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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Abstract

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 ($p \leq 0.05$), and they were positively correlated with C, N, P, and N/P, and negatively correlated with C/P and C/N; AK was the

40   dominant factor that affected the P content of *S. alopecuroides* leaves, and appropriate reduction
41   of K fertilizer would be conducive to restraining the spread of *S. alopecuroides*; soil C, N, P, and
42   K content, soil organic matter (OM), nitrate nitrogen (NO_3^-N), ammonium nitrogen (NH_4^+-N),
43   and AK had no significant effect on the ecological stoichiometry characteristics of leaves ($p >$
44   0.05).
45   **Keywords:** *S. alopecuroides* L.; ecological stoichiometry characteristics; soil physical-chemical
46   factors; redundancy analysis.

47

48   ## Introduction
49   Ecological stoichiometry is a comprehensive science that studies the equilibrium
50   relationship, quantitative relationship, and biogeochemical cycle of various chemical elements in
51   ecological processes (Sterner et al., 2002), providing an important technical means for analyzing
52   the nutrient utilization of vegetation (Elser et al., 1996). The essence of the plant growth process
53   is the regulation of the accumulation and relative proportions of C, N, and P in the plant
54   (Koerselman et al., 1996). C, N, and P are essential nutrients for plant growth and development.
55   C is the most important element in plant dry matter; N promotes the synthesis of amino acids and
56   proteins, but also enhances the photosynthetic capacity of plants; and P is not only an important
57   component of nucleic acids and enzymes but also a basic element of all living organisms; thus, C,
58   N, and P significantly affect plant growth and the regulation of physiological mechanisms (Wang
59   et al., 2011).
60   Previous studies on the stoichiometric characteristics of C, N, and P have primarily focused
61   on the stability of plant communities (Tessier et al., 2003), litter decomposition processes
62   (Mooshammer et al., 2012), and determination of plant growth restriction elements (Tjoelker et
63   al., 2005). The study of plant leaf ecological stoichiometry helps to explore plant growth
64   characteristics and nutrient limitation. Leaves are the main sites of plant photosynthesis and their
65   photosynthetic organs and rate are closely related to the N content of the leaves. The C/N and
66   C/P ratios in leaves reflect the rate of plant carbon assimilation, and, to a certain extent, can
67   reflect plant nutrient use efficiency (Wang et al., 2008). Leaf N/P is the sensitivity index, and an
68   important evaluation tool, of plant growth nutrient restriction (Xiaonan et al., 2004). In addition,
69   the growth process of plants has been found to be not only affected by C, N, and P elements, but
70   also by the external environment (Cleland et al., 2011). Soil moisture, salinity, and nutrients have
71   a significant impact on the C, N, and P content of plant leaves and their stoichiometric ratio
72   (Chen et al., 2016; Yan et al., 2011). Soil properties affect the ecological stoichiometric
73   characteristics of plant leaves by affecting the effective absorption of soil physicochemical
74   factors and nutrients. Further, the soil nutrient content and its balance are closely related to the
75   ecological stoichiometric characteristics of vegetation. Soil nutrient levels not only affect plant
76   growth and community composition but also indicate the health of the ecosystem (Li et al., 2004).
77   Therefore, it is of great significance to explore the nutrient characteristics of plant leaves and the
78   physical-chemical properties of the soil in the habitat, so as to understand the nutrient utilization

