Nutrient resorption and its influencing factors of typical desert plants in different habitats on the northern margin of the Tarim Basin, China Postprint

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Full Text

Preamble

Nutrient Resorption and Its Influencing Factors of Typical Desert Plants in Different Habitats on the Northern Margin of the Tarim Basin, China

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Abstract

Nutrient resorption from senescent leaves enables plants to conserve and recycle nutrients. To explore the adaptation strategies of desert plants to nutrient-limited environments, we selected four typical desert species—*Populus euphratica* Oliv., *Tamarix ramosissima* Ledeb., *Glycyrrhiza inflata* Batal., and *Alhagi camelorum* Fisch.—growing in the desert area on the northern margin of the Tarim Basin, China. We analyzed the contents of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and iron (Fe) in leaves and examined their resorption characteristics. The relationships between nutrient resorption efficiency and leaf functional traits and soil physicochemical properties were investigated across two habitats (saline-alkali land and sandy land).

The results showed that all four plants resorbed most elements, though Ca was enriched in the leaves of *P. euphratica*, *G. inflata*, and *A. camelorum*; Mg was enriched in *G. inflata* leaves; and Fe was enriched in all four species. Redundancy analysis revealed that leaf thickness, soil electrical conductivity, and soil P content were the primary factors affecting nutrient resorption efficiency. Leaf thickness was negatively correlated with N resorption efficiency (NRE), P resorption efficiency (PRE), and Fe resorption efficiency (FeRE). Soil electrical conductivity was positively correlated with the resorption efficiency of most elements, while soil P content was negatively correlated with the resorption efficiency of most elements in plant leaves. These findings demonstrate that soil physicochemical properties and nutrient contents significantly impact leaf nutrient resorption.

The same species exhibited different element resorption patterns across habitats, indicating that both soil environment and leaf biological characteristics influence nutrient resorption. This study provides small-scale data support for ecosystem conservation in nutrient-deficient areas by elucidating leaf functional strategies and nutrient conservation mechanisms in typical desert plants.

Keywords: nutrient resorption; leaf functional traits; soil physicochemical properties; resorption efficiency; different habitats; desert plants

Introduction

Nutrient resorption refers to the process by which perennial plants retranslocate nutrients from senescent tissues before abscission and store them in living tissues (Han et al., 2013). Desert plants have evolved diverse nutrient utilization strategies under chronic environmental stresses such as water and salt stress, high temperature, drought, and nutrient limitation. For instance, some desert shrubs allocate most biomass to underground organs (well-developed root systems) to acquire water and nutrients, while others protect seeds from stressful conditions like nutrient deficiency through delayed seed dispersal (Abdi et al., 2019; Teresa et al., 2021). Nutrient resorption represents another crucial strategy that enhances nutrient use efficiency while reducing dependence on soil nutrient supply during growth (Aerts, 1996).

Research on nutrient resorption in desert plants is essential for understanding plant resource utilization strategies and reveals important mechanisms underlying adaptation to adverse conditions. Plant nutrient resorption efficiency is influenced by both biotic and abiotic factors, including plant biological characteristics and environmental variables (Aerts et al., 2000). Previous studies have primarily focused on natural environmental factors such as latitude, temperature, rainfall patterns, and exogenous fertilization (Li et al., 2014; Sardans et al., 2017; Prieto et al., 2020; Liu et al., 2021), with most research concentrating on non-desert plants (Zeng et al., 2005; Wei et al., 2020; Zhu et al., 2022). Element studies have predominantly examined limiting elements like nitrogen (N) and phosphorus (P) (Zhang et al., 2015; Rea et al., 2018), with less attention to other elements.

Studies on desert plants have found that N and P resorption efficiencies in some halophytes increase significantly with water stress, drought index, and salt stress (Luo et al., 2021). While soil nutrients and plant nutrient resorption are negatively correlated at large scales, small-scale studies show non-significant or positive correlations between plant nutrient resorption and soil nutrients (Zhang et al., 2015). In nutrient-limited environments, plants often exhibit higher nutrient resorption efficiency. The nutrient-poor conditions of desert environments make perennial desert plants more dependent on nutrient resorption mechanisms than non-desert plants (Zhang, 2018). However, some studies have found that desert plants experience early leaf senescence due to drought, with drier habitats associated with lower nutrient resorption rates (Li et al., 2021). To better understand nutrient reutilization and responses to environmental change in desert plants, it is urgent to explore the diverse nutrient strategies of perennial desert plants and their influencing factors.

