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Changes in Soil Properties After Establishment of *Artemisia halodendron* and *Caragana microphylla* on Shifting Sand Dunes in Semiarid Horqin Sandy Land, Northern China

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ABSTRACT / In the semiarid Horqin sandy land of northern China, establishment of artificial sand-fixing shrubs on desertified sandy lands is an effective measure to control desertification and improve the regional environment. *Caragana microphylla* Lam. and *Artemisia halodendron* Turcz. ex Bess. are two of the dominant native shrub species, which are adapted well to windy and sandy environments, and thus, are widely used in revegetation programs to control desertification in Horqin region. To assess the effects of artificially planting these two shrub species on restoration of desertified sandy land, soil properties and plant colonization were measured 6 years after planting shrubs on shifting sand dunes. Soil samples were taken from two depths (0–5 cm and 5–20 cm) under the shrub canopy, in the mid-row location (alley) between shrub belts, and from nonvegetated shifting sand dune (as a control). Soil fine fractions, soil water holding capacity, soil organic C and total N have significantly increased, and pH and bulk density have declined at the 0–5-cm topsoil in both *C. microphylla* and *A. halodendron*. At the 5–20 cm subsurface soil, changes in soil properties are not significant, with exception of bulk density and organic C concentration under the canopy of *A. halodendron* and total N concentration under the canopy of *C. microphylla.* Soil amelioration processes are initiated under the shrub canopies, as higher C and N concentrations were found under the canopies compared with alleys. At the same time, the establishment of shrubs facilitates the colonization and development of herbaceous species. *A. halodendron* proved to have better effects in fixing the sand surface, improving soil properties, and restoring plant species in comparison to *C. microphylla.*

Overgrazing, excessive biomass extraction for firewood, and extensive cultivation of the natural grasslands are the most important causes of desertification (Mitchell and others 1998, Li and others 2002). Vegetation restoration is one of the most common and effective ways to combat desertification and prevent adjacent areas from sand encroachment in many of the desertified regions of the world (Ffolliott and others 1995). In desertified areas of northern China, stopping grazing and establishing artificial vegetation are commonly adopted measures for vegetation restoration and desertification control. Removal of grazing can allow the desertified grasslands to naturally recover. Planting seedlings is a way of artificially establishing vegetation by using native plants or plant species introduced from outside the area.

KEY WORDS: Shifting sand land; Soil amelioration; Vegetation restoration; Artificial shrubs

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The Horqin Sandy Land, located in the agro-pastoral transitional zone between the Inner Mongolian Plateau and the Northeast Plains (42° 41′–45°15′ N, 118°35′–123° 30′ E, elevation 180–650 m), is one of the well-known Sandy Lands in northern China. It covers an area of approximately 43,000 km^2, and is an important component of Inner Mongolian grassland resources. Over the past few decades, especially in the last 30 years, this region has undergone severe desertification. To date, the primary landscape of sparse steppe has almost disappeared completely, and most sandy grasslands have evolved into shifting, semishifting, and semifixed sandy lands corresponding to severe, moderate and light desertification (Zhu and Chen 1994).

In recent decades, much research and practical measures in desertification control have been carried out in Horqin region to rehabilitate desertified lands and improve regional environments. In a practical manner, removing livestock or adopting a rational rotation grazing regimen on light and moderately desertified grasslands, and placing sand arresters (straw checkerboards) and planting indigenous shrubs on shifting sand dunes are effective measures to restore degraded vegetation and prevent desertification (Li and others 2002). Numerous studies in this region have revealed that establishment of artificial shrubs on sand dunes can significantly reduce wind velocity, improve micrometeorological conditions (Li and others 2002), increase the colonization and development of some annual and perennial plant species (Su and Zhao 2003), Although the results from these previous studies have provided some valuable insights into the effects of revegetation on the restoration of desertified land, field studies pertaining to the effects of establishing different shrub species on soil rehabilitation are still limited. Information on these aspects is required for selection of sand-fixing shrub species at the initial stage of restoration, and for appropriate management and conservation of the environment in the Horqin region. The objective of the present study was to compare and identify changes in soil properties and plant communities after establishment of two shrubs, i.e., *Caragana microphylla* and *Artemisia halodendron*, on sand dunes.

