Ecological stoichiometry characteristics and influencing factors of carbon, nitrogen, and phosphorus in the leaves of *Sophora alopecuroides* L. in the Yili River Valley, Xinjiang

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Background. *Sophora alopecuroides* L. (*S. alopecuroides* L.) is a perennial herb widely distributed throughout Xinjiang, China. It is characterized by its rapid diffusion ability.

Method. To reveal the ecological mechanism of the rapid spread of *S. alopecuroides* and to elucidate the ecological stoichiometry characteristics of C, N, and P in the leaves of *S. alopecuroides* in the Yili River Valley and its influencing factors, *S. alopecuroides* leaves were sampled in four habitats of forest, roadside, farmland, and desert in the Yili River Valley. The variation rules of the ecological stoichiometry characteristics of C, N, and P in the leaves of *S. alopecuroides* were analyzed. The correlation between the ecological stoichiometry characteristics of leaves and environmental factors was examined by redundancy analysis (RDA).

Result. The results showed that: (1) the C, N, and P contents of *S. alopecuroides* leaves were 391.30–533.10 g/kg, 8.90–43.14 g/kg, and 0.71–2.04 g/kg, respectively, and the C/N, C/P, N/P ratios were 10.34–4.94, 209.05–698.73, and 10.78–31.43 respectively; (2) The C content and C/P ratio of *S. alopecuroides* leaves were highest in the desert habitat, the leaf N content and N/P ratio were the highest in the forest habitat, the leaf P content was the highest in the farmland habitat, and the leaf C/N ratio was the highest in the roadside habitat; (3) RDA showed that available potassium (AK) and pH were the main factors affecting the ecological stoichiometry characteristics of *S. alopecuroides* leaves in Yili Valley (*p* <!--[if !msEquation]--> <!--[endif]-->0.05), and they were positively correlated with C, N, P, and N/P, and negatively correlated with C/P and C/N; AK was the dominant factor that affected the P content of *S. alopecuroides* leaves, and appropriate reduction of K fertilizer would be conducive to restraining the spread of *S. alopecuroides*; soil C, N, P, and K content, soil organic matter (OM), nitrate nitrogen (NO_3^-N), ammonium nitrogen (NH_4^+-N), and AK had no significant effect on the ecological stoichiometry characteristics of leaves ($p > 0.05$).

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Abstract

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Keywords: *S. alopecuroides* L.; ecological stoichiometry characteristics; soil physical-chemical factors; redundancy analysis.

Introduction

Ecological stoichiometry is a comprehensive science that studies the equilibrium relationship, quantitative relationship, and biogeochemical cycle of various chemical elements in ecological processes (Sterner et al., 2002), providing an important technical means for analyzing the nutrient utilization of vegetation (Elser et al., 1996). The essence of the plant growth process is the regulation of the accumulation and relative proportions of C, N, and P in the plant (Koerselman et al., 1996). C, N, and P are essential nutrients for plant growth and development. C is the most important element in plant dry matter; N promotes the synthesis of amino acids and proteins, but also enhances the photosynthetic capacity of plants; and P is not only an important component of nucleic acids and enzymes but also a basic element of all living organisms; thus, C, N, and P significantly affect plant growth and the regulation of physiological mechanisms (Wang et al., 2011).

Previous studies on the stoichiometric characteristics of C, N, and P have primarily focused on the stability of plant communities (Tessier et al., 2003), litter decomposition processes (Mooshammer et al., 2012), and determination of plant growth restriction elements (Tjoelker et al., 2005). The study of plant leaf ecological stoichiometry helps to explore plant growth characteristics and nutrient limitation. Leaves are the main sites of plant photosynthesis and their photosynthetic organs and rate are closely related to the N content of the leaves. The C/N and C/P ratios in leaves reflect the rate of plant carbon assimilation, and, to a certain extent, can reflect plant nutrient use efficiency (Wang et al., 2008). Leaf N/P is the sensitivity index, and an important evaluation tool, of plant growth nutrient restriction (Duan Xiaonan et al., 2004). In addition, the growth process of plants has been found to be not only affected by C, N, and P elements, but also by the external environment (Cleland et al., 2011). Soil moisture, salinity, and nutrients have a significant impact on the C, N, and P content of plant leaves and their stoichiometric ratio (Chen et al., 2016; Yan et al., 2011). Soil properties affect the ecological stoichiometric characteristics of plant leaves by affecting the effective absorption of soil physicochemical factors and nutrients. Further, the soil nutrient content and its balance are closely related to the ecological stoichiometric characteristics of vegetation. Soil nutrient levels not only affect plant growth and community composition but also indicate the health of the ecosystem (Li et al., 2004). Therefore, it is of great significance to explore the nutrient characteristics of plant leaves and the physical-chemical properties of the soil in the habitat, so as to understand the nutrient utilization status in the process of plant growth and reveal the nutrient supply capacity of soil and the adaptation mechanism of plants to the environment.