79   status in the process of plant growth and reveal the nutrient supply capacity of soil and the
80   adaptation mechanism of plants to the environment.
81   *Sophora alopecuroides* L. (*S. alopecuroides* L.) is a perennial herb of the legume family
82   and is predominantly distributed in arid desert and grassland marginal areas, such as Xinjiang,
83   Ningxia, and Inner Mongolia. It has the characteristics of salinity tolerance and drought
84   resistance (Qi et al., 2008). Therefore, it is widely used in wind prevention, sand fixation, and
85   saline alkali land improvement (Chen et al., 2000). Due to the fast-spreading characteristics of *S.*
86   *alopecuroides*, populations often grow continuously and are distributed widely, which can form a
87   single superior community in a short time. In recent years, the grassland in the Yili River Valley,
88   northwestern Xinjiang, has been degenerating, resulting in the spread of a large number of
89   poisonous weeds. Among them, *S. alopecuroides* has rapidly become the dominant species due
90   to its rapid diffusion characteristics, occupying the living space of other species, resulting in the
91   degradation of grassland quality. The dominant presence of *S. alopecuroides* poses a serious
92   threat to the development of local animal husbandry and biodiversity (Dong et al., 2018). Current
93   research on *S. alopecuroides* mainly focuses on seed morphological characteristics, the
94   medicinal value of the plant, seed germination conditions, and seed dormancy (Ying et al., 2017;
95   Weiliang et al., 2016; Jin et al., 2007). However, there are few reports on the ecological
96   stoichiometric characteristics of *S. alopecuroides* leaves and the correlation between soil
97   physicochemical factors and plant ecological stoichiometric characteristics. Therefore, from the
98   perspective of ecological stoichiometric characteristics, the present study was conducted using *S.*
99   *alopecuroides* leaves from the Yili River Valley, and the variation rule of the ecological
100   stoichiometry characteristics of C, N, and P in the leaves across different habitats was analyzed
101   systematically. The relationship between the ecological stoichiometric characteristics of *S.*
102   *alopecuroides* and environmental factors was studied to reveal the survival strategy and
103   ecological mechanism of the rapid spread of *S. alopecuroides* in arid and semi-arid areas, so as to
104   serve as the theoretical basis for the scientific management and ecological restoration of
105   degraded grassland.
106
107   **Materials and Methods**
108   **Site description**
109   The study area is located in the Yili River Valley of the Xinjiang Uygur Autonomous
110   Region (80°09E—84°56E, 42°14N—44°50′N). The north, east, and south sides of the Yili River
111   Valley all constitute high mountains. The terrain changes from high to low from east to west, in
112   the shape of a trumpet, thus forming the natural landform outline of "three mountains and two
113   valleys," enjoying the reputation of a "wet island in the western region." The elevation of the Yili
114   River Valley is 530 m to 1000 m high and spans 360 km from east to west and 275 km from
115   north to south, covering an area of 56,400 km². The Yili River Valley is the wettest area in
116   Xinjiang, with a warm and humid temperate continental climate. The average annual temperature
117   is 10.4 ° C, the average sunshine hours range between 2,700 and 3,000 h, and the average
118   annual precipitation is 417.6 mm which mainly occurs during the spring and summer and

119 accounts for approximately 60%–70% of the total annual precipitation. The Yili River Valley has
120 a superior geographical location, abundant natural resources, abundant species, diverse mineral
121 resources, and unique wetland landscapes. The valley mainly constitutes grassland, meadow,
122 forest, and other vegetation types.
123

124 **Study site and sample collection**
125   Through field investigation and observation, it was found that *S. alopecuroides*, as a plant
126 with strong invasion ability, often invades four areas: forest, roadside, farmland, and desert, and,
127 thus, is widely distributed in the four regions. Soil samples were collected in September 2018,
128 and plant samples were collected in July 2019 (Figure 1) in Qapqal County, Yili River Valley,
129 under the four habitats of forest, roadside, farmland, and desert.
130   Three 1 m × 1 m quadrats were randomly set up in each of the four invasive habitats of S.
131 *alopecuroides*. In each plot, 10 plants of *S. alopecuroides* with uniform growth were randomly
132 selected, and their leaves were cut from the plants. The leaves of a further 10 *S. alopecuroides*
133 were taken as a repeat and brought back to the laboratory for low-temperature preservation. All
134 the collected leaves of *S. alopecuroides* were dried at 70 ° C for 24 h. The leaves were then
135 crushed into foam using a pulverizer, and then sealed for storage. The contents of total C, total N,
136 and total P in the leaves of the *S. alopecuroides* leaves were determined.
137   Soil samples of 0–10 cm, 10–20 cm, and 20–30 cm were collected in each field plot, and
138 each plot was repeated once. In total, 36 soil samples were collected from four plots. The
139 collected soil samples were put into sealed plastic bags, and fully integrated in the laboratory
140 after air drying, grinding, screening, and other operations, and the physical and chemical
141 properties of the soil were analyzed.
142
143   **Figure 1**
144
145

146 **Analysis of soil and plant properties**
147 **Leaf properties of plants**
148   The total C content of the *S. alopecuroides* leaves was measured using the K_2CrO_7-H_2SO_4
149 oxidation procedure. The total N content (TN) in the soil and plant samples was determined by
150 boiling the samples with perchloric acid ($HClO_4$) and sulfuric acid (H_2SO_4), and conducting
151 colorimetry analysis with a FOSS 1035 Automatic Nitrogen Analyzer. To establish total P
152 content, perchloric acid and sulfuric acid were first added to the leaves and soil samples, and the
153 colorimetric method using an Agilent CARY60 Ultraviolet-Visible Spectrophotometer was
154 conducted after boiling. Finally, the total phosphorus content (TP) in soil and plant samples was
155 measured (Bao Shidan, 2000). The C, N, and P contents were expressed in units of g/kg.
156 **Soil physical-chemical properties**
157   The content of total potassium (K) in the soil was determined by the atomic absorption
158 spectrophotometry method. To determine the content of ammonium nitrogen (NH_4^+-N) and