The desert area on the northern margin of the Tarim Basin, located in the upper reaches of the Tarim River and the northern Taklimakan Desert, represents a key region for biodiversity conservation and global change research in China (An et al., 2017). This extremely arid region features harsh conditions, scarce precipitation, and intense evaporation. Although desert plants have developed adaptation strategies through long-term evolution (Luo et al., 2017; Liu et al., 2021; Wei et al., 2021), the mechanisms of nutrient resorption remain unclear. Therefore, this study selected four typical desert plants that are widely distributed, serve important ecological functions as windbreaks and sand stabilizers, and maintain ecosystem balance. These species co-occur in two distinct habitats. By analyzing their nutrient resorption characteristics in relation to leaf functional traits and soil physicochemical properties, we investigated the factors influencing nutrient resorption in desert plant leaves. Our objective was to provide scientific reference for studying element cycling mechanisms between vegetation and soil in arid regions and to establish a theoretical basis for desert ecosystem protection and restoration. We hypothesized that higher salinization would increase leaf nutrient resorption efficiency, and that both soil physicochemical properties and leaf functional traits would jointly influence plant nutrient resorption.

Study Area

The study area (40°41′–40°42′N, 80°58′–81°15′E) is located on the northern margin of the Tarim Basin in Xinjiang Uygur Autonomous Region, China. The terrain slopes from northwest to south, with the northern portion comprising the agricultural zone of the Tarim River alluvial plain and the eastern and southern portions forming the Taklimakan Desert. The region experiences a warm temperate continental arid climate, with a mean annual temperature of approximately 10°C and mean annual precipitation below 50 mm. Strong evaporation, large temperature variations, abundant sunshine hours, and rich light and heat resources characterize the climate. The area represents a typical desert ecosystem with relatively simple soil formation, dominated by sandy soil and saline soil derived primarily from brown desert soil parent material. Vegetation consists mainly of shrubs and herbs, with dominant species including *Populus euphratica* Oliv., *Tamarix ramosissima* Ledeb., *Glycyrrhiza inflata* Batal., *Alhagi camelorum* Fisch., *Nitraria tangutorum* Bobr., and *Kalidium foliatum* (Pall.) Moq.

Experimental Design and Sample Collection

This study examined four dominant desert plants—*P. euphratica*, *T. ramosissima*, *G. inflata*, and *A. camelorum*—growing on the northern margin of the Tarim Basin. We selected two distinct habitats based on distance from oasis: saline-alkali land (Habitat I) and sandy land (Habitat II). Habitat I, distributed on the edge of the Taklimakan Desert, features aeolian sandy soil, while Habitat II, located in the ecotone between farmland and wasteland near abandoned fields, contains saline soil. Both habitats have alkaline soils with low water content, and all four species occur in both environments.

Three 20 m × 20 m plots were established in each habitat following the principle of representativeness. Areas with minimal human disturbance were selected where topographic factors such as altitude and aspect were generally uniform. In June 2021, mature leaves were collected from randomly selected plants (5 individuals each of *P. euphratica* and *T. ramosissima*; 10 individuals each of *G. inflata* and *A. camelorum* of similar size and growth status). Selected plants were marked with red cloth strips, and senescent leaves were collected from these marked individuals in October 2021. For each plant, fully expanded, intact leaves were collected in sufficient quantity depending on leaf shape and size. Half of each sample was stored in numbered bags for element content determination, while the other half was kept fresh at low temperature in darkness for morphological analysis and chlorophyll content measurement, with each sample replicated at least five times. Concurrently, soil samples (0–20 cm depth beneath plant canopies, after litter and stone removal) were collected from each quadrat, sealed in numbered bags, and stored for subsequent analysis.