Sophora alopecuroides L. (*S. alopecuroides* L.) is a perennial herb of the legume family and is predominantly distributed in arid desert and grassland marginal areas, such as Xinjiang, Ningxia, and Inner Mongolia. It has the characteristics of salinity tolerance and drought resistance (Qi et al., 2008). Therefore, it is widely used in wind prevention, sand fixation, and saline alkali land improvement (Chen et al., 2000). Due to the fast-spreading characteristics of *S. alopecuroides*, populations often grow continuously and are distributed widely, which can form a single superior community in a short time. In recent years, the grassland in the Yili River Valley, northwestern Xinjiang, has been degenerating, resulting in the spread of a large number of poisonous weeds. Among them, *S. alopecuroides* has rapidly become the dominant species due to its rapid diffusion characteristics, occupying the living space of other species, resulting in the degradation of grassland quality. The dominant presence of *S. alopecuroides* poses a serious threat to the development of local animal husbandry and biodiversity (Dong et al., 2018). Current research on *S. alopecuroides* mainly focuses on seed morphological characteristics, the medicinal value of the plant, seed germination conditions, and seed dormancy (Ying et al., 2017; Weiliang et al., 2016; Jin et al., 2007). However, there are few reports on the ecological stoichiometric characteristics of *S. alopecuroides* leaves and the correlation between soil physicochemical factors and plant ecological stoichiometric characteristics. Therefore, from the perspective of ecological stoichiometric characteristics, the present study was conducted using *S. alopecuroides* leaves from the Yili River Valley, and the variation rule of the ecological stoichiometry characteristics of C, N, and P in the leaves across different habitats was analyzed systematically. The relationship between the ecological stoichiometric characteristics of *S. alopecuroides* and environmental factors was studied to reveal the survival strategy and ecological mechanism of the rapid spread of *S. alopecuroides* in arid and semi-arid areas, and the effects of *S. alopecuroides* on soil quality in degraded steppes, so as to serve as the theoretical basis for the scientific management and ecological restoration of degraded grassland.

Materials and Methods

Site description

The study area is located in the Yili River Valley of the Xinjiang Uygur Autonomous Region (80°09E—84°56E, 42°14N—44°50′N). The north, east, and south sides of the Yili River Valley all constitute high mountains. The terrain changes from high to low from east to west, in the shape of a trumpet, thus forming the natural landform outline of "three mountains and two valleys," enjoying the reputation of a "wet island in the western region." The elevation of the Yili River Valley is 530 m to 1000 m high and spans 360 km from east to west and 275 km from north to south, covering an area of 56,400 km^2. The Yili River Valley is the wettest area in Xinjiang, with a warm and humid temperate continental climate. The average annual temperature is 10.4 ° C, the average sunshine hours range between 2,700 and 3,000 h, and the average annual precipitation is 417.6 mm which mainly occurs during the spring and summer and accounts for approximately 60%–70% of the total annual precipitation. The Yili River Valley has a superior geographical location, abundant natural resources, abundant species, diverse mineral resources, and unique wetland landscapes. The valley mainly constitutes grassland, meadow, forest, and other vegetation types.

Study site and sample collection

Through field investigation and observation, it was found that *S. alopecuroides*, as a plant with strong invasion ability, often invades four areas: forest, roadside, farmland, and desert, and, thus, is widely distributed in the four regions. Soil samples were collected in September 2018, and plant samples were collected in July 2019 (Figure 1) in Qapqal County, Yili River Valley, under the four habitats of forest, roadside, farmland, and desert.

Three 1 m × 1 m quadrats were randomly set up in each of the four invasive habitats of S. *alopecuroides*. In each plot, 10 plants of *S. alopecuroides* with uniform growth were randomly selected, and their leaves were cut from the plants. The leaves of a further 10 *S. alopecuroides* were taken as a repeat and brought back to the laboratory for low-temperature preservation. All the collected leaves of *S. alopecuroides* were dried at 70 ° C for 24 h. The leaves were then crushed into foam using a pulverizer, and then sealed for storage. The contents of total C, total N, and total P in the leaves of the *S. alopecuroides* leaves were determined.

Soil samples of 0–10 cm, 10–20 cm, and 20–30 cm were collected in each field plot, and each plot was repeated once. In total, 36 soil samples were collected from four plots. The collected soil samples were put into sealed plastic bags, and fully integrated in the laboratory after air drying, grinding, screening, and other operations, and the physical and chemical properties of the soil were analyzed.

Figure 1

Analysis of soil and plant properties

Leaf properties of plants

The total C content of the *S. alopecuroides* leaves was measured using the K_2CrO_7-H_2SO_4 oxidation procedure. The total N content (TN) in the soil and plant samples was determined by boiling the samples with perchloric acid ($HClO_4$) and sulfuric acid (H_2SO_4), and conducting colorimetry analysis with a FOSS 1035 Automatic Nitrogen Analyzer. To establish total P content, perchloric acid and sulfuric acid were first added to the leaves and soil samples, and the colorimetric method using an Agilent CARY60 Ultraviolet-Visible Spectrophotometer was conducted after boiling. Finally, the total phosphorus content (TP) in soil and plant samples was measured (Bao Shidan, 2000). The C, N, and P contents were expressed in units of g/kg.

Soil physical-chemical properties

The content of total potassium (K) in the soil was determined by the atomic absorption spectrophotometry method. To determine the content of ammonium nitrogen (NH_4^+-N) and nitrate nitrogen (NO_3^--N) in the soil, 10 g of the soil sample was weighed into a plastic bottle, calcium chloride ($CaCl_2$) extractant was added, and the mixture was shaken for 30 min under the condition of between 20 ℃ and 25 ℃, then filtered to determine the content of NH_4^+-N and NO_3^--N by colorimetry. The content of soil organic matter (OM) was determined by a K_2CrO_7-H_2SO_4 oxidation procedure. Soil pH was measured using a pH meter. To determine soil available phosphorus (AP), 2.50 g of each soil sample was weighed into a plastic bottle, $NaHCO_3$ extract and 1g of phosphorus-free activated carbon was added, the sample was shaken for 30 min under the condition of between 20 ℃ to 25 ℃, then the sample was filtered and the content of AP in the soil sample was measured by colorimetry; the content of available potassium (AK) was determined by the flame photometric method (Shidan, 2000).