159 nitrate nitrogen (NO_3^--N) in the soil, 10 g of the soil sample was weighed into a plastic bottle,
160 calcium chloride ($CaCl_2$) extractant was added, and the mixture was shaken for 30 min under the
161 condition of between 20 ℃ and 25 ℃, then filtered to determine the content of NH_4^+-N and
162 NO_3^--N by colorimetry. The content of soil organic matter (OM) was determined by a K_2CrO_7-
163 H_2SO_4 oxidation procedure. Soil pH was measured using a pH meter. To determine soil available
164 phosphorus (AP), 2.50 g of each soil sample was weighed into a plastic bottle, $NaHCO_3$ extract
165 and 1g of phosphorus-free activated carbon was added, the sample was shaken for 30 min under
166 the condition of between 20 ℃ to 25 ℃, then the sample was filtered and the content of AP in
167 the soil sample was measured by colorimetry; the content of available potassium (AK) was
168 determined by the flame photometric method (Shidan, 2000).
169
170 **Statistical analysis**
171   Excel 2010 and SPSS 19.0 software were used to analyze the data after integration. One-
172 way analyses of variance (ANOVA) was used to compare the differences in C, N, and P content
173 and their stoichiometric ratios in the leaves of *S. alopecuroides* across the four different habitats.
174 Significance analysis was performed using Duncan tables. Using CANOCO software, the Monte
175 Carlo test was conducted to select the factors that were significantly related to the ecological
176 stoichiometric characteristics of C, N, and P in the leaves of *S. alopecuroides*, and redundancy
177 analysis (RDA) was performed to analyze the correlation between C, N, and P and soil
178 physicochemical factors. According to the DCA analysis of the leaf C, N, and P contents, the
179 length of gradient (LGA) of the sorting axis was less than 3. A linear relationship was observed
180 between nutrient contents of the leaves and soil environmental factors, which was suitable for the
181 linear sorting method; thus, RDA was used.
182   In the generated sorting diagram, the quadrant in which the arrow was located represented
183 the positive and negative correlation between the factors and the sorting axis, whilst the hollow
184 arrow represented the ecological stoichiometry characteristics of the leaves. The solid arrow
185 represented the physical-chemical factors of the soil. The length of the line represented the
186 relationship between the ecological stoichiometry characteristics of the leaves of *S.
187 alopecuroides* and the soil chemical factors. The angle between the two arrows represented the
188 correlation between the ecological stoichiometry characteristics of the leaves and the soil
189 chemical factors. The smaller the angle, the greater the correlation. The solid line represented the
190 factors that were significantly related to the stoichiometric characteristics of the leaves ($p <$
191 0.05).
192
193
194 **Results**
195 **Content and stoichiometric ratios of C, N and P in the *S. alopecuroides* leaves**
196   As can be seen from Table 1, the average values of C, N, and P contents in the leaves of *S.
197 alopecuroides* in the Yili River Valley were 470.09 g/kg, 32.71 g/kg, and 1.43 g/kg, respectively.
198 The coefficients of variation of C, N, and P were 10.96%, 30.41%, and 30.86%, respectively. The

199 average values of C/N, C/P, and N/P were 16.88, 364.67, and 23.20, respectively, and the
200 variation coefficients were 57.04%, 38.42%, and 24.00%, respectively. The coefficients of
201 variation of C, N, P, and the stoichiometric ratio of leaves were generally large, among which the
202 coefficient of variation of C/N ratio was the largest, which indicated that the C content and N
203 content of the leaves had the highest degree of variation and the strongest variability. It can be
204 seen from Figure 2A and 2B that there was no significant correlation between C and the content
205 of N and P in the sampled leaves ($p > 0.05$), while the content of N and P in the leaves exhibited
206 a highly significant positive correlation (Figure 2C; $p < 0.01$).The regression equation (y =
207 $0.0009x^2 - 0.0095x + 0.7532$) clearly reflected the increasing trend of P content in leaves with
208 increasing N content.
209
210   **Table 1**
211
212   **Figure 2**
213
214
215 **Contents and stoichiometric ratios of C, N, and P in *S. alopecuroides* leaves in different**
216 **habitats**
217   There were some differences in the C and P contents of *S. alopecuroides* leaves in different
218 habitats (Table 2). The C content of leaves in different habitats showed an increasing trend: the C
219 content of leaves in the desert habitat was much higher than that in the forest. The coefficient of
220 variation of C content in the leaves was 11.58%, 13.28%, 14.93%, and 5.73%, for the forest,
221 roadside, farmland, and desert habitats, respectively. There was no significant difference in N
222 content among the four habitats. The variation coefficients of N content in the forest, roadside,
223 farmland, and desert habitats were 7.52%, 63.30%, 3.37%, and 31.24%, respectively. The P
224 content in the leaves sampled from the four habitats in order from highest to lowest was farmland
225 > forest > roadside > desert, and the P content in the leaves of the desert was significantly lower
226 than that in the farmland. The variation coefficients of P content in the leaves of the forest,
227 roadside, farmland, and desert were 13.62%, 40.12%, 6.96%, and 44.23%, respectively.
228   There was a significant difference in the stoichiometric ratio of C/P in the leaves in different
229 habitats, but there was no significant difference in C/N and N/P (Table 3). The leaf C/N in the
230 forest was slightly lower than that in the desert, roadside, and farmland. The coefficient of
231 variation of C/N in the forest, roadside, farmland, desert was 7.59%, 75.31%, 12.19%, and
232 22.65%, respectively. The N/P of leaves in the farmland habitat was less than that in the forest,
233 roadside, and desert. The coefficients of variation of N/P in the forest, roadside, farmland, and
234 desert habitats were 13.31%, 41.23%, 5.09%, and 19.31%, respectively. The leaf C/P of the four
235 habitats from largest to smallest was desert > roadside > forest > farmland, and the leaf C/P of
236 the farmland habitat was significantly lower than that of the desert. The coefficients of variation
237 of C/P in the leaves the forest, roadside, farmland, and desert habitats were 8.69%, 32.98%,
238 14.29%, and 38.67%, respectively.

