desert, located in the mid-latitude region, is China's largest desert and the world's second-largest shifting desert. The oases on the edges of the desert are ecologically fragile areas influenced by both natural and human factors. This area experiences strong sunlight throughout the year and has scarce rainfall, with an annual average precipitation of 10-80 mm [3]. The Taklamakan Desert is primarily located in China's Xinjiang Uygur Autonomous Region, where desertification control has consistently been a key focus for various levels of government. Currently,

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the main approach is the construction of shelterbelts within and around the oases, along with windbreak and sand-fixation projects along roadsides. To conserve irrigation water, grass grids are commonly used along roadsides to mitigate the impact of wind and sand on road traffic. In recent years, there has also been research on using non-biomass materials to create windbreaks and sand-fixation barriers [4], although this research is mostly at the small-scale experimental stage. With advancements in water-saving irrigation technology, large-scale planting of shelterbelts has begun in the southern oases of Xinjiang [5]. There is also increasing research on irrigation water and ecological water requirements for roadside shelterbelts [6-10]. Overall, the implementation of windbreak and sand-fixation projects along roadsides in southern Xinjiang has been effective, with few occurrences of road blockages caused by shifting dunes.

However, research on Oasis farmland shelterbelts is relatively limited. There are three common types of farmland shelterbelts. The most prevalent type is economic fruit trees, as they not only serve as windbreaks and sand-fixation but also generate higher economic income. Another common type includes fast-growing tree species, which can produce timber in a relatively short period. In some areas on the desert edge, local shrubs are often planted around farmland for windbreaks and sand-fixation purposes. Regardless of the type, little theoretical research has been conducted on them. Without theoretical support, the blind planting of shelterbelts can lead to adverse consequences. In some northern regions of China, there have been instances of artificial sand-fixation forests aging prematurely or dying [11]. Therefore, researching tree species for oasis farmland shelterbelts in southern Xinjiang is of significant theoretical and practical importance. Although large numbers of farmland shelterbelts are planted in the southern Xinjiang oases, there are few comparative studies on the environmental adaptability of these shelterbelt species. Additionally, there is a lack of research on the water competition relationship between these shelterbelt species and crops.

Drought and intense sunlight are typical environmental characteristics of the Taklamakan Desert and its surrounding areas. Zepu County is located in the central part of the southern edge of the Taklamakan Desert, at the border between the desert and the oasis, making it highly representative of the environment (Fig. 1). The most common tree species in the field shelterbelts in Zepu County and its surrounding areas are *Populus euphratica*, *Elaeagnus angustifolia*, *Salix matsudana*, *Populus nigra*, and *Populus tomentosa*. These five tree species are the most commonly used field species in southern Xinjiang and were therefore selected as the research objects. *Populus euphratica* is characterized by its tall branches and good shading effect. In China, there is a proverb about *Populus euphratica* trees: "Does not die for a thousand years, does not fall for a thousand years, and does not decay for a thousand years". The general public recognizes *Populus euphratica* as a species that is highly resistant to drought, possesses strong environmental adaptability, and exhibits remarkable vitality. The spirit of Kashi University, the sole comprehensive university in southern Xinjiang, is often described as being "As tenacious as *Populus euphratica* and as dedicated as a red candle". Consequently, there is relatively more research on *Populus euphratica*, but the mechanisms of its water use still have differing viewpoints. Some studies suggest that the water absorption of *Populus euphratica* suckers mainly comes from the shallow root system of the mother plant [12]. As the tree ages, its use of deep soil water gradually increases, but the overall water use efficiency of the plant continues to decline [13]. However, a few studies indicate that the water use efficiency of *Populus euphratica* does not significantly change with age [14]. Therefore, more research is needed to confirm these differing conclusions. To date, most studies have treated *Populus euphratica* as a common tree species, with few studies on its suitability as a field tree species. Research on the other four tree species for shelterbelts is relatively limited.

