

Effects of enclosure on biomass, carbon, nutrient storage and allocation for *Seriphidium transiliense* in a sagebrush desert grassland

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Abstract. We hypothesized that *Seriphidium transiliense* in a sagebrush desert grassland could improve the storage of biomass carbon and nutrient after 3 years of enclosure. Also, we expect distinctive allocation strategies of nutrient, carbon and biomass partitioning into root (R), root crown (RC), reproductive shoot (RS) and vegetative shoot (VS) plant characteristics or modules. Therefore, the storage and allocation pattern of biomass, carbon and nutrients (N, P, K, Ca and Mg) in different modules were monitored during September and October, from 2009 to 2011. The results showed that the P content of root, the N content of reproductive shoot, the Ca content of root crown and vegetative shoot in enclosure of moderate degraded plot were significantly higher than outside plots ($P < 0.05$). The storage of N, P, K significantly increased after enclosure ($P < 0.05$). The storage of C, the biomass of reproductive shoot and vegetative shoot increased with the decreasing degradation intensity and the values increased in enclosure of moderate degraded plot. The proportion of N, K of reproductive shoot, the proportion of Ca, Mg and C of vegetative shoot, the ratios of N and C of root crown all showed an increasing trend after enclosure. The ratios of N and C of reproductive shoot in enclosure of moderate degraded plot were significantly higher than outside plots ($P < 0.05$). The present results suggested the nutrient elements supply capacity of the soil, the resource allocation to vegetative shoot and reproductive shoot all increased in the sagebrush desert grassland after enclosure. The improvement of soil and these performances of *Seriphidium transiliense* population were beneficial to its ecological restoration.

Keywords: Enclosure, *Seriphidium transiliense*, biomass, nutrient elements, storage and allocation.

Introduction

Plant resource allocation is the core of life history theory, and is described as the allocation ratios of assimilated resource to different functional organs (Bazzaz and Grace 1997). Carbon (C) is fixed in the plant via photosynthesis (Mccarthy and Enquist 2007) and the storage and allocation of C can vary in pattern. Several studies of plant resource allocation have measured the distribution of biomass (Mccarthy and Enquist 2007). However, sometimes nutrient elements are a more important resource than biomass. The allocation pattern of key nutrient elements is also a plant ecological response strategy (Peri and Lasagno 2010). The changes in nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) content in plants may result in significant changes to biogeochemical cycles in the entire ecosystem. The differential concentration and allocation of nutrients in plant components may be a response to differences in biomass accumulation and biological functions between tissues such as photosynthesis and nutrient uptake (Taiz and Zeiger, 2006). Therefore, this study is important for revealing the adaptation strategies of a plant population under environmental stress by examining nutrient storage and allocation. We hypothesized that the dominant species

Seriphidium transiliense in the sagebrush desert grassland could improve the storage of biomass, carbon and nutrient after 3 years enclosure. Also, we expect differences in the allocation strategies of nutrient, carbon and biomass to plant characteristic modules of root (R), root crown (RC), reproductive shoot (RS) and vegetative shoot (VS). Therefore, the aim was to provide the evidence for changes to plant nutrient allocations in response to vegetation restoration of sagebrush desert grassland in Xinjiang, China.

Materials and Methods

Study areas

Three study areas of were selected in the sagebrush desert grassland in Changji, Xinjiang, China (43.858°-43.870°N, 87.136°-87.142°E, altitudes 825-897 m). The climate is temperate and arid with a mean annual temperature of 6.5°C, a long-term annual rainfall of 180-190mm evenly distributed throughout the year. The soils were classified as gray desert soil. The soil parent materials were loessial substances. Soil layers were deep and soil organic matter of the 0-10 cm layer was about 10-15 g/kg. The vegetation is dominated by *S. transiliense*, and accompanied by *Tulip tianschanica*, *Gagea bulbifera*, *Trigonella arcuata*, *Petrosimonia sibirica*, and *Ceratocarpus arenarius*.

Methods

We established in the study area three 40 × 40m plots which respectively represented the moderate degraded plot (MDp), heavy degraded plot (HDp) and over degraded plot (ODp) (Liu et al 2009). Selected sites had been used intensively for grazing, but had been fenced to exclude grazing from 2007. Outside each of these enclosures, sheep grazed at 1.5 sheep/ha during April/May and September/October, with a sampling area of 40 x 40 m outside each of the enclosures. As there were no *S. transiliense* plants in the enclosed HDp and ODp plots, plant sampling only occurred from four sample areas; within the moderately degraded plot enclosure (MDp-E) and from outside (MDp-OE), and outside HDp and ODp. We selected 40 plants at random for each sampling area at six times, August and September, 2009 to 2011. As well, at each sampling 1 m² quadrats were sampled for % coverage, height of *S. transiliense* and annual plants, and total and *S. transiliense* biomass.