239
240 **Table 2**
241
242 **Table 3**
243
244
245 **Correlation between ecological stoichiometry characteristics of *S. alopecuroides* leaves and**
246 **soil physical-chemical factors**
247   RDA was used to study the correlation between the ecological stoichiometry characteristics
248 of *S. alopecuroides* leaves and soil physical-chemical factors (AK, pH, NO_3^--N, NH_4^+-N, AP,
249 OM, soil C content, soil N content, soil P content, soil K content). It can be seen from Table 4
250 that the interpretation amounts of the first and second sorting axes were 54.8% and 26.9%,
251 respectively. The first two axes jointly explained 81.7% of the change in leaf ecological
252 stoichiometry characteristics. The cumulative interpretation of the leaf ecological stoichiometry
253 characteristics and soil physical-chemical factors of *S. alopecuroides* leaves reached 86.8%,
254 indicating that the first two axes could reflect the large difference between the soil
255 physicochemical factors and the leaf stoichiometric characteristics, and were mainly determined
256 by the first sorting axis.
257   According to the RDA (Figure 3), the arrow line between AK and pH was the longest,
258 which was consistent with the importance ranking results in Table 5. Together, AK and pH had
259 the greatest impact on the ecological stoichiometry characteristics of *S. alopecuroides* leaves. AP
260 and pH were positively correlated with leaf C, N, P, and N/P, and negatively correlated with leaf
261 C/P and C/N. The direction of the arrow line of AK and leaf P content was the same with a small
262 angle, which indicated that AK was significantly positively related to leaf P content, and AK
263 may be an important factor affecting leaf P content of *S. alopecuroides* leaves in the Yili River
264 Valley.
265   It was found that different soil physicochemical factors exhibited significant differences in
266 the ecological stoichiometry characteristics of *S. alopecuroides* leaves (Table 5). The effects of
267 soil physicochemical factors on stoichiometric characteristics were as follows: AK > pH > NO_3^--
268 N > soil P content > NH_4^+-N > soil N content > soil K content > soil OM > soil C content > AP.
269 Among them, AK and pH had a significant effect on the stoichiometric characteristics of leaves
270 ($p \leq 0.05$). AK had the most significant effect on the stoichiometric characteristics of leaves,
271 accounting for 19.9% of the total interpretation (4.487, $p = 0.05$). NO_3^--N, soil P content, NH_4^+-
272 N, soil N content, soil K content, OM, soil C content, and AP had no significant effect on the
273 stoichiometric characteristics of the leaves ($p > 0.05$).
274
275 **Table 4**
276
277 **Table 5**
278

279 **Figure 3**

280

281 ## Discussion

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

283 **different habitats**

284   The average C content (470.09 mg/g) of *S. alopecuroides* leaves in the Yili Valley was

285 slightly higher than that of 492 global terrestrial plants (464 mg/g) (Elser et al., 2000a),

286 indicating that the organic C content of *S. alopecuroides* in the Yili River valley was higher and

287 the ability of C storage was stronger. C content differed among the four habitats; among them,

288 the C content of the sampled *S. alopecuroides* leaves grown in the desert was higher than that in

289 the other habitats, which may be due to the fact that the C element usually exists in plants in the

290 form of OM. Under the conditions of low soil moisture and high salt content, a high stress and

291 low interference habitat is easily formed.