Southern Xinjiang is characterized by intense sunlight and arid conditions. Selecting field shelterbelt tree species that are both adapted to the environmental characteristics of Southern Xinjiang and have low water requirements holds significant potential for guiding agricultural planning in Southern Xinjiang and surrounding areas.

Materials and Methods

Experimental Materials

Transpiration occurs simultaneously with photosynthesis, and under strong light exposure, vigorous transpiration helps reduce leaf surface temperature. Under water-deficient conditions, the stomata of plant leaves can partially or completely close to reduce water stress [15]. Therefore, the intensity of transpiration is an important characteristic of plant adaptation to drought environments [16]. Additionally, leaf water use efficiency is a crucial indicator for evaluating plant water adaptation strategies [17]. The water use efficiency of plants not only affects their survival status but also, to some extent, reflects their adaptability to the environment. Therefore, quantitatively studying the water use characteristics of plants is an important basis for selecting protective forests [18]. There are two common methods for studying water use characteristics: one is in-situ measurement, mainly based on leaf-scale micro-scale water use efficiency research, commonly using a photosynthesis meter to measure leaf water use efficiency (WUE) to evaluate their water adaptation strategies [17]. The other method is ex situ experimentation, analyzing the isotopic composition in the laboratory to study

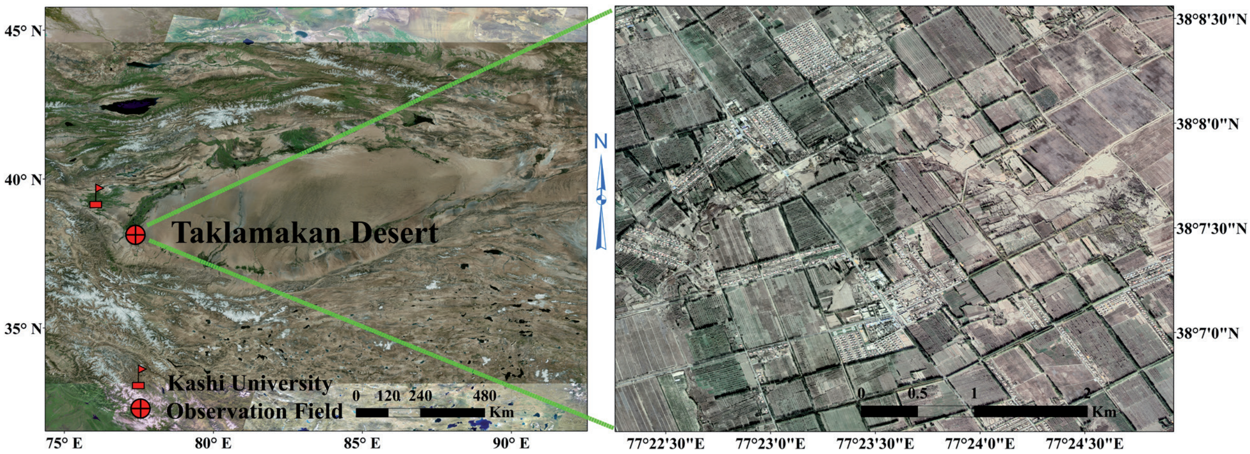

Fig. 1. Location map of the study area.

the macroscopic water use status of plants [18]. Because photosynthesis meters can quickly determine leaf water use efficiency and transpiration rate, this study primarily assesses the adaptation ability of five tree species to arid environments by using a photosynthesis meter to observe their leaf water use efficiency. Additionally, analyzing the response rate of transpiration rate to light intensity indicates the adaptation ability of plants to strong light. By comparing the transpiration water volume of five tree species, we can study their competition for water with field crops. Adult plants with a diameter at breast height greater than 20cm were selected as experimental subjects based on visual inspection.