For each *S. transiliense* plant, the aboveground part was collected by cutting and underground part by excavating. The aboveground part was divided into vegetative shoot (VS) and reproductive shoot (RS), the underground part was divided into root (R) and root crown (RC). The material for each module was dried at 70°C to a constant weight. The dried plant material for each module was ground in a mill containing 1 mm stainless steel screen for nutrient analysis. N content was determined using the semi-micro Kjeldahl technique (Sparks 1996). P, K, Ca and Mg content were determined with a plasma emission spectrometer (TAS-990). C content was determined using a wet digestion method (Oxidant: H₂SO₄+KMnO₄).

Nutrient storage of plants was estimated by multiplying mean nutrient content from chemical analysis and the mass of each biomass module (dry weight). The allocation pattern of C and nutrient was estimated by the ratios of C and nutrients storage of respective modules to the C and nutrients storage of total plant. Ratios of nutrient elements and C were estimated by nutrients storage divided by C storage in same module. Comparisons of the main factors for each treatment were carried out by two-way analyses of variance (ANOVA) with the F-test. Significantly different averages were separated with standard error of means (SEM) to evaluate least significant differences (LSD). This analysis was carried out to detect potential interactions between a module variable and different degraded plot. All tests were evaluated at $P < 0.05$.

Results

Community characteristics

Plant cover was lower in ODp than MDp (Table 1). The height, density and above ground biomass of *S. transiliense* were all lower in the more heavily degraded treatments (HDp and ODp), but the same pattern was not evident in the height of other plants, plant community density or total above ground biomass.

C and nutrient content

C and nutrient content varied according to plant part and degree of degradation (Table 2). N content of RC and RS, decreased with degradation treatment, but in VS N content

Table 1. Community characteristics in enclosure plots and outside degraded plots. Mean values of 6 harvests.

Community characteristics	MDp		HDp	ODp
	E	OE		
Coverage (%)	34.7 a	28.0 ab	26.6 abc	15.2 c
Height of <i>S. transiliense</i> (cm)	17.5 a	16.4 ab	1.2 c	0.5 cd
Height of early spring plant / annual plant (cm)	7.4 a	10.6 a	11.3 a	10.0 a
Above ground biomass (g/m ²)	88.9 b	103.5 ab	119.7 a	74.1 c
Above ground biomass of <i>S. transiliense</i> (g/m ²)	36.91 a	22.18 b	0.18 c	0.06 d
Density (plant number/m ²)	677 bc	639 c	1691 a	1010 ab
Density of <i>S. transiliense</i> (plant number/m ²)	72.30 a	52.22 a	0.21 b	0.09 b

Note: Comparisons of the main factors for each treatment were carried out by two-way analyses of variance (ANOVA) with the F-test. Different letters in the same row mean significant differences at $P < 0.05$.

was lowest in the grazed area (MDpOE). P content of roots also decreased with degradation, but was as low in MDpOE as ODp. P in RC and RS was lowest in MDpE and in VS was lowest in ODp. K was highest in ODp for R and lowest in MDpE for VS. Ca was highest in ODp for R and RS and highest in MDpE for RC and VS. Mg in ODP was highest in RS and lowest in VS. For C, MDpOE had lower levels in RC, but higher levels in RS than the enclosures.

Biomass, C and nutrient accumulation

The accumulation of C and nutrient is related to the biomass of plant parts and content of C and nutrient (Table 3). The root biomass, N and C per plant was highest in HDp and lowest in MDpOE, which was grazed. There was a general trend where biomass, N, K, Ca, Mg and C were all higher in MDpE for RS and VS. For VS, P, Ca and Mg, were all lowest in ODp. Generally biomass, N, Mg, and C decreased in plants with degradation.

Allocation pattern of C and nutrient

The proportion of biomass and nutrients allocated to each plant module for different the treatments is shown in Table 4. There was a higher proportion of biomass and C in R and RC for HDp than the other treatments. There was a higher proportion of biomass, N and K in RS for the MDp treatments. The proportion of biomass, N, K, Ca and C in VS was lowest for HDp. There were lower proportions of P, K and Ca in R for the grazed MDpOE treatment. The proportion of K, Ca and Mg was higher in ODp for R also. In RC and RS, MDpE had the lowest proportion of P whereas MDpOE had the highest P.