292 *S. alopecuroides* easily stores carbon, reduces its reproductive and competitive ability, maintains

293 normal growth, and achieves balanced resource allocation (Dayong, 2000). It may also be the

294 case that in an environment with sufficient resources, it is easy to reach environmental capacity

295 saturation, which would aggravate interspecific competition and lead to a decrease in natural

296 resources. Yili Valley belongs to the arid and semi-arid region of Xinjiang. The average N

297 content in the leaves of *S. alopecuroides* (32.71 mg/g) is not only much higher than that of

298 Chinese plant leaves (20.2 mg/g) (Han et al., 2005), but also higher than that of plant leaves at a

299 global scale (20.6 mg/g) (Elser et al., 2000a). This is consistent with the conclusion that N

300 content in the leaves of plants in arid desert environments was relatively high (Yulin et al., 2010),

301 and the N content in the leaves of *S. alopecuroides* L. in the four habitats was basically stable as

302 there were no significant differences. The reason for a high N content in the leaves of *S.*

303 *alopecuroides* may be that it is a leguminous plant with strong nodulation and, thus, nitrogen

304 fixation ability. Therefore, the plant leaves exhibit high internal stability of N, which provided a

305 sufficient N source for the leaves. The average content of P in the leaves of *S. alopecuroides*

306 (1.43 mg/g) was lower than that of plants in China (1.5 mg/g) (Han et al., 2005) and of that in

307 global plants (1.99 mg/g) (Elser et al., 2000a). This is because the Yili River Valley has a

308 temperate continental climate, and its abundant precipitation enhances the leaching of available P

309 in the soil, which is not conducive to the accumulation of P, resulting in less P absorption by

310 plant leaves (Liping et al., 2018). Previous studies have shown that human disturbance, such as

311 the application of fertilizer, affects plant chemometrics characteristics. Cultivation, fertilization,

312 irrigation, and other activities will improve the local soil nutrient content and soil quality and

313 improve the effective P content (Luo Yan, et al., 2016), which can provide a good environment

314 for the growth of *S. alopecuroides* leaves. This explains the finding of a higher P content in the

315 sampled *S. alopecuroides* leaves in the farmland habitat than that of the other habitats.

316   C/N and C/P represent the ability to assimilate C when plants absorb nutrient elements. To

317 some extent, it can reflect the utilization efficiency of nutrient elements in plants, and its ratio is

318 closely related to the growth rate of organisms (Davis et al., 2006). In this study, the C/N (16.88)

319   of *S. alopecuroides* leaves was lower than that of global plants (22.5) (Elser et al., 2000b), and
320   C/P (364.67) was much higher in the *S. alopecuroides* leaves than that of global plants (232)
321   (Elser et al., 2000b), indicating that the nutrient utilization efficiency of *S. alopecuroides* L. was
322   low. It can be seen from Table 3 that the C/N and C/P ratios of *S. alopecuroides* leaves grown in
323   the desert and roadside habitats were higher than those in the farmland and forest habitats. This
324   finding may be due to the fact that, in an environment with sufficient nutrition, the growth rate of
325   plants is fast, the synthesis of organic matter is high, and its C/N and C/P ratio are low. In the
326   environment of nutrient deficiency, plant growth is relatively slow, the utilization efficiency of
327   nutrient elements is high, and the C/N and C/P ratios are high (Ng et al., 2014).The ratio of N, P,
328   and N/P in plant leaves reflect the dynamic balance between soil nutrient supply and plant
329   nutrient demand; N/P ratio can be used to determine the limiting growth factors of plant nutrients
330   (Xiaonan et al., 2004). Studies have shown that when leaf N/P < 14, plant growth is mainly
331   restricted by N; when leaf N/P > 16, plant growth is mainly restricted by P; and when leaf NP is
332   more than 14, but less than 16, plant growth is mainly restricted by both N and P (Aerts et al.,
333   2000). *S. alopecuroides* is a nitrogen-fixing plant species, so it is generally N-limited, due to its
334   higher leaf P content (mean = 1.53 mg/g), indicating that it may not be P-limited. Therefore, the
335   rule for judging restrictive elements, that is, an N/P of 14 or 16, does not apply to nitrogen-fixing
336   plants to a large extent. Further studies are needed to determine which nutrients limit plant
337   growth.
338
339
340   **Factors affecting the ecological stoichiometry characteristics of C, N, and P in *S.***
341   ***alopecuroides* leaves**
342   Plants need to absorb nutrients from the soil to supplement the nutrients needed for the
343   growth and development of leaves, so soil physical-chemical factors have a greater impact on the
344   C, N, and P ecological stoichiometry characteristics of *S. alopecuroides* leaves. According to the
345   observed RDA ranking, AK and pH were the main factors affecting the C, N, and P
346   stoichiometric characteristics. Soil pH can change soil nutrient content and distribution area, thus
347   affecting plant growth and developmental processes (Zhan et al., 2013). In this study, pH was
348   positively correlated with C, N, and P contents and N/P in *S. alopecuroides* leaves, and was
349   negatively correlated with C/P and C/N, indicating that pH was closely related to leaf growth,
350   which was similar to the finding that pH affects the growth and development of plants by
351   affecting the physical, chemical, and biological characteristics of soil (Kaijie et al., 2015). In this
352   study, it was observed that with the increase in the contents of AK, C, N, P, and N/P in the leaves
353   also increased, but C/P and C/N decreased, in which the content of P in the leaves was positively
354   correlated with the content of AK, indicating that AK was the main factor affecting the content
355   of P in the leaves. This may be due to the fact that the absorption efficiency of *S. alopecuroides*
356   leaves to soil nutrients is different in arid and semi-arid areas compared to that of other
357   environments; the absorption efficiency of AK is higher in arid and semi-arid areas, which
358   provides a good environment for the growth of *S. alopecuroides* leaves.