Statistical analysis

Excel 2010 and SPSS 19.0 software were used to analyze the data after integration. One-way analyses of variance (ANOVA) was used to compare the differences in C, N, and P content and their stoichiometric ratios in the leaves of *S. alopecuroides* across the four different habitats. Significance analysis was performed using Duncan tables. Using CANOCO software, the Monte Carlo test was conducted to select the factors that were significantly related to the ecological stoichiometric characteristics of C, N, and P in the leaves of *S. alopecuroides*, and redundancy analysis (RDA) was performed to analyze the correlation between C, N, and P and soil physicochemical factors. According to the DCA analysis of the leaf C, N, and P contents, the length of gradient (LGA) of the sorting axis was less than 3. A linear relationship was observed between nutrient contents of the leaves and soil environmental factors, which was suitable for the linear sorting method; thus, RDA was used.

In the generated sorting diagram, the quadrant in which the arrow was located represented the positive and negative correlation between the factors and the sorting axis, whilst the hollow arrow represented the ecological stoichiometry characteristics of the leaves. The solid arrow represented the physical-chemical factors of the soil. The length of the line represented the relationship between the ecological stoichiometry characteristics of the leaves of *S. alopecuroides* and the soil chemical factors. The angle between the two arrows represented the correlation between the ecological stoichiometry characteristics of the leaves and the soil chemical factors. The smaller the angle, the greater the correlation. The solid line represented the factors that were significantly related to the stoichiometric characteristics of the leaves ($p < 0.05$).

Results

Content and stoichiometric ratios of C, N and P in the *S. alopecuroides* leaves

As can be seen from Table 1, the average values of C, N, and P contents in the leaves of *S. alopecuroides* in the Yili River Valley were 470.09 g/kg, 32.71 g/kg, and 1.43 g/kg, respectively. The coefficients of variation of C, N, and P were 10.96%, 30.41%, and 30.86%, respectively. The average values of C/N, C/P, and N/P were 16.88, 364.67, and 23.20, respectively, and the variation coefficients were 57.04%, 38.42%, and 24.00%, respectively. The coefficients of variation of C, N, P, and the stoichiometric ratio of leaves were generally large, among which the coefficient of variation of C/N ratio was the largest, which indicated that the C content and N content of the leaves had the highest degree of variation and the strongest variability. It can be seen from Figure 2A and 2B that there was no significant correlation between C and the content of N and P in the sampled leaves ($p > 0.05$), while the content of N and P in the leaves exhibited a highly significant positive correlation (Figure 2C; $p < 0.01$).The regression equation ($y = 0.0009x^2 - 0.0095x + 0.7532$) clearly reflected the increasing trend of P content in leaves with increasing N content.

Table 1

Figure 2

Contents and stoichiometric ratios of C, N, and P in *S. alopecuroides* leaves in different habitats

There were some differences in the C and P contents of *S. alopecuroides* leaves in different habitats (Table 2). The C content of leaves in different habitats showed an increasing trend: the C content of leaves in the desert habitat was much higher than that in the forest. The coefficient of variation of C content in the leaves was 11.58%, 13.28%, 14.93%, and 5.73%, for the forest, roadside, farmland, and desert habitats, respectively. There was no significant difference in N content among the four habitats. The variation coefficients of N content in the forest, roadside, farmland, and desert habitats were 7.52%, 63.30%, 3.37%, and 31.24%, respectively. The P content in the leaves sampled from the four habitats in order from highest to lowest was farmland > forest > roadside > desert, and the P content in the leaves of the desert was significantly lower than that in the farmland. The variation coefficients of P content in the leaves of the forest, roadside, farmland, and desert were 13.62%, 40.12%, 6.96%, and 44.23%, respectively.

There was a significant difference in the stoichiometric ratio of C/P in the leaves in different habitats, but there was no significant difference in C/N and N/P (Table 3). The leaf C/N in the forest was slightly lower than that in the desert, roadside, and farmland. The coefficient of variation of C/N in the forest, roadside, farmland, desert was 7.59%, 75.31%, 12.19%, and 22.65%, respectively. The N/P of leaves in the farmland habitat was less than that in the forest, roadside, and desert. The coefficients of variation of N/P in the forest, roadside, farmland, and desert habitats were 13.31%, 41.23%, 5.09%, and 19.31%, respectively. The leaf C/P of the four habitats from largest to smallest was desert > roadside > forest > farmland, and the leaf C/P of the farmland habitat was significantly lower than that of the desert. The coefficients of variation of C/P in the leaves the forest, roadside, farmland, and desert habitats were 8.69%, 32.98%, 14.29%, and 38.67%, respectively.

Table 2

Table 3

Correlation between ecological stoichiometry characteristics of *S. alopecuroides* leaves and soil physical-chemical factors

RDA was used to study the correlation between the ecological stoichiometry characteristics of *S. alopecuroides* leaves and soil physical-chemical factors (AK, pH, NO_3^--N, NH_4^+-N, AP, OM, soil C content, soil N content, soil P content, soil K content). It can be seen from Table 4 that the interpretation amounts of the first and second sorting axes were 54.8% and 26.9%, respectively. The first two axes jointly explained 81.7% of the change in leaf ecological stoichiometry characteristics. The cumulative interpretation of the leaf ecological stoichiometry characteristics and soil physical-chemical factors of *S. alopecuroides* leaves reached 86.8%, indicating that the first two axes could reflect the large difference between the soil physicochemical factors and the leaf stoichiometric characteristics, and were mainly determined by the first sorting axis.