Experimental Methods

The experiment was conducted from April 17th to April 20th, 2017. Measurements were taken six times a day at Beijing time: 8:00, 10:00, 12:00, 14:00, 16:00, and 18:00, using a portable photosynthesis meter (LI-COR 6400, Lincoln, USA) to measure the diurnal variation of photosynthesis in the above five tree species. Leaf water use efficiency (WUE) is as follows: WUE = Pn/Tr [19-22], where Pn represents the net photosynthetic rate of leaves and Tr represents the transpiration rate of leaves. The daytime transpiration water consumption is calculated by integrating transpiration rates (Tr) over the daytime.

Results

Comparison of Water Use Efficiency of Five Tree Species

The comparison of water use efficiency among the five tree species revealed that *Populus tomentosa* and *Populus nigra* have relatively high water use efficiency with significant fluctuations in the daytime. Similar to *Populus euphratica*, their water use efficiency peaks around 10:00 AM and then continuously declines. The *Salix matsudana* is moderate, and the *Populus euphratica* and *Elaeagnus angustifolia* have smaller daily fluctuations in water use efficiency (Fig. 2). These results indicate that *Populus tomentosa* and *Populus nigra* have higher water use efficiency, making them more suitable for the arid natural environment of southern Xinjiang. In contrast, *Populus euphratica* and *Elaeagnus angustifolia* have lower water use efficiency, making them more suitable for planting in areas with good groundwater or irrigation conditions. Therefore, in terms of water use efficiency alone, *Populus tomentosa* and *Populus nigra* are better suited to the arid climate conditions of southern Xinjiang.

Comparison of Transpiration Rate and Transpiration Water Consumption

The comparison of the transpiration rates of the five plants (Fig. 3) shows that *Populus tomentosa* has the largest fluctuation in transpiration rate, which rapidly increases from 8:00 to 18:00 Beijing time. In contrast, *Populus nigra* shows the smallest fluctuation and consistently maintains the lowest transpiration rate, with a leaf water consumption of only 17.39 g•m^{-2}. *Salix matsudana* and *Populus tomentosa* both display an increasing trend in transpiration rate, with higher water consumption levels. During the daytime, *Salix matsudana* reaches a leaf water consumption of 41.75 g•m^{-2}, while Populus tomentosa reaches 39.5 g•m^{-2}. *Populus euphratica* and *Elaeagnus angustifolia*, with moderate transpiration rates, have medium daytime leaf water consumption, reaching 34.06 g•m^{-2} and 33.59 g•m^{-2} respectively. If used as field trees, *Salix matsudana* and *Populus tomentosa* are likely to produce water competition with crops more obviously. Among the five plants, *Populus nigra* has the least water consumption for transpiration and competes with the least water competition with crops. Considering only the water consumption per unit leaf area, it is most suitable to be used as a field tree species on the side of the farmland road.

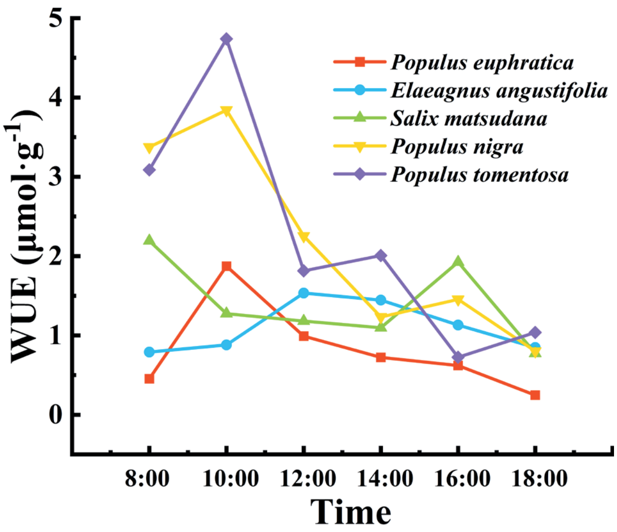

Fig. 2. Comparison of water use efficiency of five trees.