Laboratory Analyses

Leaf physiological traits were determined using a portable chlorophyll meter (CCM-200, Lanende, Shandong, China) for relative chlorophyll content. Leaf structural traits were measured as follows: leaf area (mm^2) using a scanner (LIDE300, Canon, Guangdong, China), leaf thickness (mm) using a vernier caliper (accuracy 0.01 mm), and saturated fresh weight and dry weight (g) using an electronic balance. Specific leaf area was calculated as: specific leaf area (mm^2/g) = leaf area (mm^2) / leaf dry weight (g). Leaf dry matter content was calculated as: leaf dry matter content = leaf dry weight (g) / leaf saturated fresh weight (g).

Plant leaf samples were dried and crushed at 65°C, while soil samples were dried, ground naturally, and sieved through 100 mesh. Element contents in soil and plants were determined according to Dong (1997). Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and iron (Fe) contents were measured by atomic absorption spectrometry. Soil physicochemical properties were determined following Bao (2000) and Zheng (2013). Soil water content, pH, and electrical conductivity were measured using the drying method, potentiometric method, and electrical conductivity method, respectively.

The nutrient resorption efficiency (NuRE, %) was calculated as follows:

$$NuRE = \left(1 - \frac{Nusenesced}{Nugreen}\right) \times MLCF \times 100$$

where $Nugreen$ is nutrient concentration in mature leaves (mg/g); $Nusenesced$ is nutrient concentration in senescent leaves (mg/g); and $MLCF$ is a mass loss correction factor compensating for leaf mass loss during senescence, based on the global average of 0.784 for deciduous plants (Vergutz et al., 2012).

Statistical Analyses

Data processing and statistical analysis were performed using SPSS 23.0, Origin 2018, and R 3.4.0 software. One-way analysis of variance (ANOVA) compared differences in resorption efficiency of various nutrient elements, leaf functional traits, and soil physicochemical properties across habitats and plant species. Independent t-tests examined differences in resorption efficiency, leaf functional traits, and soil physicochemical properties for the same plant across habitats. Redundancy analysis (RDA) and Pearson correlation analysis assessed relationships between nutrient resorption efficiency and influencing factors in desert plant leaves.

In this study, element resorption efficiency for each plant served as the dependent variable, with soil physicochemical properties and leaf functional traits as explanatory variables. RDA screening and analysis were conducted after standardizing these factors. Test results confirmed all factors contributed to the model (expansion coefficients of soil physicochemical properties were all less than 20) and could be analyzed as environmental variables. Monte Carlo tests quantitatively evaluated the independent contribution of each influencing factor to element resorption characteristics.

Leaf Nutrient Content Characteristics of Typical Desert Plants

Figure 1 [Figure 1: see original paper] presents leaf nutrient content characteristics of typical desert plants on the northern margin of the Tarim Basin. Leaf N content (LNC), leaf P content (LPC), and leaf K content (LKC) were higher in mature leaves than in senescent leaves, while leaf Ca content (LCaC), leaf Mg content (LMgC), and leaf Fe content (LFeC) were generally lower in mature leaves than in senescent leaves. *A. camelorum* exhibited significantly higher LNC than other plants ($P < 0.05$) in both mature and senescent leaves across both habitats. Except for *P. euphratica*, LNC was generally higher in Habitat I than in Habitat II. *T. ramosissima* showed lower LPC than other species, with most plants having significantly lower LPC in Habitat I than in Habitat II ($P < 0.05$).

A. camelorum had significantly higher LKC than the other three species ($P < 0.05$), with LKC generally higher in Habitat I. Differences in LCaC among plants were small, though most species showed lower LCaC in Habitat I than in Habitat II ($P < 0.05$), except *P. euphratica* which displayed the opposite trend. LMgC patterns were similar to LCaC, being mostly lower in Habitat I than in Habitat II ($P < 0.05$), though mature leaves of *G. inflata* and *A. camelorum* showed the reverse pattern. *G. inflata* had significantly higher LFeC than other species ($P < 0.05$), while *T. ramosissima* and *A. camelorum* showed significantly lower LFeC in Habitat I than in Habitat II ($P < 0.05$), contrary to other species.

Characteristics of Leaf Nutrient Resorption in Typical Desert Plants

All four plants resorbed N, P, and K from leaves, while Ca was enriched in *P. euphratica*, *G. inflata*, and *A. camelorum*; Mg was enriched in *G. inflata*; and Fe accumulated in all four species (Fig. 2 [Figure 2: see original paper]). Little variation existed in NRE and PRE among different plant leaves. NRE in *P. euphratica* and *G. inflata* leaves was significantly higher in Habitat I than in Habitat II ($P < 0.05$). *P. euphratica* showed higher K resorption efficiency (KRE) than other species, with most plants exhibiting significantly higher KRE in Habitat I than in Habitat II ($P < 0.05$).