According to the RDA (Figure 3), the arrow line between AK and pH was the longest, which was consistent with the importance ranking results in Table 5. Together, AK and pH had the greatest impact on the ecological stoichiometry characteristics of *S. alopecuroides* leaves. AP and pH were positively correlated with leaf C, N, P, and N/P, and negatively correlated with leaf C/P and C/N. The direction of the arrow line of AK and leaf P content was the same with a small angle, which indicated that AK was significantly positively related to leaf P content, and AK may be an important factor affecting leaf P content of *S. alopecuroides* leaves in the Yili River Valley.

It was found that different soil physicochemical factors exhibited significant differences in the ecological stoichiometry characteristics of *S. alopecuroides* leaves (Table 5). The effects of soil physicochemical factors on stoichiometric characteristics were as follows: AK > pH > NO_3^--N > soil P content > NH_4^+-N > soil N content > soil K content > soil OM > soil C content > AP. Among them, AK and pH had a significant effect on the stoichiometric characteristics of leaves ($p \leq 0.05$). AK had the most significant effect on the stoichiometric characteristics of leaves, accounting for 19.9% of the total interpretation (4.487, $p = 0.05$). NO_3^--N, soil P content, NH_4^+-N, soil N content, soil K content, OM, soil C content, and AP had no significant effect on the stoichiometric characteristics of the leaves ($p > 0.05$).

Table 4

Table 5

Figure 3

Discussion

Ecological stoichiometry characteristics of C, N, and P in the leaves of *S. alopecuroides* in different habitats

The average C content (470.09 mg/g) of *S. alopecuroides* leaves in the Yili Valley was slightly higher than that of 492 global terrestrial plants (464 mg/g) (Elser et al., 2000a), indicating that the organic C content of *S. alopecuroides* in the Yili River valley was higher and the ability of C storage was stronger. C content differed among the four habitats; among them, the C content of the sampled *S. alopecuroides* leaves grown in the desert was higher than that in the other habitats, which may be due to the fact that the C element usually exists in plants in the form of OM. Under the conditions of low soil moisture and high salt content, a high stress and low interference habitat is easily formed.

S. alopecuroides easily stores carbon, reduces its reproductive and competitive ability, maintains normal growth, and achieves balanced resource allocation (Dayong, 2000). It may also be the case that in an environment with sufficient resources, it is easy to reach environmental capacity saturation, which would aggravate interspecific competition and lead to a decrease in natural resources. Yili Valley belongs to the arid and semi-arid region of Xinjiang. The average N content in the leaves of *S. alopecuroides* (32.71 mg/g) is not only much higher than that of Chinese plant leaves (20.2 mg/g) (Han et al., 2005), but also higher than that of plant leaves at a global scale (20.6 mg/g) (Elser et al., 2000a). This is consistent with the conclusion that N content in the leaves of plants in arid desert environments was relatively high (Yulin et al., 2010), and the N content in the leaves of *S. alopecuroides* L. in the four habitats was basically stable as there were no significant differences. The reason for a high N content in the leaves of *S. alopecuroides* may be that it is a leguminous plant with strong nodulation and, thus, nitrogen fixation ability. Therefore, the plant leaves exhibit high internal stability of N, which provided a sufficient N source for the leaves. The average content of P in the leaves of *S. alopecuroides* (1.43 mg/g) was lower than that of plants in China (1.5 mg/g) (Han et al., 2005) and of that in global plants (1.99 mg/g) (Elser et al., 2000a). This is because the Yili River Valley has a temperate continental climate, and its abundant precipitation enhances the leaching of available P in the soil, which is not conducive to the accumulation of P, resulting in less P absorption by plant leaves (Liping et al., 2018). Previous studies have shown that human disturbance, such as the application of fertilizer, affects plant chemometrics characteristics. Cultivation, fertilization, irrigation, and other activities will improve the local soil nutrient content and soil quality and improve the effective P content (Luo Yan, et al., 2016), which can provide a good environment for the growth of *S. alopecuroides* leaves. This explains the finding of a higher P content in the sampled *S. alopecuroides* leaves in the farmland habitat than that of the other habitats.

