Influence of Shrubs on Soil Chemical Properties in Alxa Desert Steppe, China

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Abstract: Alxa desert steppe is one of severely the degraded rangelands in the Northwest China. Shrubs, as the dominant life form in the desert steppe, play an important role in protecting this region from further desertification. Chemical properties of three soil layers (0 to 10, 10 to 20 and 20 to 30 cm) at three locations (the clump center [A], in the periphery of shrub canopies [B], and the inter-shrub space [C], at least one m away from the edge of shrub canopies) were investigated in two prominent shrub communities (*Zygophyllum xanthoxylum*, *Ammopiptanthus monglicus*) in Alxa desert steppe. The results showed that: (1) soils in three layers at the clump center exhibited significantly higher contents of organic carbon (SOC), total N, total P, and lower pH value compared to the inter-shrub space. Soils in the 0 to 10-cm and 10 to 20-cm depths under periphery of shrub canopy showed significantly higher contents of SOC and total N, and slight, but significantly lower, pH value compared to the same soil layers in the inter-shrub space. However, there was no significant difference in total P in three soil layers between shrub periphery and inter-shrub space; (2) the soil enrichment ratios of SOC, total N, and total P at clump center were significantly higher, while ratio for pH significantly lower compared to the shrub periphery; and (3) SOC and total P contents at all locations around *Z. xanthoxylum* were higher, while total N and pH values lower compared to soils around *A. monglicus*. The enrichment ratios of SOC, total N, and total P at the same location were not significantly different between *Z. xanthoxylum* and *A. monglicus*. The litter-fall seems to influence the soil chemical properties at clump center, shrub periphery, and inter-shrub open space, resulting in "fertile island" under shrub canopies. This study shows that shrubs play a vital role in accumulating SOC and nutrients and maintaining soil fertility in Alxa desert steppe.

Introduction

Alxa desert steppe is one of the severely degraded rangelands in the arid and semiarid areas in the northwestern China. Grazing has been the most common management practice in this region. In recent decades, this region has become one of the major sources of sandstorms in the northwestern China (Wang and others 2004) due to overgrazing and population growth (Fu and Chen 2003). Overgrazing may induce dramatic changes in vegetation composition and in soil nutrient cycling in native rangelands (Fu and Chen 2003). The degree of rangeland degradation can be measured by declines in soil fertility (Fang and Peng 1997).

Zygophyllum xanthoxylum and *Ammopiptanthus monglicus*, the two dominant shrub species belonging to the family of *Zygophyllaceae* and *Leguminosae*, respectively, are widely distributed in the Alxa desert steppe as the main forage species for camels, sheep, and goats (Cheng and Zhang 2001). These shrubs play an important role in protecting this area from wind erosion (Charley and West 1975; Garner and Steinberger 1989). These shrubs may also affect the distribution and biochemical cycle of soil nutrients (Halvorson and others 1995), resulting in the formation of islands of fertility around shrubs (Schlesinger 1996).

The development of islands of fertility may be important strategies and mechanisms for shrubs to use and recycle soil nutrients effectively. Thus, shrubs are important for maintaining the stability of arid ecosystems (Martinez-Meza and Whitford 1996). Information about shrub-soil interaction and shrub-induced soil chemical changes is vital for a better understanding of the ecological processes in Alxa desert steppe. The objective of this study was to investigate the effects of two prominent shrub species on soil nutrient accumulation and distribution. The study attempted to quantify the magnitudes of element enrichment in SOC, total N, and total P under shrub canopy as compared to the inter-shrub space and to test if there are any differences in enrichment ratios in SOC, total N, and total P between the two shrub communities.

Materials and Methods

Study Site

The study was conducted in a desert steppe of Alxa (105°35′ E, 39°08′ N; elevation 1360m), western Inner Mongolia, China. The climate is arid with mean annual precipitation of 105 mm and nearly 70 percent of rainfall occurs between July and September. Mean annual evaporation capacity is 3,000 to 4,100 mm. Mean annual temperature is about 8°C. Mean annual wind velocity ranges from 3.44 to 4.74 ms^{-1}. The brown desert soil in this region is highly

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Table 1. Morphological traits of shrubs (n = 6).