Except for *T. ramosissima*, most plants showed negative Ca resorption efficiency (CaRE), with *A. camelorum* demonstrating significantly greater Ca enrichment in Habitat I than in Habitat II ($P < 0.05$). *G. inflata* leaves showed negative Mg resorption efficiency (MgRE), while the other three species resorbed Mg. No significant differences in Fe resorption efficiency (FeRE) were observed among the four plants between habitats, except for *T. ramosissima*.

Leaf Functional Traits and Soil Physicochemical Properties of Typical Desert Plants

Figure 3 [Figure 3: see original paper] illustrates leaf functional traits of typical desert plants. *T. ramosissima* had significantly greater leaf thickness than other species ($P < 0.05$), with no significant difference between habitats. *A. camelorum* showed lower leaf dry matter content than other plants, while *T. ramosissima* and *G. inflata* had significantly higher leaf dry matter content in Habitat II than in Habitat I ($P < 0.05$). *P. euphratica* exhibited significantly higher specific leaf area than other species ($P < 0.05$), with no significant habitat differences for any species. *T. ramosissima* had significantly lower relative chlorophyll content than other species ($P < 0.05$), while most plants showed significantly higher relative chlorophyll content in Habitat I than in Habitat II ($P < 0.05$).

As shown in Table 1 , soil water content in the study area was low, ranging from 1.62% to 4.49%, with higher values under plant canopies in Habitat I than in Habitat II. Soils were alkaline, with maximum pH reaching 9.78. Soil pH under *P. euphratica* was significantly higher than under other species. Soil electrical conductivity in Habitat I was generally higher than in Habitat II for all plants. Soil nutrient content was generally low, though soil N content under *P. euphratica* canopies was relatively high. Soil N content under plant canopies was generally higher in Habitat I than in Habitat II, while P, K, Ca, Mg, and Fe contents showed no significant differences.

Effects of Soil Physicochemical Properties and Leaf Functional Traits on Nutrient Resorption Efficiency

RDA revealed that leaf functional traits and soil physicochemical properties explained 78.6% and 1.4% of variance in RDA1 and RDA2, respectively (Fig. 4 [Figure 4: see original paper]). The first two ordination axes accounted for 80.0% of the relationship between leaf functional traits, soil physicochemical properties, and nutrient resorption efficiency. According to RDA results (Fig. 4a), soil Ca content, soil Fe content, specific leaf area, and relative chlorophyll content were positively correlated with NRE, PRE, and FeRE. Soil P content, soil K content, and leaf thickness were negatively correlated with resorption efficiency of these three elements. Soil K content, soil electrical conductivity, soil pH, and leaf thickness were positively correlated with KRE, MgRE, and CaRE, while soil P content, soil Ca content, soil Fe content, and leaf dry matter content were negatively correlated with resorption efficiency of these three elements.

The correlation matrix (Fig. 4b) showed that NRE was strongly correlated with relative chlorophyll content ($r = 0.65$) and leaf thickness ($r = –0.61$). PRE showed strong correlation with leaf thickness ($r = –0.80$). KRE was strongly correlated with soil Ca content ($r = –0.47$) and leaf dry matter content ($r = –0.53$). CaRE was strongly correlated with leaf thickness ($r = 0.88$) and relative chlorophyll content ($r = –0.67$). MgRE showed strong correlation with leaf thickness (r = 0.41), soil Ca content (r = –0.55), and leaf dry matter content (r = –0.69). FeRE was strongly correlated with relative chlorophyll content (r = 0.52), soil P content (r = –0.43), and leaf thickness (r = –0.58).

Monte Carlo tests on these 13 influencing factors yielded an importance ranking (Table 2): leaf thickness, soil electrical conductivity, soil P content, soil K content, soil pH, soil N content, relative chlorophyll content, specific leaf area, leaf dry matter content, soil Mg content, soil Ca content, soil Fe content, and soil water content. Leaf thickness had an extremely significant effect on nutrient resorption efficiency ($P < 0.01$), while soil electrical conductivity and soil P content had significant effects ($P < 0.05$). These three factors accounted for 30.7%, 17.5%, and 10.4% of all influencing factors, respectively, indicating they are the primary determinants of plant nutrient resorption efficiency.