C/N and C/P represent the ability to assimilate C when plants absorb nutrient elements. To some extent, it can reflect the utilization efficiency of nutrient elements in plants, and its ratio is closely related to the growth rate of organisms (Davis et al., 2006). In this study, the C/N (16.88) of *S. alopecuroides* leaves was lower than that of global plants (22.5) (Elser et al., 2000b), and C/P (364.67) was much higher in the *S. alopecuroides* leaves than that of global plants (232) (Elser et al., 2000b), indicating that the nutrient utilization efficiency of *S. alopecuroides* L. was low. It can be seen from Table 3 that the C/N and C/P ratios of *S. alopecuroides* leaves grown in the desert and roadside habitats were higher than those in the farmland and forest habitats. This finding may be due to the fact that, in an environment with sufficient nutrition, the growth rate of plants is fast, the synthesis of organic matter is high, and its C/N and C/P ratio are low. In the environment of nutrient deficiency, plant growth is relatively slow, the utilization efficiency of nutrient elements is high, and the C/N and C/P ratios are high (Ng et al., 2014).The ratio of N, P, and N/P in plant leaves reflect the dynamic balance between soil nutrient supply and plant nutrient demand; N/P ratio can be used to determine the limiting growth factors of plant nutrients (Duan Xiaonan et al., 2004). Studies have shown that when leaf $N/P < 14$, plant growth is mainly restricted by N; when leaf $N/P > 16$, plant growth is mainly restricted by P; and when leaf NP is more than 14, but less than 16, plant growth is mainly restricted by both N and P (Aerts et al., 2000). *S. alopecuroides* is a nitrogen-fixing plant species, so it is generally N-limited, due to its higher leaf P content (mean = 1.53 mg/g), indicating that it may not be P-limited. Therefore, the rule for judging restrictive elements, that is, an N/P of 14 or 16, does not apply to nitrogen-fixing plants to a large extent. Further studies are needed to determine which nutrients limit plant growth.

Factors affecting the ecological stoichiometry characteristics of C, N, and P in *S. alopecuroides* leaves

Plants need to absorb nutrients from the soil to supplement the nutrients needed for the growth and development of leaves, so soil physical-chemical factors have a greater impact on the C, N, and P ecological stoichiometry characteristics of *S. alopecuroides* leaves. According to the observed RDA ranking, AK and pH were the main factors affecting the C, N, and P stoichiometric characteristics. Soil pH can change soil nutrient content and distribution area, thus affecting plant growth and developmental processes (Zhan et al., 2013). In this study, pH was positively correlated with C, N, and P contents and N/P in *S. alopecuroides* leaves, and was negatively correlated with C/P and C/N, indicating that pH was closely related to leaf growth, which was similar to the finding that pH affects the growth and development of plants by affecting the physical, chemical, and biological characteristics of soil (Kaijie et al., 2015). In this study, it was observed that with the increase in the contents of AK, C, N, P, and N/P in the leaves also increased, but C/P and C/N decreased, in which the content of P in the leaves was positively correlated with the content of AK, indicating that AK was the main factor affecting the content of P in the leaves. This may be due to the fact that the absorption efficiency of *S. alopecuroides* leaves to soil nutrients is different in arid and semi-arid areas compared to that of other environments; the absorption efficiency of AK is higher in arid and semi-arid areas, which provides a good environment for the growth of *S. alopecuroides* leaves.

By analyzing the influence of soil physicochemical factors on the ecological stoichiometry characteristics of *S. alopecuroides* leaves, the internal stability of grassland ecosystems in the arid and semi-arid areas of Xinjiang was explored. According to the RDA, the OM, nitrate nitrogen, NH_4^+-N, and AK, the contents of soil C, N, P, and K did not significantly affect the stoichiometric characteristics of C, N, and P in the sampled *S. alopecuroides* leaves. However, the independent analysis of soil physicochemical factors on the stoichiometry characteristics showed some deficiencies. First, the effects of soil physicochemical factors on the C, N, and P ecological stoichiometry characteristics of *S. alopecuroides* leaves were not independent. Secondly, soil physicochemical factors had mutual influence and restriction. Therefore, based on the independent analysis, it is necessary to further analyze the double or even multiple effects of soil physicochemical factors on the ecological stoichiometry characteristics of C, N, and P in *S. alopecuroides* leaves, so as to make the results more accurate (Xiaofei et al., 2019).

As the dominant species of degraded grassland in the Yili River Valley, the growth, development, and distribution of *S. alopecuroides* seriously affects the grassland ecosystem in the valley. Studying the relationship between the C, N, and P ecological stoichiometry characteristics of *S. alopecuroides* leaves and environmental factors are of great significance to reveal the ecological mechanisms of the successful diffusion of *S. alopecuroides* plants in the Yili River Valley.

Conclusions

(a) The contents of C, N, and P in the leaves of *S. alopecuroides* in Yili Valley were 391.30–533.10 g/kg, 8.90–43.14 g/kg, and 0.71–2.04 g/kg, respectively. The C/N, C/P, and N/P ratios were 10.34–44.94, 209.05–698.73, and 10.78–31.43, respectively. Compared with the global and national plant leaves, the C and N contents of the *S. alopecuroides* leaves in the arid desert environment were higher.

(b) There were significant differences in C and P contents, and the C/P ratio between *S. alopecuroides* leaves in different habitats, but there was no significant difference in the content of C and N, and C/N and N/P ratios in leaves from different habitats. The order of leaf P content in the four habitats was farmland > forest > roadside > desert, and the order of leaf C/P was desert > roadside > forest > farmland, which indicated that reclamation of farmland could improve the content of AP and provide a good environment for the growth of *S. alopecuroides* leaves.

(c) AK and pH were the main factors affecting the ecological stoichiometry characteristics of *S. alopecuroides* leaves in Yili Valley ($p \leq 0.05$); they were positively correlated with C, N, and P contents and the N/P ratio, and negatively correlated with C/P and C/N ratios. AK is the dominant factor that affects the P content of *S. alopecuroides* leaves. Appropriate reduction of K fertilizer is conducive to restraining the spread of *S. alopecuroides*.