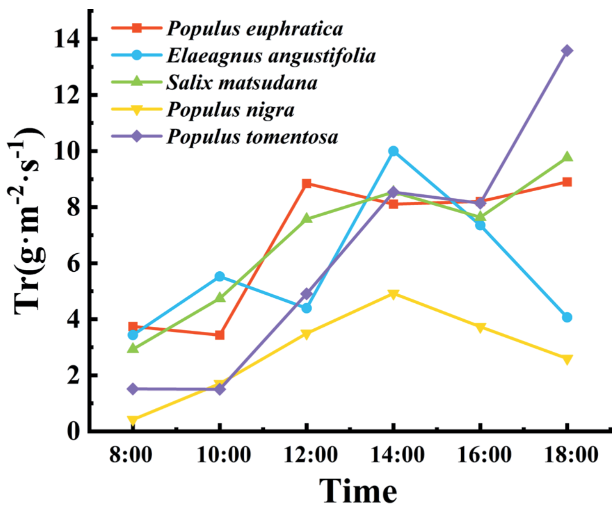

Fig. 3. Comparison of transpiration rates (Tr) of five trees.

Both *Elaeagnus angustifolia* and *Populus nigra* reach their maximum transpiration rate around noon and then gradually decrease, indicating a good circadian rhythm. This suggests that these two plants are highly responsive to light intensity and are well-suited for the strong-light climate conditions.

Discussion

The results indicate that the two cultivated tree species, *Populus tomentosa* and *Populus nigra*, have higher water use efficiency, while that of *Populus euphratica* is the lowest. As the tree age of *Populus euphratica* increases, its water source shifts from shallow soil water to deeper soil water, and its water use efficiency decreases with increasing tree age [13]. Therefore, as the tree age of *Populus euphratica* increases, its consumption of soil water, which will greatly increase, especially the consumption of deep soil water will sharply increase with the growth of tree age. In the arid region of southern Xinjiang, the presence of a large-scale *Populus euphratica* forest would lead to a significant consumption of groundwater in the oasis, eventually resulting in the depletion of groundwater and the disappearance of the oasis. This would force the Oasis population to migrate to new areas with available groundwater sources. This may explain the large number of withered *Populus euphratica* trees left behind after the disappearance of many ancient cities in the Taklamakan Desert [23-26]. In terms of water use efficiency, *Populus tomentosa* and *Populus nigra* have higher water use efficiency and can better utilize soil water under arid environmental conditions. Therefore, they are more suitable as tree species for farmland. Although the water use efficiency of *Elaeagnus angustifolia* is relatively low, its water use efficiency is the most stable and exhibits the smallest variation. To a certain extent, this indicates that *Elaeagnus angustifolia* has the strongest adaptability to intense light and arid environments.

From the perspective of daytime transpiration water volume and transpiration rate, the *Salix matsudana* transpires the most water, thus it is likely to consume the most soil water. This situation can make the *Salix matsudana* quickly consume soil water during the irrigation season, increasing soil porosity and allowing plant roots to get more air. But for the perennially arid region of southern Xinjiang, the characteristic of consuming a large amount of soil water makes the *Salix matsudana* inappropriate as a field tree species. According to the daytime water evaporation volume, the order from high to low is *Salix matsudana*, *Populus tomentosa*, *Populus euphratica*, *Elaeagnus angustifolia*, and *Populus nigra*. The *Populus nigra*

Table 1. Daytime transpiration water consumption (TrWC).

Tree species	Regression equation	R^2	TrWC /g•m^{-2}
Populus euphratica	y = 0.2424x4 - 3.436x3 + 16.329x2 - 28.258x + 18.76	0.9179	34.057
Elaeagnus angustifolia	y = 0.0702x4 - 1.2272x3 + 6.694x2 - 12.132x + 10.334	0.7871	33.5882
Salix matsudana	y = -0.0827x4 + 1.1417x3 - 5.6584x2 + 13.108x - 5.805	0.894	41.7532
Populus nigra	y = 0.0452x4 - 0.7289x3 + 3.5897x2 - 5.0832x + 2.5963	0.9835	17.393
Populus tomentosa	y = -0.1346x4 + 1.698x3 - 6.9213x2 + 12.382x - 5.8353	0.8744	39.5105