Nutrient Resorption Characteristics of Typical Desert Plant Leaves in Different Habitats

Nutrient resorption characteristics reflect both plant adaptation mechanisms to environmental conditions and key strategies for efficient nutrient use. Differences in soil nutrient supply capacity between the two habitats resulted in varying nutrient resorption efficiencies among plants. N, P, and K are primary elements limiting plant growth and participate in various essential physiological processes. This study found that NRE and KRE in most plants across both habitats were lower than global means for terrestrial plants (62.1% and 70.1%, respectively), while PRE exceeded the global mean (64.9%; Vergutz et al., 2012). Lower NRE and KRE may relate to species identity and growth environment. The high PRE observed suggests P limitation on plant growth.

Nutrient resorption efficiency also varied between habitats. Liu et al. (2015) demonstrated that system nutrient supply capacity is a major factor limiting plant growth, with plants in low-nutrient habitats exhibiting lower resorption rates. In this study, N, P, and K resorption efficiencies were higher in Habitat I than in Habitat II, corresponding to higher soil nutrient content and supply capacity in Habitat I. Calcium plays a crucial role in maintaining physiological balance and cellular stability in plant leaves. Zhou et al. (2016) found that plants can reduce Na toxicity by regulating Ca uptake, thereby alleviating cell membrane damage from environmental stress. The negative CaRE in *P. euphratica*, *G. inflata*, and *A. camelorum* under conditions of water shortage, high temperature, and salinity indicates Ca accumulation in senescent leaves. Given that Habitat I had higher soil salinization than Habitat II, the greater Ca enrichment degree in *A. camelorum* in Habitat I suggests this species may adapt to high-salt habitats by accumulating more Ca.

Magnesium is a key chlorophyll component, and its leaf content relates to photosynthetic capacity (Zhang, 2018). Only *G. inflata* showed negative MgRE, possibly due to its biological characteristics. *G. inflata* has rapid growth rates, requiring more Mg to synthesize additional chlorophyll and enhance photosynthetic capacity, leading to continued accumulation in senescent leaves. Iron, though a trace element, plays an important role in plant growth but has received limited attention. The negative FeRE values across all four species in both habitats may result from high Fe content in mature leaves, enabling plants to meet growth needs through root absorption without mobilizing nutrients from old leaves, consistent with Zhou et al. (2022).

Leaf Functional Traits and Soil Physicochemical Properties Under Canopy in Different Habitats

Leaf thickness and leaf dry matter content characterize plant self-protection mechanisms and nutrient retention capacity (Zhang et al., 2016). *T. ramosissima* exhibited greater leaf thickness and dry matter content than other species in both habitats. As green assimilating branches, *T. ramosissima* leaves possess unique morphology that reduces evaporation, facilitating adaptation to arid habitats. Additionally, higher leaf dry matter content accumulation in several plants in Habitat II reflects adaptive changes in leaf functional traits related to drought (Pescador et al., 2015).

Specific leaf area and relative chlorophyll content relate to resource use efficiency and light acquisition capacity (Wang et al., 2022). *P. euphratica*, the dominant tree species, showed significantly higher specific leaf area than other species, reflecting an efficient resource utilization strategy. Its height advantage enables greater light capture, providing more living space and adaptation to resource-limited habitats. *G. inflata* and *A. camelorum*, as herbaceous species, had higher relative chlorophyll contents, increasing growth rates through more efficient photosynthesis to utilize environmental resources, making them “quick investment-return” species as proposed by Osnas et al. (2013). Furthermore, higher relative chlorophyll content in Habitat I than in Habitat II may relate to differences in soil water content and nutrient supply, as low water content indirectly inhibits chlorophyll synthesis and N deficiency hinders chlorophyll production (Wang et al., 2022).