359   By analyzing the influence of soil physicochemical factors on the ecological stoichiometry
360   characteristics of *S. alopecuroides* leaves, the internal stability of grassland ecosystems in the
361   arid and semi-arid areas of Xinjiang was explored. According to the RDA, the OM, nitrate
362   nitrogen, NH_4^+-N, and AK, the contents of soil C, N, P, and K did not significantly affect the
363   stoichiometric characteristics of C, N, and P in the sampled *S. alopecuroides* leaves. However,
364   the independent analysis of soil physicochemical factors on the stoichiometry characteristics
365   showed some deficiencies. First, the effects of soil physicochemical factors on the C, N, and P
366   ecological stoichiometry characteristics of *S. alopecuroides* leaves were not independent.
367   Secondly, soil physicochemical factors had mutual influence and restriction. Therefore, based on
368   the independent analysis, it is necessary to further analyze the double or even multiple effects of
369   soil physicochemical factors on the ecological stoichiometry characteristics of C, N, and P in *S.*
370   *alopecuroides* leaves, so as to make the results more accurate (Xiaofei et al., 2019).
371   As the dominant species of degraded grassland in the Yili River Valley, the growth,
372   development, and distribution of *S. alopecuroides* seriously affects the grassland ecosystem in
373   the valley. Studying the relationship between the C, N, and P ecological stoichiometry
374   characteristics of *S. alopecuroides* leaves and environmental factors are of great significance to
375   reveal the ecological mechanisms of the successful diffusion of *S. alopecuroides* plants in the
376   Yili River Valley.
377

378   **Conclusions**
379   (a) The contents of C, N, and P in the leaves of *S. alopecuroides* in Yili Valley were 391.30–
380   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
381   were 10.34–44.94, 209.05–698.73, and 10.78–31.43, respectively. Compared with the global and
382   national plant leaves, the C and N contents of the *S. alopecuroides* leaves in the arid desert
383   environment were higher.
384   (b) There were significant differences in C and P contents, and the C/P ratio between *S.*
385   *alopecuroides* leaves in different habitats, but there was no significant difference in the content
386   of C and N, and C/N and N/P ratios in leaves from different habitats. The order of leaf P content
387   in the four habitats was farmland > forest > roadside > desert, and the order of leaf C/P was
388   desert > roadside > forest > farmland, which indicated that reclamation of farmland could
389   improve the content of AP and provide a good environment for the growth of *S. alopecuroides*
390   leaves.
391   (c) AK and pH were the main factors affecting the ecological stoichiometry characteristics of
392   *S. alopecuroides* leaves in Yili Valley ($p \leq 0.05$); they were positively correlated with C, N, and
393   P contents and the N/P ratio, and negatively correlated with C/P and C/N ratios. AK is the
394   dominant factor that affects the P content of *S. alopecuroides* leaves. Appropriate reduction of K
395   fertilizer is conducive to restraining the spread of *S. alopecuroides*.
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503 **Figure legends**
504 **Figure.1**
505 **Diagram of sampling point in Yili Valley**
506
507 **Figure.2**
508 **Correlation of contents of C, N and P in leaves of *S. alopecuroides***
509
510 **Figure.3**
511 **Redundancy analysis of the influence of soil physical-chemical properties on the ecological**
512 **stoichiometry characteristics of leaves**
513 LC: (leaf C) carbon content of *S. alopecuroides* leaves; LN: (leaf N) nitrogen content of *S.*
514 *alopecuroides* leaves; LP: (leaf P) phosphorus content of *S. alopecuroides* leaves; L(C/N):
515 carbon nitrogen ratio of leaves; L(N/P): nitrogen phosphorus ratio of leaves; L(C/P): carbon
516 phosphorus ratio of leaves; C: soil carbon content; N: soil nitrogen content; P: soil phosphorus
517 content; K: soil potassium content.
518