has the least daytime water transpiration volume, and its transpiration rate has a good consistency with the change of light intensity, reaching the peak of the day at about 14:00 Beijing time (local time 12:00). The transpiration rate has nearly the same trend with light intensity, which allows the *Populus nigra* to reduce leaf temperature through transpiration under strong light conditions, reduce water evaporation, and maintain the water content in the plant body under weak light conditions. Camarero et al. [27] obtained similar results in their study of three *Populus nigra* species along the Mediterranean coast, where the transpiration rate of *Populus nigra* exhibited a similar trend to light intensity. Similar to the *Populus nigra*, the *Elaeagnus angustifolia* also has a good circadian rhythm, with both plants showing the highest transpiration rate at noon. However, the transpiration rate of the other three plants shows an irregular rising trend, especially the *Populus tomentosa*, whose transpiration rate is increasing with time. Because the experiment observation was only conducted until 18:00 Beijing time, it is inferred that the transpiration rate of the *Populus tomentosa* may quickly drop to a lower level after sunset.

Populus nigra exhibits the lowest daytime transpiration water consumption and demonstrates a strong synchronization between transpiration rate and light intensity variations. Not only does it have a high water use efficiency, but it also has the lowest transpiration water consumption. These findings align with those of Bogeat-Triboulot et al. [28], who studied three genotypes of *Populus nigra* in Europe and found that the transpiration rate changes of *Populus nigra* were strongly synchronized with light intensity. Therefore, *Populus nigra* is the most suitable species for field trees, followed by *Elaeagnus angustifolia*. The other three species exhibit poor coordination with light intensity changes and have higher transpiration water consumption, making them unsuitable as farmland species. This result is likely related to the stomatal density and the degree of stomatal openings in the plants. Higher stomatal density and greater stomatal opening promote transpiration. However, it is difficult

Table 2. Comparison of the number of stomata on the lower epidermis of leaves from five farmland trees.

Tree species	Leaf area/μm^2	Number of stomata or surface features
Populus euphratica	364879.7	4
Elaeagnus angustifolia	364879.8	Leaf surface covered with ring-shaped filamentous structure
Salix matsudana	364879.7	19
Populus tomentosa	516962.6	Leaf surface covered with elongated filamentous structure
Populus nigra	362566.8	26

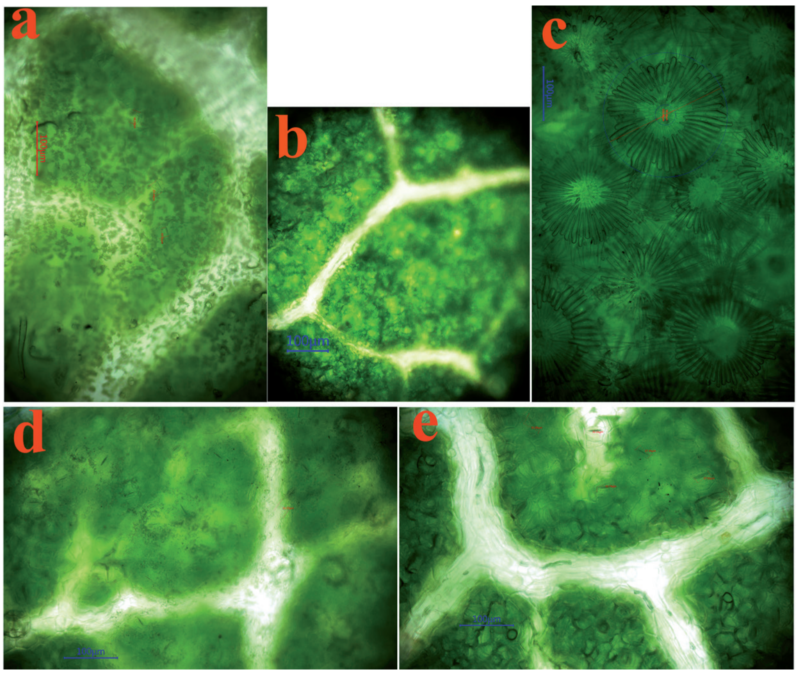

Fig. 4. Microscopic observation of stomata on the abaxial surface of leaves of five trees (a is *Populus euphratica*, b is *Populus tomentosa*, c is *Elaeagnus angustifolia*, d is *Salix matsudana*, e is *Populus nigra*).