The northern Tarim Basin margin is an extremely arid region with severe water shortages and soil desertification and salinization. Consequently, soil water content under plant canopies was generally below 5.00%, soils were alkaline, and soil electrical conductivity was relatively high. Soils were relatively barren, with N (0.11 mg/g), K (16.70 mg/g), and Fe (24.20 mg/g) contents lower than national averages reported by Chen et al. (1991) (N: 0.84 mg/g; K: 18.00 mg/g; Fe: 28.00 mg/g). Soil moisture and nutrient content in Habitat I exceeded those in Habitat II, confirming that soil nutrient supply affects leaf nutrient resorption efficiency.

Relationship of Nutrient Resorption Efficiency with Leaf Functional Traits and Soil Physicochemical Properties

Element nutrient resorption is species-specific and environmentally mediated. Leaf thickness, soil electrical conductivity, and soil P content were the primary factors affecting nutrient resorption in desert plants on the northern Tarim Basin margin.

Thick leaves help plants resist physical damage. This study found leaf thickness was negatively correlated with NRE, PRE, and FeRE, contrasting with previous studies (Liu et al., 2015; Zhou et al., 2022). This effect may relate to leaf lifespan, as long-lived leaves typically have higher nutrient use efficiency than short-lived leaves. To adapt to harsh environments like drought and herbivory, desert plants with thick leaves may allocate more nutrients to defensive tissues, potentially impeding nutrient resorption, translocation, and reuse. However, the trade-off strategies between leaf functional traits and nutrient resorption for environmental adaptation remain unclear and require further investigation.

Soil electrical conductivity was positively correlated with resorption efficiency of most elements. Higher soil salinization and salinity typically reduce soil nutrient availability, making nutrient acquisition difficult. Plants must transfer more elements from senescent leaves to meet growth demands and resist saline-alkali stress, resulting in higher resorption efficiency. Flowers et al. (2008) confirmed that many halophytes in saline habitats have higher protein contents, with saline environments stimulating growth and enhancing nutrient resorption capacity. In nutrient-limited, high-salinity soils where moisture and nutrients are easily lost and difficult to replenish, soil nutrient supply becomes the primary factor limiting plant growth. Soil P content on the northern Tarim Basin margin was negatively correlated with resorption efficiency of most elements. The higher PRE compared to other elements indicates P limitation on plant growth. Studies show that when nutrient imbalances limit growth via a specific element, plants exhibit higher resorption efficiency for that limiting element (Li et al., 2021). Additionally, nutrient resorption capacity is lower in high-P soils, consistent with our results. As soil nutrient content increases, plant leaf nutrient resorption efficiency decreases (Aerts, 1996; Kobe et al., 2005), representing an adaptive nutrient regulation mechanism.

Conclusions

Populus euphratica, *Tamarix ramosissima*, *Glycyrrhiza inflata*, and *Alhagi camelorum* are typical dominant desert plants on the northern margin of the Tarim Basin. Their adaptation strategies provide a theoretical basis for screening viable species in the region. This study of nutrient resorption and its influencing factors revealed that all four species resorb N, P, and K, confirming the strategy of using nutrient resorption efficiency to adapt to barren habitats. Calcium was enriched in leaves of *P. euphratica*, *G. inflata*, and *A. camelorum*, with enrichment increasing with soil salinization, reflecting adaptation to saline habitats through adjusted Ca resorption efficiency. Magnesium was enriched in *G. inflata* leaves, and iron was enriched across all four species. *Tamarix ramosissima* exhibited greater leaf thickness and dry matter content, *P. euphratica* had higher specific leaf area, and *G. inflata* and *A. camelorum* had higher relative chlorophyll contents. Leaf thickness, soil electrical conductivity, and soil P content were the main factors influencing nutrient resorption efficiency. In the arid, saline-alkali, and barren habitats of the northern Tarim Basin margin, different plants have evolved distinct survival strategies. The coordinated evolution between leaf functional traits and nutrient resorption efficiency represents adaptation to special habitats, though the internal trade-off mechanisms require further study.

Conflict of Interest

The authors declare no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Author Contributions

Conceptualization: GONG Lu; Data curation: ZHOU Chongpeng; Methodology: ZHOU Chongpeng; Investigation: ZHOU Chongpeng; Formal analysis: ZHOU Chongpeng; Writing - original draft: ZHOU Chongpeng; Writing - review and editing: GONG Lu, WU Xue, LUO Yan; Funding acquisition: WU Xue; Resources: GONG Lu, WU Xue; Supervision: GONG Lu; Project administration: WU Xue; Software: ZHOU Chongpeng; Validation: GONG Lu; Visualization: ZHOU Chongpeng.