Item	Family	Height cm	Crown diameter cm	Biomass of shrub g	Height of mound cm
Z. xanthoxylum	Zygophyllaceae, shrub	59~87.5	129~202.5	221.63~594.06	19~25
A. monglicus	Leguminosae, shrub	61.05~84	178~280.5	425.35~862.99	31~60

susceptible to wind erosion due to its coarse texture and loose structure characteristics according to the Alxa soil classification system (Plan Committee of Alxa League 1991).

Sampling

Z. xanthoxylum and *A. monglicus* are two dominant woody shrub species in the study area. In August of 2003, six individuals of *Z. xanthoxylum* and *A. monglicus*, respectively, were randomly selected and the morphological traits of the plants were measured (table 1). Soil samples were taken from three depths (0 to 10 cm, 10 to 20 cm, 20 to 30 cm) in each of the three locations around an individual shrub plant. The three locations were: center of the shrub clump (A), under the periphery of the shrub canopy (B), and the inter-shrub space (at least one meter away from the edge of shrub canopy) (C). For each individual plant, four soil samples each at one direction were taken and the samples were then mixed for lab analysis.

Laboratory Analyses

Soil samples were air-dried, sieved to pass a 2-mm screen to remove plant materials and other debris, and analyzed for pH (1:1 distilled water). The samples were ground and then sieved to pass a 0.5-mm screen and analyzed for organic carbon (oxidization with potassium dichromate in presence of H_2SO_4, heated at 180°C for 5 minutes), total nitrogen (Kjeldahl method), and total phosphorus (by spectrophotometer after NaOH digestion) (Institute of Soil Sciences, Chinese Academy of Sciences 1978).

Data Analyses

The enrichment ratio (E) was used to evaluate the spatial pattern of soil element distribution (Wezel and others 2000), where $E_A = A/C$, $E_B = B/C$. The more E differs from 1, the more soil elements in A or B deviate from C. $E > 1$ means a higher concentration for the elements analyzed in either A or B than in C. An E value less than 1 for pH value means a more acid soil environment in either A or B than in C.

Data were analyzed using SPSS 11 package for significance at $P \leq 0.05$. Significant differences in mean soil properties analyzed in the three locations and in the three depths in the same sampling location were determined by analyzing replicate means (n = 6) with a one-way analysis variance (ANOVA) and least significance difference tests (LSD). The figures of results showed as means ± S.E.

Results

General Trends in Soil Chemical Properties Around Shrubs

The following data are averages around the two shrub communities. SOC, total N, and total P generally showed a declining trend from the canopy center to the inter-shrub space in the 0 to 10-cm, 10 to 20-cm, and 20 to 30-cm soil profiles, respectively (table 2, fig. 1). SOC and total N were significantly higher in 0 to 10-cm and 10 to 20-cm soil layers under periphery of the shrub canopy compared to the adjacent inter-shrub open space. The means of SOC and total N in 0 to 10-cm soils under the canopy periphery increased by 58 and 60 percent respectively, and total P was not significantly different ($P = 0.345$), but pH values decreased 0.30 units ($P < 0.05$) compared to the inter-shrub space. SOC, total N, and total P in 0 to 10-cm soils in the clump center were higher by 164 percent, 117 percent, and 19 percent respectively, but pH values lower by 0.70 units ($P < 0.05$) than in soils in the inter-shrub space. SOC, total N, and total P in 10 to 20-cm soil layers at the clump center increased by 103 percent, 96 percent, and 20 percent respectively, while pH decreased 0.40 units ($P < 0.05$) compared to the inter-shrub space. There were significant differences in SOC and total N in 20 to 30-cm soil layers between clump center and the inter-shrub space. However, SOC, total N, and total P in 20 to 30-cm soil layers between canopy periphery and the inter-shrub space were not different.