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Figure legends

Figure.1

Diagram of sampling point in Yili Valley

Figure.2

Correlation of contents of C, N and P in leaves of *S. alopecuroides*

Figure.3

Redundancy analysis of the influence of soil physical-chemical properties on the ecological stoichiometry characteristics of leaves

LC: (leaf C) carbon content of *S. alopecuroides* leaves; LN: (leaf N) nitrogen content of *S. alopecuroides* leaves; LP: (leaf P) phosphorus content of *S. alopecuroides* leaves; L(C/N): carbon nitrogen ratio of leaves; L(N/P): nitrogen phosphorus ratio of leaves; L(C/P): carbon phosphorus ratio of leaves; C: soil carbon content; N: soil nitrogen content; P: soil phosphorus content; K: soil potassium content.

Figure 1

Diagram of sampling point in Yili Valley

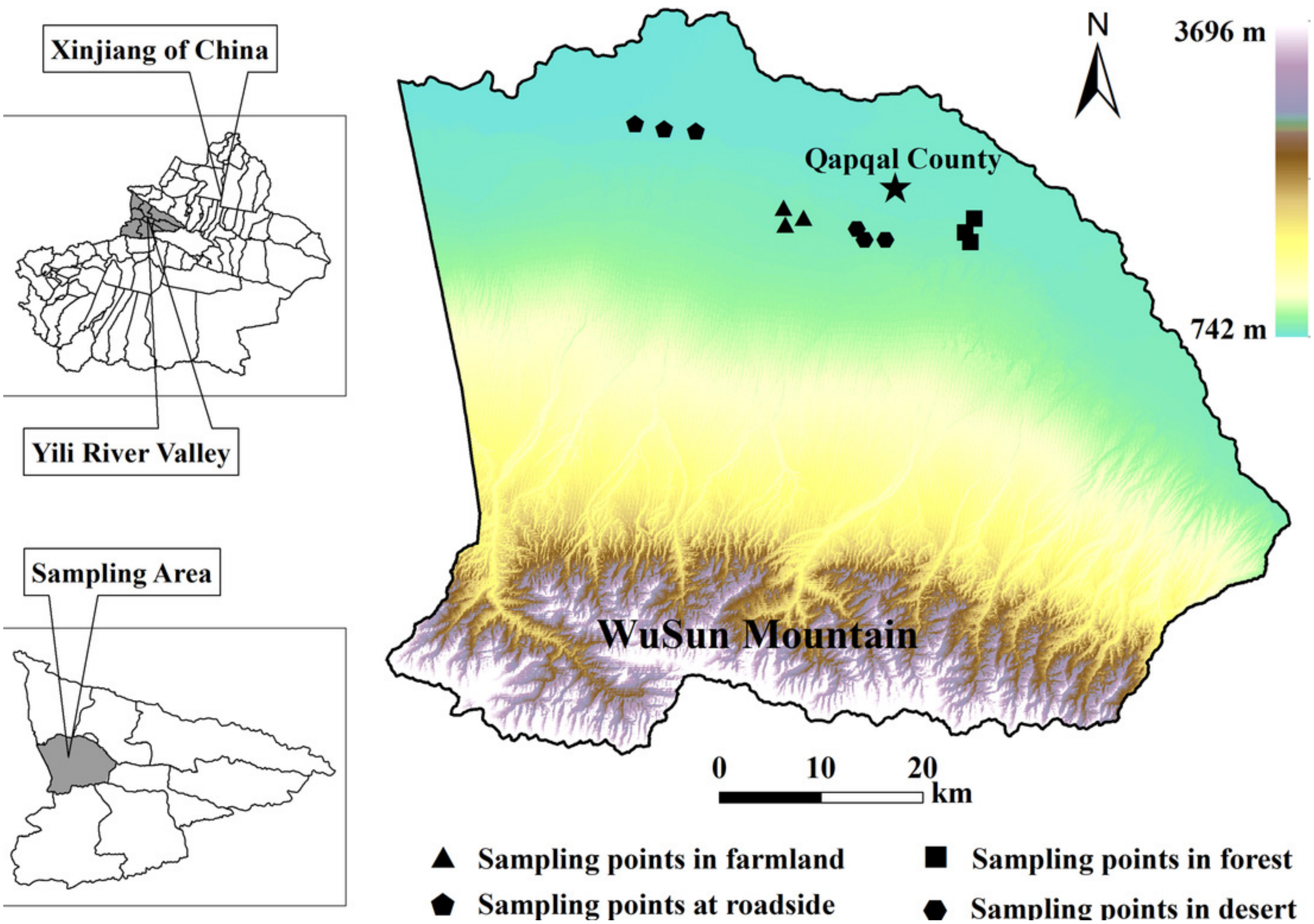

Figure 2