to observe stomatal opening in the field. Observations of plant samples collected and analyzed in the laboratory showed that the stomata were predominantly closed (Fig. 4). Numerous studies [29-31] have shown that a significant number of plants exhibit a higher stomatal density on the lower epidermis compared to the upper epidermis. Therefore, microscopic observations were conducted in the laboratory on the lower epidermis of the leaves of the five trees (Fig. 4). The abaxial surface of *Elaeagnus angustifolia* leaves is covered with numerous ring-shaped filamentous structures, but no obvious stomatal structures were found. The surface of *Populus tomentosa* is also covered with irregularly distributed filamentous structures, and no distinct stomatal structures were identified. *Populus nigra* leaves have the highest stomatal density, *Salix matsudana* is medium, and *Populus euphratica* is the least (Table 2). Therefore, under strong light, *Populus nigra* and *Salix matsudana* may regulate transpiration by controlling the opening degree of a large number of stomata. The transpiration of *Elaeagnus angustifolia* and *Populus tomentosa* may be related to the filamentous structure. However, it is difficult to explain the underlying mechanisms based solely on the data from this study, and further research is needed to explore the mechanisms involved.

Although this study is based on the photosynthesis process at the leaf scale and has not yet investigated the water use system of the entire plant, the research results and methods still hold significant reference value for the selection of field tree species in mid-latitude arid regions.

Additionally, although the five field tree species studied in this paper are not far apart, which reduces the impact of environmental background factors to some extent, there are still differences in soil water, soil nutrients, and other environmental factors. Due to the simultaneous comparison of five tree species in field experiments and the need to keep the timing of all experimental processes relatively close, more repeated experiments were not conducted, resulting in a relatively insufficient number of samples. More observational data are needed to corroborate the research findings. Furthermore, there are many factors that affect plant photosynthesis, such as tree age, soil water retention capacity, and soil moisture content. The extent to which these factors interfere with the results of this study also requires further research for verification.

Conclusions

Among the five commonly seen field tree species in southern Xinjiang, *Populus nigra* has a high water use efficiency, the lowest transpiration rate, and the lowest water consumption from photosynthetic evaporation. Additionally, the transpiration rate of *Populus nigra* shows strong synchronization with changes in light intensity, indicating that *Populus nigra* leaves have a strong adaptability to varying light conditions. This may be due to the high stomatal density of *Populus nigra* leaves. By controlling the degree of stomatal opening, *Populus nigra* may regulate transpiration water loss, thereby ensuring suitable temperature conditions for leaf survival. Therefore, *Populus nigra* is the most suitable field tree species in southern Xinjiang.

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Conflict of Interest

The authors declare no conflict of interest.