The enrichment ratios of soil organic C, total N, and total P at the clump center were significantly higher, while pH values significantly lower than the canopy periphery with exception of total P at 10 to 20-cm soil layers. Our data showed that contents and enrichment ratios of SOC and total N decreased with the increase of depth.

Soil Chemical Properties as Related to Shrub Species

Soil chemical properties were somewhat related to shrub species (fig. 1). SOC and total P in the topsoil layers under the canopy around *Z. xanthoxylum* were higher, while total N and pH value lower than those around *A. monglicus*. The enrichment ratios of SOC, total N, and total P at the same soil depths were not significantly different between *Z. xanthoxylum* and *A. monglicus* (table 3).

Table 2. Soil chemical properties and enrichment ratios for two shrub communities (E_A and E_B, n = 6). A: clump center, B: canopy periphery, C: inter-shrub space.

				Value	**Enrichment ratio**		**t-test** [1]
Depth	**Variable**	**Unit**	**Location**	**Mean ± S. E.**	**E_A (A/C)**	**E_B (B/C)**	**P**
0-10 cm	Organic C	g kg^{-1}	A	4.834±0.27a			
			B	2.893±0.21b			
			C	1.831±0.12c	2.74	1.64	<0.001
	Total N	g kg^{-1}	A	0.496±0.01a			
			B	0.366±0.02b			
			C	0.228±0.01c	2.20	1.63	<0.001
	Total P	mg·kg^{-1}	A	0.266±0.01a			
			B	0.243±0.01ab			
			C	0.223±0.02b	1.21	1.10	0.009
	pH		A	8.68±0.10a			
			B	9.08±0.08b			
			C	9.38±0.04c	0.93	0.97	<0.001
10-20 cm	Organic C	g kg^{-1}	A	3.338±0.17a			
			B	2.262±0.12b			
			C	1.727±0.13c	2.03	1.30	0.002
	Total N	g kg^{-1}	A	0.397±0.02a			
			B	0.285±0.02b			
			C	0.202±0.01c	1.96	1.43	<0.001
	Total P	mg·kg^{-1}	A	0.246±0.01a			
			B	0.228±0.01a			
			C	0.209±0.01a	1.20	1.09	0.132
	pH		A	8.99±0.08a			
			B	9.25±0.05b			
			C	9.42±0.06b	0.95	0.99	0.001
20-30 cm	Organic C	g kg^{-1}	A	2.749±0.23a			
			B	1.808±0.07b			
			C	1.660±0.10b	1.67	1.11	0.002
	Total N	g kg^{-1}	A	0.338±0.01a			
			B	0.259±0.01b			
			C	0.184±0.01b	1.85	1.40	<0.001
	Total P	mg·kg^{-1}	A	0.228±0.01a			
			B	0.214±0.01a			
			C	0.202±0.01a	1.14	1.06	0.028
	pH		A	9.02±0.11a			
			B	9.26±0.03b	0.96	0.99	0.050
			C	9.39±0.04b			

[1] t-test for paired samples for enrichment ratios.
Means followed by the same letters are not different at P = 0.05 level.

Correlation Between Organic C, Total N, and Total P at the Various Locations

Contents of elements were linearly correlated between clump center and canopy periphery (table 4). The highest values of coefficient *r* were found between A and B for SOC (r = 0.705**), total N (r = 0.851**), and total P (r = 0.974**). The correlation coefficients between canopy periphery (B) and clump center (A) were higher than between canopy periphery and the inter-shrub space (C). No significant correlations were observed between total N and SOC in inter-shrub space, nor were there significant correlations between total N and total P in A, B, and C.