Correlation of contents of C, N and P in leaves of *S. alopecuroides*

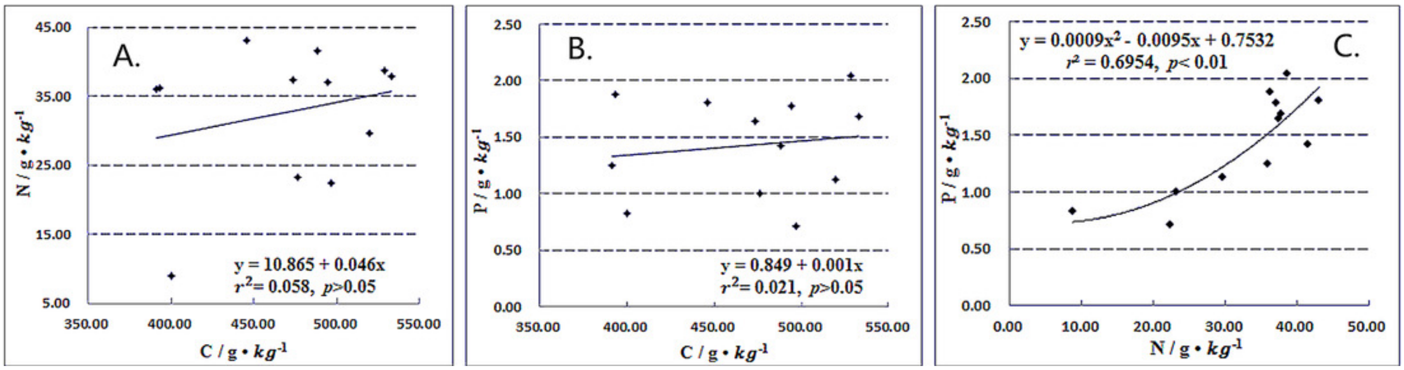

Figure 3

Redundancy analysis of the influence of soil physical-chemical properties on the ecological stoichiometry characteristics of leaves

LC: (leaf C) carbon content of *S. alopecuroides* leaves; LN: (leaf N) nitrogen content of *S. alopecuroides* leaves; LP: (leaf P) phosphorus content of *S. alopecuroides* leaves; L(C/N): carbon nitrogen ratio of leaves; L(N/P): nitrogen phosphorus ratio of leaves; L(C/P): carbon phosphorus ratio of leaves; C: soil carbon content; N: soil nitrogen content; P: soil phosphorus content; K: soil potassium content.

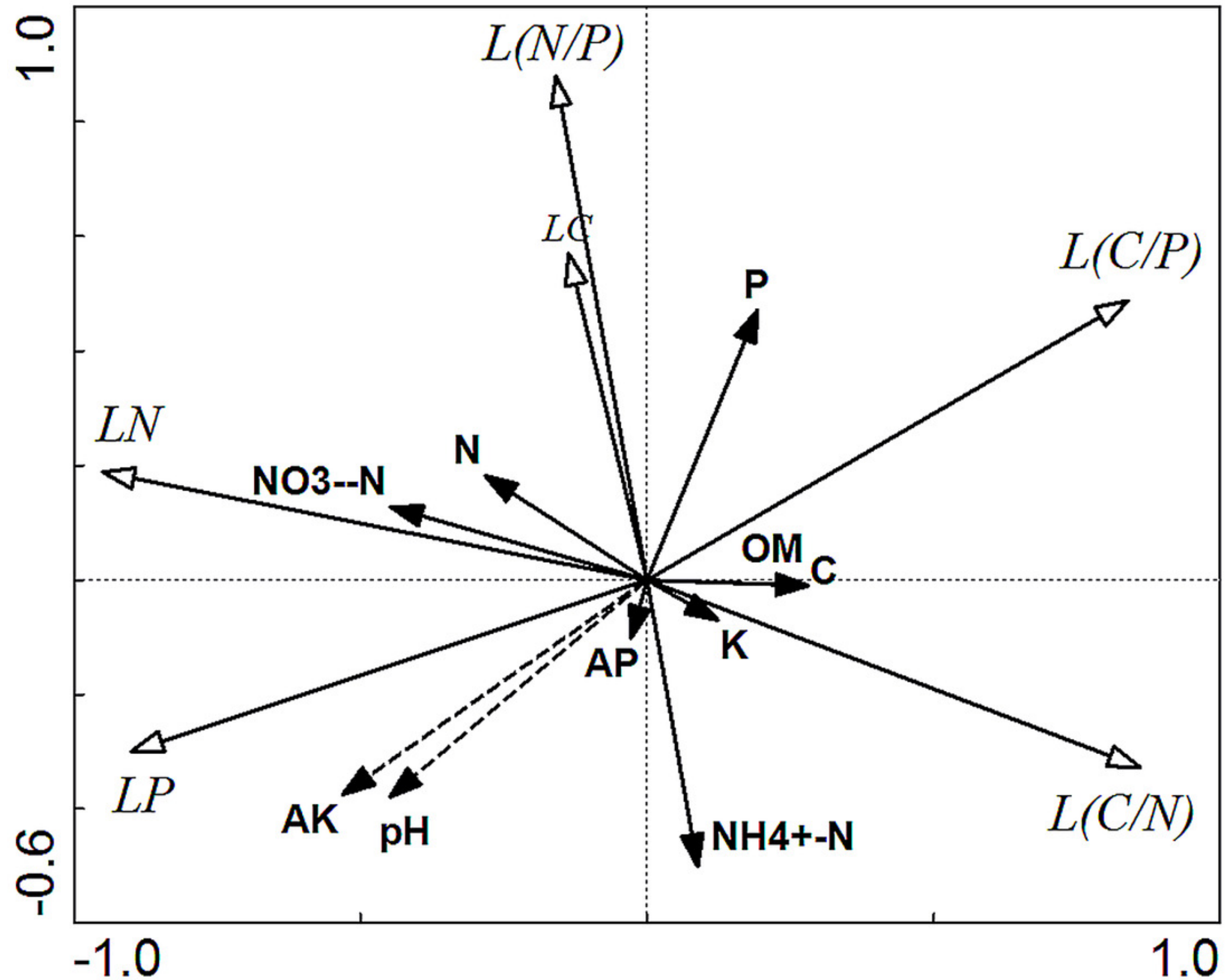
1.0
-0.6
-1.0
1.0
L(N/P)
LC
L(C/P)
P
LN
NO3--N
N
OM
C
K
AP
LP
AK
pH
NH4+-N
L(C/N)

Table 1(on next page)

Ecological stoichiometry characteristics of C, N and P in the *Sophora alopecuroides* leaves.