References

1. LI C., HAN H., ABLIMITI M., LIU R., ZHANG H., FAN J. Morphological and physiological responses of desert plants to drought stress in a man-made landscape of the Taklimakan desert shelter belt. Ecological Indicators, **140**, **2022**.
2. PANG Y., WU B., JIA X., XIE S. Wind-proof and sand-fixing effects of Artemisia ordosica with different coverages in the Mu Us Sandy Land, northern China. Journal of Arid Land, **14** (8), 877, **2022**.
3. LI S., GU F., WANG H., PANG Y., MU G., LEI J., LIU X., ZHANG Z., YAN J. Exogenic forces action mechanism in the development process of erosion landform on alluvial plains composed of fluvial-lacustrine deposits in the Taklimakan Desert. Arid Land Geography, **35** (3), 358, **2012**.
4. LV Y., FENG Y., LIU X. Study of the Physiological Characteristics of Didymodon vinealis with the Aid of Attapulgite-Based Nanocomposite. Polish Journal of Environmental Studies. **31** (5), 4205, **2022**.
5. ZHOU Z., XU X. Experiment on Planting the Introduced Plants in the Hinterland of the Taklimakan Desert. Arid Zone Research, **21** (4), 363, **2004**.
6. LIU J., ZHAO Y., SIAL T. A., LIU H., WANG Y., ZHANG J. Photosynthetic Responses of Two Woody Halophyte Species to Saline Groundwater Irrigation in the Taklimakan Desert. Water, **14** (9), 1385, **2022**.
7. LIU J., ZHAO Y., ZHANG J., HU Q., XUE J. Effects of Irrigation Regimes on Soil Water Dynamics of Two Typical Woody Halophyte Species in Taklimakan Desert Highway Shelterbelt. Water. **14** (12), 1908, **2022**.
8. CONGJUAN L., ABULIMITI M., JINGLONG F., HAIFENG W. Ecologic Service, Economic Benefits, and Sustainability of the Man-Made Ecosystem in the Taklamakan Desert. Frontiers in Environmental Science, **10**, **2022**.