Figure 1

Diagram of sampling point in Yili Valley

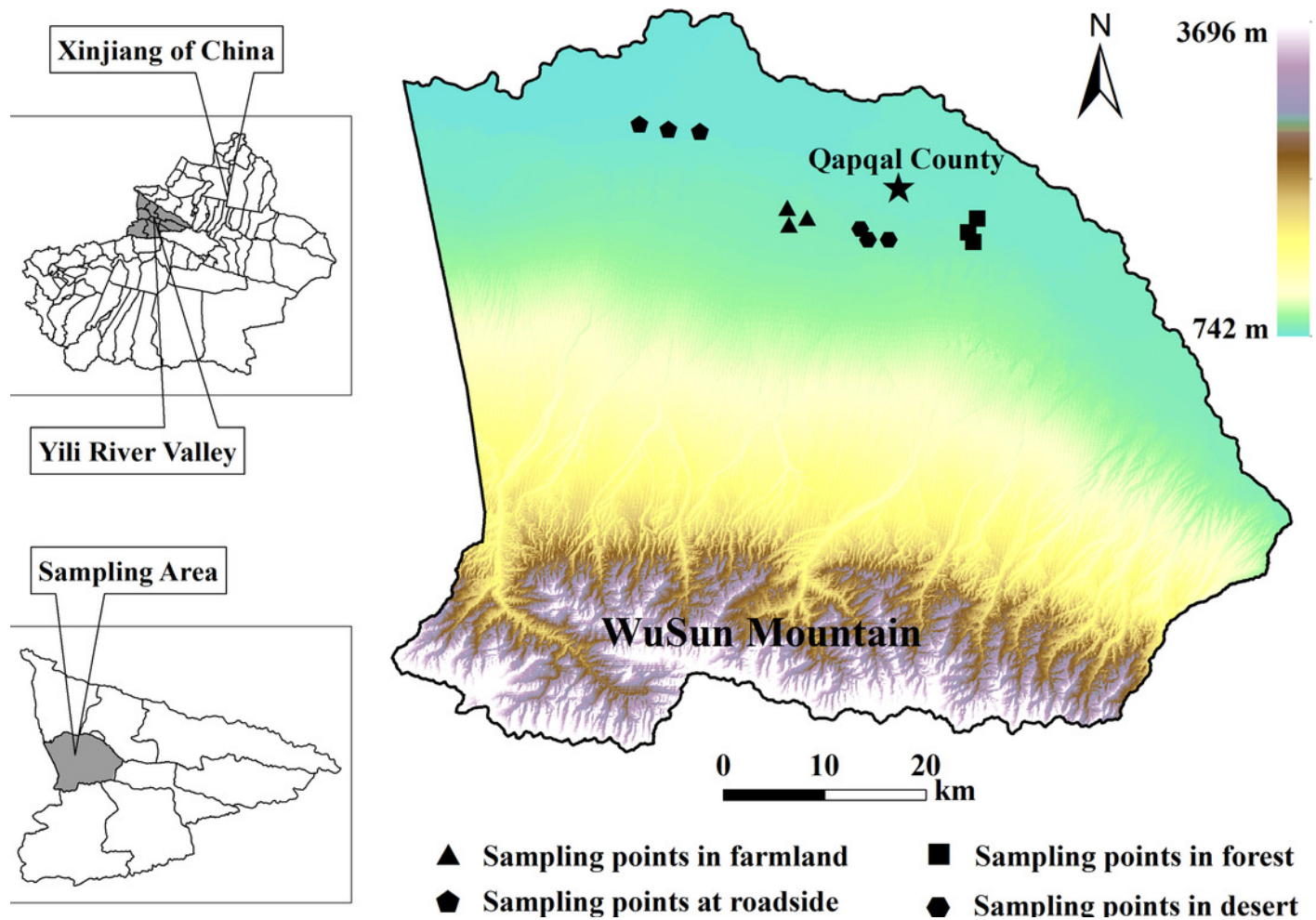



Figure 2

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

Manuscript to be reviewed

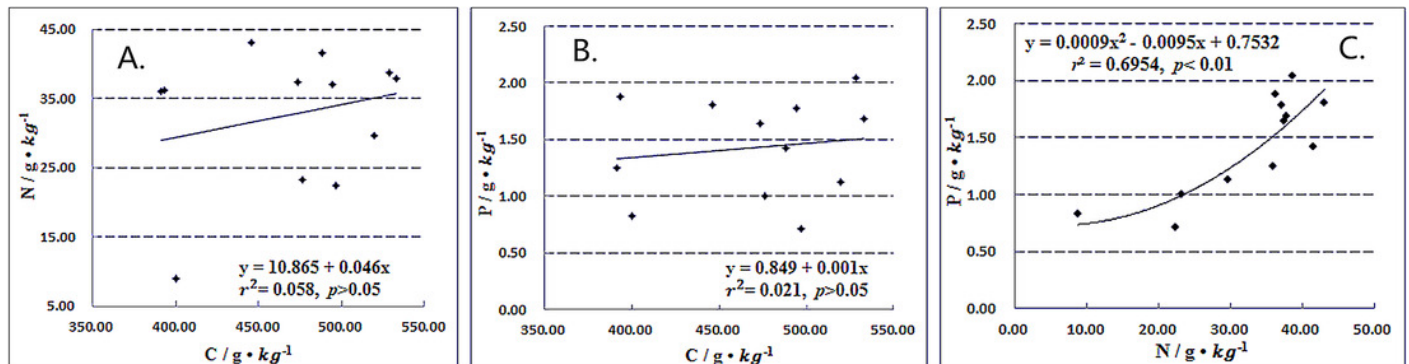
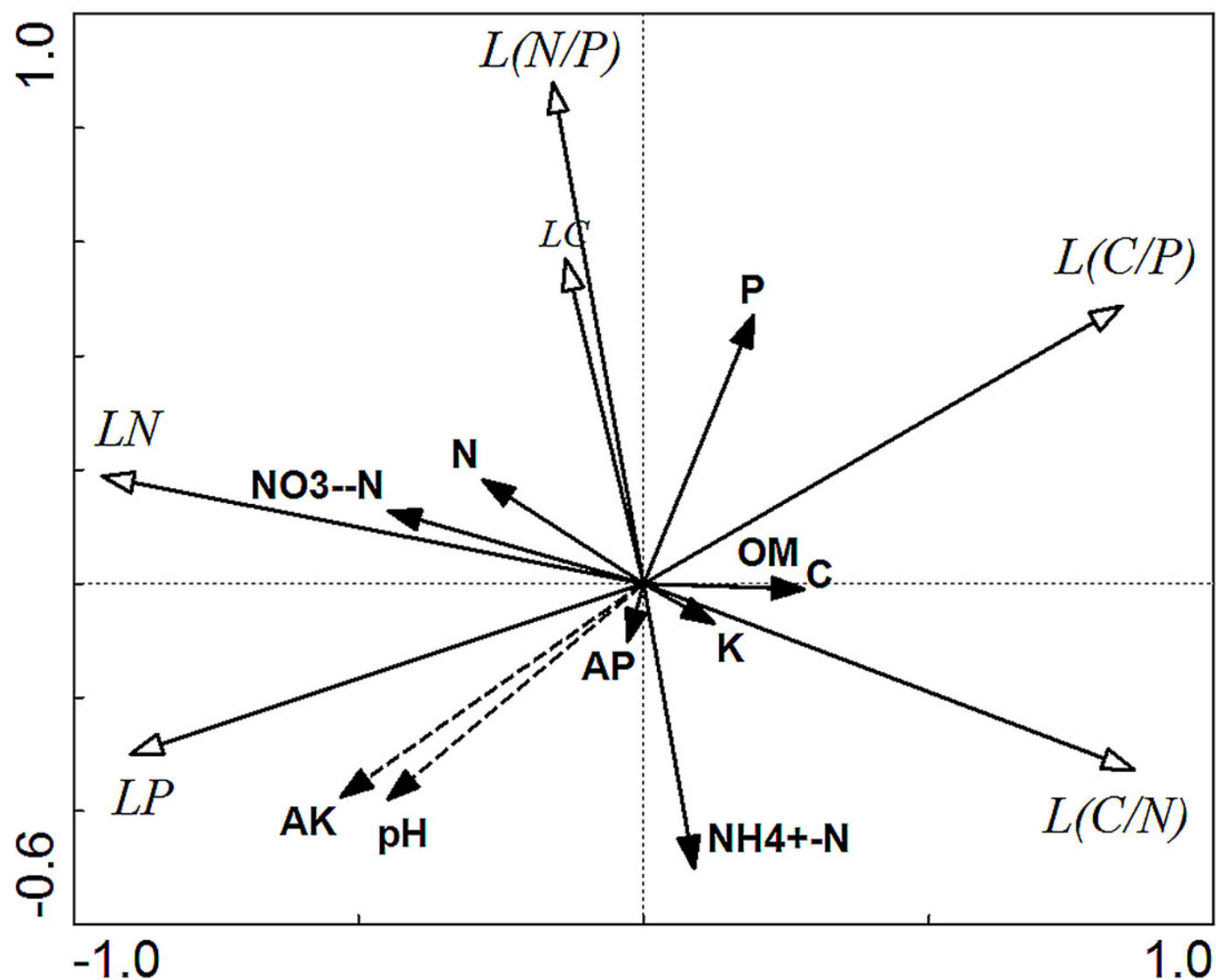



Figure 3

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.

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

1 **Table 1**

2 **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

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 ($p <0.05$).

1   Table 2

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

3   **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

4   The value is (mean ± SD). Different letters in the upper right corner of the peer data indicate that the data in

5   different habitats are significantly different (p <0.05).

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).

1 **Table 3**

2 **Ratios of carbon-nitrogen, carbon-phosphorus, nitrogen-phosphorus and coefficient of variation in**

3 **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

4 The value is (mean ± SD). Different letters in the upper right corner of the peer data indicate that the data in

5 different habitats are significantly different (p <0.05).

Correlation between ecological stoichiometry characteristics of leaves and sorting axis.

1 **Table 4**

2 **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		

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

1 **Table 5**

2 **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