Discussion

The concentrations of nutrients in soils under shrub canopies tend to be greater than in the shrub interspace, thus forming "islands of fertility." This phenomenon has been well documented in arid and semiarid ecosystems (Garner and Steinbergar 1989; Schlesinger and others 1990; Halvorson and others 1995; Whitford and others 1997; Wezel and others 2000; Su and others 2004). The increased spatial heterogeneity of soil resources may be a useful indicator of desertification in arid and semi-arid ecosystems (Schlesinger and others 1990). Our results show that fertile islands become relatively stable features in this landscape. In these

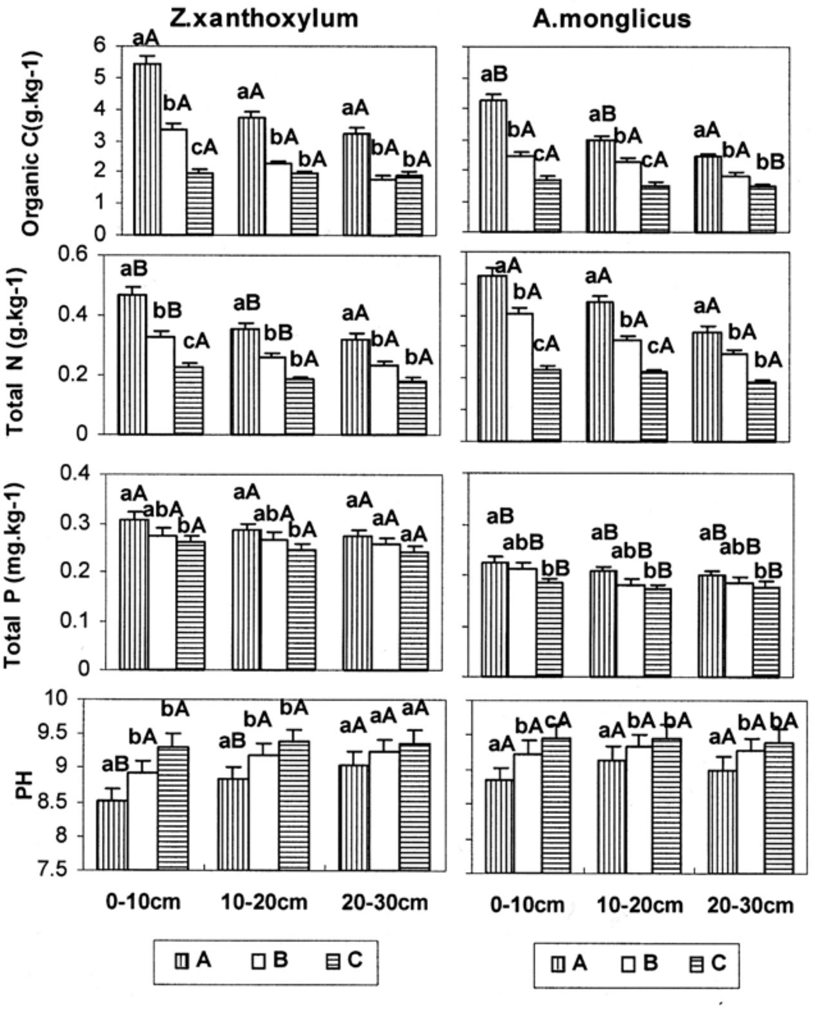

Figure 1. Soil chemical properties as related to shrub species in Alxa desert steppe. A: in the center of clump, B: under shrub canopies, C: the inter-shrub space. Means at the same soil depth within a species not followed by the same lowercase letters differ ($P < 0.05$, LSD multiple range tests). Means at the same location and same soil depth not followed by the same uppercase letters differ (between species difference, $P < 0.05$, *t*-tests).

Table 3. Enrichment ratios of soil nutrients for two shrub species in Alxa desert steppe.