Table 1

Ecological stoichiometry characteristics of C, N and P in the *Sophora alopecuroides* leaves.

	C(g/kg)	N(g/kg)	P(g/kg)	C/N	C/P	N/P
Mean	470.09	32.71	1.43	16.88	364.67	23.20
Median	482.26	36.70	1.53	13.48	314.75	23.06
Standard Error	14.87	2.87	0.13	2.78	40.44	1.61
Range	391.30~533.10	8.90~43.14	0.71~2.04	10.34~44.94	209.05~698.73	10.78~31.43
Coefficient of Variation (%)	10.96	30.41	30.86	57.04	38.42	24.00

Table 2(on next page)

Contents of C, N and P in leaves of *Sophora alopecuroides* in different habitats and their variation coefficients.

The value is (mean ± SD). Different letters in the upper right corner of the peer data indicate that the data in different habitats are significantly different ($p < 0.05$).

Table 2

Contents of C, N and P in leaves of *Sophora alopecuroides* in different habitats and their variation coefficients.

	Forest	**Roadside**	**Farmland**	**Desert**
C (g/kg)	$(450.98 \pm 52.21)^{b}$	$(455.22 \pm 60.44)^{ab}$	$(472.05 \pm 70.47)^{ab}$	$(502.09 \pm 28.76)^{a}$
Coefficient of Variation (%)	11.58	13.28	14.93	5.73
N (g/kg)	$(38.35 \pm 2.88)^{a}$	$(27.25 \pm 17.25)^{a}$	$(37.39 \pm 1.26)^{a}$	$(27.83 \pm 8.69)^{a}$
Coefficient of Variation (%)	7.52	63.30	3.37	31.24
P (g/kg)	$(1.44 \pm 0.20)^{ab}$	$(1.25 \pm 0.50)^{ab}$	$(1.90 \pm 0.13)^{a}$	$(1.13 \pm 0.50)^{b}$
Coefficient of Variation (%)	13.62	40.12	6.96	44.23

The value is (mean ± SD). Different letters in the upper right corner of the peer data indicate that the data in different habitats are significantly different ($p < 0.05$).

Table 3(on next page)

Ratios of carbon-nitrogen, carbon-phosphorus, nitrogen-phosphorus and coefficient of variation in leaves of *Sophora alopecuroides* in different habitats.

The value is (mean ± SD). Different letters in the upper right corner of the peer data indicate that the data in different habitats are significantly different (p <0.05).

Table 3

Ratios of carbon-nitrogen, carbon-phosphorus, nitrogen-phosphorus and coefficient of variation in leaves of *Sophora alopecuroides* in different habitats.

	Forest	**Roadside**	**Farmland**	**Desert**
C/N	$(11.75 \pm 0.89)^{a}$	$(24.26 \pm 18.27)^{a}$	$(12.60 \pm 1.54)^{a}$	$(18.93 \pm 4.29)^{a}$
Coefficient of Variation (%)	7.59	75.31	12.19	22.65
C/P	$(315.27 \pm 27.39)^{ab}$	$(397.90 \pm 131.21)^{ab}$	$(248.56 \pm 35.51)^{b}$	$(496.97 \pm 192.18)^{a}$
Coefficient of Variation (%)	8.69	32.98	14.29	38.67
N/P	$(26.99 \pm 3.59)^{a}$	$(20.37 \pm 8.40)^{a}$	$(19.71 \pm 1.00)^{a}$	$(25.71 \pm 4.97)^{a}$
Coefficient of Variation (%)	13.31	41.23	5.09	19.31

The value is (mean ± SD). Different letters in the upper right corner of the peer data indicate that the data in different habitats are significantly different ($p < 0.05$).

Table 4(on next page)

Correlation between ecological stoichiometry characteristics of leaves and sorting axis.

Table 4

Correlation between ecological stoichiometry characteristics of leaves and sorting axis.

Sort axis	The axis I	The axis II	The axis III	The axis IV
Characteristic Value	0.548	0.269	0.113	0.008
Correlation Between Leaf Stoichiometric Characteristics And Factors of Soil Physical And Chemical	0.986	0.980	0.893	0.972
Cumulative Interpretation of Stoichiometric Characteristics (%)	54.8	81.7	93.0	93.8
Stoichiometric Characteristics And Cumulative Interpretation of Factors For Soil Physical And Chemical (%)	58.3	86.8	98.8	99.7
Typical Eigenvalues	0.941			
Total Eigenvalue	1			

Table 5 (on next page)

Significance rank and significance test of soil physicochemical factors in explanation.

Table 5

Significance rank and significance test of soil physicochemical factors in explanation.

Environmental Factor	Significance Rank	Explanatory Capacity (%)	Importance (*F* Value)	Saliency (*p* Value)
AK	1	19.9	4.487	0.042
pH	2	15.4	2.916	0.050
NO_3^--N	3	14.1	1.646	0.188
Soil P Content	4	8.6	0.939	0.418
NH4+-N	5	8.5	0.924	0.444
Soil N Content	6	5.8	0.620	0.628
Soil K Content	7	4.9	0.512	0.722
OM	8	4.6	0.480	0.72
Soil C Content	9	4.5	0.476	0.698
AP	10	0.7	0.073	0.982