References

Abdi E, Saleh H R, Majnonian B, et al. 2019. Soil fixation and erosion control by *Haloxylon persicum* roots in arid lands, Iran. *Journal of Arid Land*, 11(1): 86–96.

Aerts R. 1996. Nutrient resorption from senescing leaves of perennials: Are there general patterns? *Journal of Ecology*, 84(4): 597–608.

Aerts R, Chapin III F S. 2000. The mineral nutrition of wild plants revisited: A re-evaluation of processes and patterns. *Advances in Ecological Research*, 30: 1–67.

An S Q, Gong L, Zhu M L, et al. 2017. Root stoichiometric characteristics of desert plants and their correlation with soil physicochemical factors in the northern Tarim Basin. *Acta Ecologica Sinica*, 37(16): 5444–5450. (in Chinese)

An Z. 2011. Effects of N addition on C, N, P stoichiometry and photosynthetic characteristics of *Stipa bungeana* and *Leymus secalinus* in the grassland on Loess Plateau. Msc Thesis. Lanzhou: Lanzhou University. (in Chinese)

Arco J M D, Escudero A, Garrido M V. 1991. Effects of site characteristics on nitrogen retranslocation from senescing leaves. *Ecology*, 72(2): 701–708.

Bao S D. 2000. *Soil and Agricultural Chemistry Analysis*. Beijing: China Agriculture Press, 1–495. (in Chinese)

Chen J S, Wei F S, Zheng C J. 1991. Background concentrations of elements in soils of China. *Water, Air and Soil Pollution*, 57–58(1): 699–712.

Dong M. 1997. *Survey, Observation and Analysis of Terrestrial Biocommunities*. Beijing: Standards Press of China, 1–290. (in Chinese)

Flowers T J, Colmer T D. 2008. Salinity tolerance in halophytes. *New Phytologist*, 179(4): 945–963.

Han W X, Tang L Y, Chen Y H. 2013. Relationship between the relative limitation and resorption efficiency of nitrogen vs phosphorus in woody plants. *PLoS ONE*, 8(12): e83366, doi: 10.1371/journal.pone.0083366.

Kobe R K, Lepczyk C A, Iyer M. 2005. Resorption efficiency decreases with increasing green leaf nutrients in a global data set. *Ecology*, 86(10): 2780–2792.

Li S X, Zhang Y X, Guo J P. 2021. Effects of nitrogen addition on leaf stoichiometry and nutrients reabsorption efficiency of *Larix principis-rupprechtii*. *Journal of Soil and Water Conservation*, 35(5): 249–254, 263. (in Chinese)

Li Y L, Jing C, Mao W, et al. 2014. N and P resorption in a pioneer shrub (*Artemisia halodendron*) inhabiting severely desertified lands of Northern China. *Journal of Arid Land*, 6(2): 174–185.

Liu H W, Liu W D, Wang W, et al. 2015. Leaf traits and nutrient resorption of major woody species in the karst limestone area of Chongqing. *Acta Ecologica Sinica*, 35(12): 4071–4080. (in Chinese)

Liu S S, Xu G Q, Li Y, et al. 2021. Difference and consistency of responses of five sandy shrubs to changes in groundwater level in the Hailiutu River Basin. *Acta Ecologica Sinica*, 41(2): 615–625. (in Chinese)

Liu Y L, Li L, Li X Y, et al. 2021. Effect of nitrogen and phosphorus addition on leaf nutrient concentrations and nutrient resorption efficiency of two dominant alpine grass species. *Journal of Arid Land*, 13(10): 1041–1053.

Luo Y, Gong L, Zhu M L, et al. 2017. Stoichiometry characteristics of leaves and soil of four shrubs in the upper reaches of the Tarim River Desert. *Acta Ecologica Sinica*, 37(24): 8326–8335. (in Chinese)

Luo Y, Chen Y, Peng Q W, et al. 2021. Nitrogen and phosphorus resorption of desert plants with various degree of propensity to salt in response to drought and saline stress. *Ecological Indicators*, 125: 107488, doi: 10.1016/j.ecolind.2021.107488.