		Z. xanthoxylum			*A. monglicus*			t-test for E	
Variable	Depth	E_A A/C	E_B B/C	t-test[1] P value	E_A A/C	E_B B/C	t-test[1] *p*	P value (between species) (E_A)	(E_B)
Organic C									
	0-10 cm	2.81a	1.77a	0.001	2.66a	1.51a	0.010	0.609	0.495
	10-20 cm	2.02b	1.18b	0.002	2.03ab	1.44a	0.095	0.954	0.030
	20-30 cm	1.68b	0.93b	0.001	1.66b	1.24a	0.097	0.779	0.018
Total N									
	0-10 cm	2.12a	1.49a	0.001	2.29a	1.77a	0.001	0.528	0.302
	10-20 cm	1.90a	1.37a	0.018	2.01b	1.51b	0.001	0.573	0.602
	20-30 cm	1.81a	1.30a	0.001	1.87b	1.47b	0.001	0.872	0.212
Total P									
	0-10 cm	1.19a	1.05a	0.043	1.23a	1.15a	0.147	0.686	0.088
	10-20 cm	1.18a	1.10a	0.006	1.23a	1.08a	0.266	0.704	0.788
	20-30 cm	1.15a	1.08a	0.330	1.13a	1.05a	0.005	0.561	0.435
pH									
	0-10 cm	0.92a	0.96a	0.018	0.94a	0.98a	0.002	0.828	0.742
	10-20 cm	0.94ab	0.98ab	0.001	0.97b	0.99b	0.064	0.118	0.069
	20-30 cm	0.97b	0.99b	0.207	0.96b	0.99b	0.097	0.181	0.723

A: clump center, B: canopy periphery, C: inter-shrub space.

[1] t-test for paired samples of enrichment ratios. Means under each category within a column not followed by the same letters are different at p = 0.05.

Table 4. Pearson linear correlation coefficients (r) between SOC, total N, and total P in soils of the different locations (n =36).

Variable	Sampling location	Organic C			Total N			Total P	
		A	B	C	A	B	C	A	B
Organic C	B	0.705**							
	C	0.418*	0.419**						
Total N	A	0.632**	0.552**	0.235					
	B	0.431**	0.448**	0.166	0.851**				
	C	0.237	0.293	-0.177	0.743**	0.738**			
Total P	A	0.781**	0.517**	0.564**	0.197	0.027	-0.158		
	B	0.634**	0.437**	0.562**	0.162	0.002	-0.132	0.974**	
	C	0.610**	0.513**	0.643**	0.160	0.016	-0.114	0.956**	0.999**

ecosystems, shrubs protect topsoil from wind erosion and effectively trap wind-blown materials and litters from unprotected areas. Microtopographic mounds ranging from 19- to 60-cm height were observed around shrub crowns (table 1). This suggests that topsoil material mainly accumulated under shrub canopies. Such mounds create a landscape that alternates between mounds and inter-shrub open space. The mound itself is a soil forming process (Rostagno and others 1991), because it creates patches with higher concentrations of soil resources.

Higher concentrations of total N and total P were linked to the higher concentration of SOC under shrub canopies because SOC is the most important factor in the storage of nutrients in infertile soils (table 4, Wezel and others 2000). It is evident from our data that shrubs exert great impacts on nutrient redistribution, with a significant accumulation of growth-limiting nutrients such as total N and total P under the shrub canopies. This effect was particularly evident in the 0 to 10-cm and 10 to 20-cm soil layers.

Higher concentration and enrichment ratios of SOC were found in soils under *Z. xanthoxylum* and higher content and enrichment ratios of total N were found under *A. monglicus*. This may relate to the fact that *A. monglicus* is a legume that has root nodules to fix nitrogen, thus producing a higher concentration of total N in the soil around the shrub (Cheng and Zhang 2001).

Nutrient enrichment at the clump center was more pronounced than at the shrub periphery (fig. 1, table 2). This is because there is much greater litter-fall at the clump center than some distance away from the center. In addition, shrub plants tend to have more roots at the clump center than near the canopy periphery. A larger amount of organic substrates, such as exudates, secretions, sloughed cells, and mucilage may be released from roots and deposited in the rooting zone at the clump center (Lynch and Whipps 1990; Petersen and Bottger 1991) leading to higher enrichment ratios.

No significant statistical differences in E_A and E_b between the two shrub species were found, which may suggest that two species were both capable of altering nutrient redistribution in the soil. The capacity to accumulate soil nutrients under their canopies is similar regardless of whether the shrub is leguminous or not.

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