9. LI C., WANG Y., LEI J., XU X., WANG S., FAN J., FAN S. Damage by wind-blown sand and its control measures along the Taklimakan Desert Highway in China. Journal of Arid Land, **13** (1), 98, **2021**.
10. ZHAO Y., XUE J., WU N., HILL R.L. An Artificial Oasis in a Deadly Desert: Practices and Enlightenments, **14** (14), 2237, **2022**.
11. JIANG D., ZHANG N., LAMUSA A., LI X., ZHOU Q., TOSHIO O., GUO S. Plant Drought Resistance and Afforestation Density Based on Water Balance in Sandy Land, China:A Review. Journal of Northwest Forestry College, **28** (6), 75, **2013**.
12. PENG G., ZHAO C., LI J., HAN M., LI J. Water Source of Root Suckers of Populus euphratica in the Tarim River Basin,Xinjiang. Arid Zone Research, **31** (6), 1093, **2014**.
13. LIU S.B, CHEN Y.N., CHEN Y.P, DENG H.J., FANG G.H. Study on the depth of water uptake byPopulus euphraticatrees of different ages in the lower reaches of the Heihe River, based on the stable isotope techniques. Acta Ecologica Sinica, **36** (3), 729, **2016**.
14. LI T., LUO G.-M., DONG K.-P., PENG L.-P., DAI Y., NIJAT M. Water use of Populus euphratica in different development stages growing near the river. bank at the tail of the Keriya River. Chinese Journal of Ecology, **40** (4), 989, **2021**.
15. SPERRY J.S., WANG Y., WOLFE B.T., MACKAY D.S., ANDEREGG W.R., MCDOWELL N.G., POCKMAN W.T. Pragmatic hydraulic theory predicts stomatal responses to climatic water deficits. New Phytol, **212** (3), 577, **2016**.
16. SPERRY J.S., LOVE D.M. What plant hydraulics can tell us about responses to climate-change droughts. New Phytol, **207** (1), 14, **2015**.
17. LI Y., TIAN L., ZHOU H., WANG H., HE X., JIN Y., ZHANG H. Comparison of water use efficiency of sand-binding species along revegetation chronosequence in an alpine desert. Ecological Indicators, **153**, **2023**.
18. WU Y., LIAO Z., YU X., QIANG Y., HUI W., LI G. Stable isotopic analysis of water utilization characteristics of four xerophytic shrubs in the Hobq Desert, Northern China. Frontiers in Plant Science, **14**, **2023**.
19. MI J., GREGORICH E.G., XU S., MCLAUGHLIN N.B., LIU J. Effect of bentonite as a soil amendment on field water-holding capacity, and millet photosynthesis and grain quality. Scientific Reports, **10** (1), 18282, **2020**.
20. YAN S., CHONG P., ZHAO M. Effect of salt stress on the photosynthetic characteristics and endogenous hormones, and: A comprehensive evaluation of salt tolerance in Reaumuria soongorica seedlings. Plant Signaling & Behavior, **17** (1), 2031782, **2022**.
21. WANG P., SU C., WU J., XIE Y., FAN J., WANG J., HUI W., YANG H., GONG W. Response of Photosynthetic Characteristics to Different Salicylic Acid Concentrations in Relation to Waterlogging Resistance in Zanthoxylum armatum. Horticultural Science and Technology, **41** (4), 349, **2023**.
22. RAN Q., ZHANG S., ARIF M., YIN X., CHEN S., REN G. Effects of arbuscular mycorrhizal fungi on carbon assimilation and ecological stoichiometry of maize under combined abiotic stresses. Journal of Plant Ecology, **17** (2), **2024**.
23. XIE H., LIANG J., VACHULA R.S., RUSSELL J.M., CHEN S., GUO M., WANG X., HUANG X., CHEN F. Changes in the hydrodynamic intensity of Bosten Lake and its impact on early human settlement in the northeastern Tarim Basin, Arid Central Asia. Palaeogeography Palaeoclimatology Palaeoecology, **576**, **2021**.
24. LI K., QIN X., ZHANG L., WANG S., XU B., MU G., WU Y., TIAN X., WEI D., GU Z., WANG C., ZHANG J., XU D., TANG Z., LIN Y., LI W., LIU J., JIAO Y. Oasis landscape of the ancient Loulan on the west bank of Lake Lop Nur, Northwest China, inferred from vegetation utilization for architecture. Holocene, **29** (6), 1030, **2019**.
25. MISCHKE S., LIU C., ZHANG J., ZHANG C., ZHANG H., JIAO P., PLESSEN B. The world's earliest Aral-Sea type disaster: the decline of the Loulan Kingdom in the Tarim Basin. Scientific Reports, **7**, **2017**.
26. QIN X., LIU J., JIA H., LU H., XIA X., ZHOU L., MU G., XU Q., JIAO Y. New evidence of agricultural activity and environmental change associated with the ancient Loulan kingdom, China, around 1500 years ago. Holocene, **22** (1), 53, **2012**.
27. CAMARERO J.J., COLANGELO M., RODRIGUEZ-GONZALEZ P.M. Tree growth, wood anatomy and carbon and oxygen isotopes responses to drought in Mediterranean riparian forests. Forest Ecology and Management, **529**, **2023**.
28. BOGEAT-TRIBOULOT M.B., BURE C., GERARDIN T., CHUSTE P.A., LE THIEC D., HUMMEL I., DURAND M., WILDHAGEN H., DOUTHE C., MOLINS A., GALMES J., SMITH H.K., FLEXAS J., POLLE A., TAYLOR G., BRENDEL O. Additive effects of high growth rate and low transpiration rate drive differences in whole plant transpiration efficiency among black poplar genotypes. Environmental and Experimental Botany, **166**, **2019**.
29. CAVUSOGLU K., KILIC S., KABAR K. Effects of pretreatments of some growth regulators on the stomata movements of barley seedlings grown under saline (NaCl) conditions. Plant Soil and Environment, **53** (12), 524, **2007**.
30. KILIC S., KARATAS A., CAVUSOGLU K., UNLU H., UNLU H.O., PADEM H. Effects of Different Light Treatments on the Stomata Movements of Tomato (Lycopersicon esculentum Mill. cv. Joker) Seedlings. Journal of Animal and Veterinary Advances, **9** (1), 131, **2010**.
31. HUANG X., LIN S., HE S., LIN X., LIU J., CHEN R., LI H. Characterization of stomata on floral organs and scapes of cut 'Real' gerberas and their involvement in postharvest water loss. Postharvest Biology and Technology, **142**, 39, **2018**.