Osnas J L D, Lichstein J W, Reich P B, et al. 2013. Global leaf trait relationships: mass, area, and the leaf economics spectrum. *Science*, 340(6133): 741–744.

Pescador D S, de Bello F, Valladares F, et al. 2015. Plant trait variation along an altitudinal gradient in Mediterranean high mountain grasslands: Controlling the species turnover effect. *PLoS ONE*, 10(3): e0118876, doi: 10.1371/journal.pone.0118876.

Prieto I, Querejeta J I. 2020. Simulated climate change decreases nutrient resorption from senescing leaves. *Global Change Biology*, 26(1): 1795–1807.

Rea A M, Mason C M, Donovan L A. 2018. Evolution of nutrient resorption across the herbaceous genus *Helianthus*. *Plant Ecology*, 219(8): 887–899.

Sardans J, Grau O, Chen H Y H, et al. 2017. Changes in nutrient concentrations of leaves and roots in response to global change factors. *Global Change Biology*, 23(9): 3849–3856.

Teresa N, Hatem A S, Ali E, et al. 2021. Delayed seed dispersal species and related traits in the desert of the United Arab Emirates. *Journal of Arid Land*, 13(9): 962–976.

van Heerwaarden L M, Toet S, Aerts R. 2003. Current measures of nutrient resorption efficiency lead to a substantial underestimation of real resorption efficiency: Facts and solutions. *Oikos*, 101(3): 664–669.

Vergutz L, Manzoni S, Porporato A, et al. 2012. Global resorption efficiencies and concentrations of carbon and nutrients in leaves of terrestrial plants. *Ecological Monographs*, 82(2): 205–220.

Wang C, Lu J, Yao H F, et al. 2022. Leaf functional traits and environmental responses of *Abies georgei* var. *smithii*. *Journal of Forest and Environment*, 42(2): 123–130. (in Chinese)

Wei L, Kao S J, Liu C X. 2020. Mangrove species maintains constant nutrient resorption efficiency under eutrophic conditions. *Journal of Tropical Ecology*, 36(1): 36–38.

Wei Y H, Liang W Z, Han L, et al. 2021. Leaf functional traits of *Populus euphratica* and its response to groundwater depths in Tarim extremely arid area. *Acta Ecologica Sinica*, 41(13): 5368–5376. (in Chinese)

Wright I J, Westoby M. 2002. Leaves at low versus high rainfall: coordination of structure, lifespan and physiology. *New Phytologist*, 155(3): 403–416.

Zeng D H, Chen G S, Chen F S, et al. 2005. Foliar nutrients and their resorption efficiencies in four *Pinus sylvestris* var. *mongolica* plantations of different ages on sandy soil. *Scientia Silvae Sinicae*, 41(5): 21–27. (in Chinese)

Zhang J L, Zhang S B, Chen Y J, et al. 2015. Nutrient resorption is associated with leaf vein density and growth performance of dipterocarp tree species. *Journal of Ecology*, 103(3): 541–549.

Zhang M X. 2018. Resorption patterns of 10 nutrient elements in leaves of woody plants in northern China. PhD Dissertation. Beijing: China Agricultural University. (in Chinese)

Zhang X, Wang Z N, Lu J Y, et al. 2016. Responses of leaf traits to drought at different growth stages of alfalfa. *Acta Ecologica Sinica*, 36(9): 2669–2676. (in Chinese)

Zheng B T. 2013. *Technical Guidelines for Soil Analysis*. Beijing: China Agriculture Press, 1–67. (in Chinese)

Zhou L L, Addo-Danso S D, Wu P F, et al. 2016. Leaf resorption efficiency in relation to foliar and soil nutrient concentrations and stoichiometry of *Cunninghamia lanceolata* with stand development in southern China. *Journal of Soils and Sediments*, 16(5): 1448–1459.

Zhou L L, Zheng Y Y, Li S B, et al. 2022. Leaf nutrient resorption characteristics among mangrove tree species. *Journal of Northwest Forestry University*, 37(3): 51–56. (in Chinese)

Zhu D H, Peng S H, Wang J Y, et al. 2022. Responses of nutrient resorption to human disturbances in *Phoebe bournei* forests. *Forests*, 13(6): 905–917.

Note: Figure translations are in progress. See original paper for figures.