Elemental ratios are shown in Table 5. The N/C was lowest in the ODp for RC and RS, but not different in other plant parts. The P/C was highest in MDpE for R, in MDpOE for RC, in MDpOE and HDp for RS and in HDp for VS. K/C was highest in ODp for R and HDp for

Table 2. Elemental content of *S. transiliense* in plots and plant parts (g/kg) . Mean values of 6 harvests.

Modules	Treatments	Content of elements					
		N	P	K	Ca	Mg	C
R	MDpE	37.94 b	39.45 a	9.99 b	7.98 b	1.86 cd	339.97 a
	MDpOE	36.79 bc	16.31 c	7.80 c	2.40 d	1.44 d	337.41 a
	HDp	37.50 bc	27.23 b	8.02b c	6.67 c	1.46 d	356.98 a
	ODp	41.44 ab	14.89 c	14.63 a	14.23 a	1.74 cd	330.95 ab
RC	MDpE	48.75 a	9.32 d	8.82 bc	7.65 b	1.81 cd	330.59 ab
	MDpOE	35.45 bc	36.20 a	10.58 ab	6.98 c	3.54 bc	284.75 c
	HDp	36.64 bc	19.44 bc	9.47 b	6.24 c	1.19 d	318.09 b
	ODp	30.20 c	14.47 c	8.07 bc	5.37 cd	3.48 bc	338.68 a
RS	MDpE	49.48 a	2.76 e	9.44 b	7.46 b	3.73 bc	277.70 c
	MDpOE	42.12 ab	20.86 bc	10.80 ab	12.76 ab	2.42 c	361.83 a
	HDp	40.51 ab	11.39 cd	12.09 ab	8.59 ab	2.73 c	273.41 c
	ODp	30.64 c	6.10 de	10.49 ab	15.93 a	7.51 a	308.86 b
VS	MDpE	27.17 cd	10.85 cd	9.60 b	7.50 b	5.62 ab	300.52 ab
	MDpOE	22.54 d	10.36 cd	14.21 a	7.27 bc	3.89 b	338.71 a
	HDp	34.69 c	19.99 bc	11.73 ab	6.93 c	6.02 a	338.98 a
	ODp	36.02 bc	6.87 de	15.17 a	2.52 d	1.37 d	334.65 a

Note: Different letters in the same column mean significant differences at $P < 0.05$.

Table 3 Biomass and elements storage of *S. transiliense* in plots and plant parts. Mean values of 6 harvests.

Modules	Treatments	Biomass(g)	Storage of elements (mg/plant)					
			N	P	K	Ca	Mg	C
R	MDpE	1.93 cd	73.22 b	76.14 a	19.28 bc	15.40 bc	3.59 c	656.14 cd
	MDpOE	1.55 d	57.02 cd	25.28 f	12.09 cd	3.72 f	2.23 cd	522.99 d
	HDp	2.11 bc	79.13 b	57.46 b	16.92 c	14.07 c	3.08 c	753.23 c
	ODp	1.74 cd	72.11 bc	25.91 f	25.46 b	24.76 ab	3.03 c	575.85 d
RC	MDpE	1.25 de	60.94 c	11.65 gh	11.03 cd	9.56 cd	2.26 cd	413.24 e
	MDpOE	1.07 de	37.93 de	38.73 de	11.32 cd	7.47 d	3.79 c	304.68 fg
	HDp	1.65 cd	60.46 c	32.08 ef	15.63 c	10.30 cd	1.96 cd	524.85 d
	ODp	1.16 de	35.03 e	16.79 g	9.36 d	6.23 de	4.04 c	392.87 ef
RS	MDpE	0.96 e	47.50 d	2.65 j	9.06 d	7.16 d	3.58 c	266.59 g
	MDpOE	0.73 ef	30.75 ef	15.23 g	7.88 de	9.31 cd	1.77 de	264.14 g
	HDp	0.48 fg	19.44 g	5.47 i	5.80 ef	4.12 ef	1.31 e	131.24 h
	ODp	0.38 g	11.64 g	2.32 j	3.99 f	4.25 ef	2.85 cd	117.37 h
VS	MDpE	4.55 a	123.62 a	49.37 bc	43.68 a	34.13 a	25.57 a	1367.37 a
	MDpOE	3.15 ab	71.00 bc	32.63 e	44.77 a	22.90 b	12.25 b	1066.94 ab
	HDp	2.22 bc	77.01 b	44.38 cd	26.04 b	15.38 bc	13.36 b	752.54 c
	ODp	2.71 bc	97.61 ab	18.62 fg	41.11 a	6.83 de	3.71 c	906.90 b

Note: Different letters in the same column mean significant differences at $P < 0.05$.

RS.Ca/C was lowest in MDpOE for R and ODp for VS. Mg/C was highest in MDpOE for RC and in ODp for RS and lowest in ODp for VS.

Conclusion

The supply capacity of N, Mg, Ca and C to *S. transiliense* improved after enclosure. The resources of *S. transiliense* were mainly allocated to aboveground growth when measured in August and September. The reproductive

growth improved after enclosure, and resulted in the higher nutrient allocation. The productivity and regeneration of *S. transiliense* population improved after enclosure.

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Table 4. Proportion of elements and biomass of *S. transiliense* plant parts. Mean values of 6 harvests.

Modules	Treatments	Biomass proportion	Proportion of elements					
			N	P	K	Ca	Mg	C
R	MDpE	26.53 d	23.98 cd	54.43 a	23.23 d	23.23 cd	10.26 e	24.27 c
	MDpOE	25.36 d	28.99 c	22.63 d	15.90 e	8.53 g	10.95 e	24.23 c
	HDp	33.51 bc	33.52 bc	41.22 b	26.28 cd	32.12 bc	15.66 de	34.84 b
	ODp	29.32 cd	33.33 bc	40.72 b	31.88 c	58.91 a	22.06 cd	28.89 bc
RC	MDpE	20.36 ef	19.95 d	8.37 ef	13.24 ef	14.48 f	6.55 f	15.29 d
	MDpOE	21.80 e	19.28 d	34.62 bc	14.85 e	17.28 e	18.91 d	14.11 d
	HDp	29.00 cd	25.64 cd	23.01 d	24.26 cd	23.46 cd	10.10 e	24.28 c
	ODp	23.97 de	16.18 de	26.42 cd	11.75 ef	14.73 f	29.41 c	19.71 cd
RS	MDpE	9.09 gh	15.56 de	1.86 h	10.95 ef	10.86 fg	10.26 e	9.86 ef
	MDpOE	10.83 g	15.62 de	13.60 e	10.38 ef	21.43 de	8.96 ef	12.23 de
	HDp	6.74 h	8.22 f	3.94 g	9.02 fg	9.34 g	6.57 f	6.07 f
	ODp	5.18 h	5.36 fg	3.62 g	5.00 g	10.21 fg	21.32 cd	5.89 fg
VS	MDpE	44.02 a	40.50 ab	35.34 bc	52.59 a	51.43 a	72.93 a	50.58 a
	MDpOE	42.01 ab	36.11 b	29.16 c	58.87 a	52.76 a	61.19 b	49.42 a
	HDp	30.76 cd	32.63 bc	31.83 c	40.44 b	35.08 b	67.68 ab	34.81 b
	ODp	41.53 ab	45.12 a	29.25 c	51.38 a	16.15 ef	27.21 c	45.50 a

Note: Different letters in the same column mean significant differences at $P < 0.05$.

Table 5. Elemental ratios of *S. transiliense* plant parts (%). Mean values of 6 harvests.

Modules	Treatments	N/C	P/C	K/C	Ca/C	Mg/C
R	MDpE	11.16 ab	11.60 ab	2.94 b	2.35 bc	0.55 de
	MDpOE	10.90 abc	4.84 c	2.31 bc	0.71 e	0.42 e
	HDp	10.50 abc	7.63 b	2.24 bc	1.87 c	0.41 e
	ODp	12.52 ab	4.50 c	4.43 a	4.31 a	0.52 de
RC	MDpE	14.74 a	2.83 de	2.66 bc	2.32 bc	0.56 de
	MDpOE	12.44 ab	12.70 a	3.71 ab	2.46 bc	1.25 b
	HDp	11.53 ab	6.12 bc	2.97 b	1.96 c	0.38 e
	ODp	8.91 bc	4.28 cd	2.39 bc	1.58 cd	1.02 bc
RS	MDpE	17.82 a	0.98 f	3.41 ab	2.70 b	1.35 b
	MDpOE	11.62 ab	5.76b c	2.99 b	3.52 ab	0.68 cd
	HDp	14.79 a	4.19 cd	4.42 a	3.13 ab	0.99 c
	ODp	9.88 bc	1.96 e	3.41 ab	3.66 ab	2.47 a
VS	MDpE	9.04 bc	3.61 cd	3.20 ab	2.49 bc	1.87 ab
	MDpOE	6.65 c	3.06 d	4.20 a	2.15 bc	1.15 bc
	HDp	10.23 abc	5.90 bc	3.46 ab	2.05 bc	1.78 ab
	ODp	10.76 abc	2.05 e	4.53 a	0.75 e	0.41 e

Note: Different letters in the same column mean significant differences at $P < 0.05$.

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