Materials and Methods

Study Area Description

The study was carried out at the Naiman Desertification Research Station, Chinese Academy of Sciences, located in Naiman county, Inner Mongolia, China (42°55′ N, 120°41′ E, 385 m a.s.l.), at the southwest end of the Horqin Sandy Land. The area is characterized by sand dunes alternating with gently undulating lowlands. The surface sand deposits are 20–120 m thick. The climate is largely governed by the Eurasian continental system, giving a dry and windy winter and spring, and a warm and comparatively wet summer followed by a short, cool autumn. The average annual temperature is 6.8°C with monthly averages ranging from a minimum of –13.1°C in January to a maximum of 23.7°C in July. Annual precipitation is 360 mm, with more than 70% occurring during the growing season of July to September. The threshold wind velocity for sand movement (5 m s^{-1}) is exceeded during more than 200 days per year (mainly in spring and winter). Gales with wind velocity >17 m s^{-1} occur 17–24 days per year (Zhu and Chen 1994). The soils are sandy, with loose structure and very low organic matter, and are very susceptible to wind erosion (Su and others 2004).

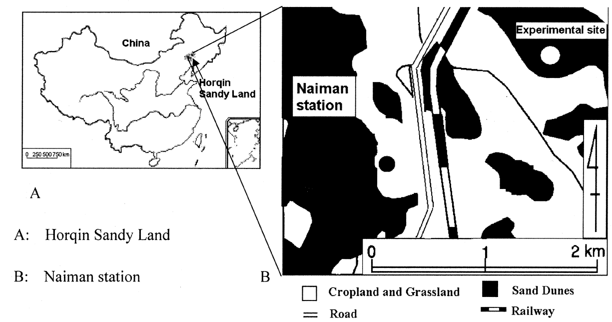

Figure 1. Map showing the location of the Horqin Sandy Land and the study site.

The vegetation in desertified sandy grasslands is generally dominated by psammophytes including some grasses (e.g., *Cleistogenes squarrosa* L (Trin.) Keng, *Setariaviridis* (L.) Beauv., *Phragmites australis* Trin. ex Steudel Nomencl., *Digitaria ciliaris* (Rotz) Koeler, *Leymus chinensis* (Trin.) Tzvel., *Pennisetum centrasiaticum* Tzvel.), forbs (*Mellissitus ruthenicus* (L.) C.W.Chang, *Salsola collina* Pall., *Corispermum elongatum* Bge. ex Maxim., *Agriophyllum quarrosum* (L.) Moq., *Artemisia scoparia* Waldst.et Kit.), shrubs (e.g., *Caragana microphylla* Lam., *Lespedeza davurica* (Laxm.) Schindl.), and subshrubs (e.g., *Artemisia halodendron* Turcz ex Bess., *Artemisia frigida* Willd.). *A. halodendron* is a pioneering subshrub in shifting and semishifting sand dunes. *C. microphylla*, a leguminous shrub, is the dominant plant species on semifixed and fixed sandy land. They adapt well to windy and sandy environment, and thus, are widely used in vegetation reestablishment programs to stabilize shifting sand.

Experimental Design

The experiment site was located about 2 km northwest of the Naiman Desertification Research Station and was composed of moving sand dunes before the experiment (Figure 1). The size of the moving sand dunes averaged 5–8 m height relative to the interdunal depression and about 300–600 m in length and 20–40 m in width. An area of 100 ha (1000 × 1000 m) and an area of 18 ha (60 × 300 m) were fenced in 1997 with posts and barbed wires, and grazing was prohibited. The two fenced areas were about 500 m apart. Two of the sand-fixing shrub

Table 1. Average values ± SD for soil properties (0–20 cm) on shifting sand dune before establishment of shrub, n = 10

Particle size distribution (%)					
Sand	Silt	Clay	Bulk density (g cm^{-3})	Organic C (g kg^{-1})	Total N (g kg^{-1})
97.2 ± 1.3	1.6 ± 1.0	1.2 ± 0.6	1.63 ± 0.06	0.52 ± 0.13	0.08 ± 0.016

species, *C. microphylla* and *A. halodendron* seedlings, were planted on different sites in each of the two fenced areas at the end of July 1997. The current-year twigs of *A. halodendron* were taken in the raining season from nearby fixed sand dunes, and the current year seedlings of *C. microphylla* propagated by seeds were taken in the nursery, respectively, and were transplanted at a depth of 15 cm; planting was arranged in belts (row spacing 1 m, neighboring plant seedling spacing 0.5 m), and the orientation of the belts was perpendicular to the prevailing wind direction. At the same time, several patches without planting shrubs were reserved on different sand dunes, allowing the vegetation to naturally recover. These patches were distributed near the planting areas. Prior to planting shrubs, the vegetation cover on the shifting sand dunes was generally less than 5% and the dominant plant species was *Agriophyllum squarrosum*; also, moving sand often encroached in adjacent grassland and farmland during the dry winter and spring seasons. Soil properties on sand dunes before planting shrubs are provided in Table 1. In August 2003 (after shrubs were established for 6 years), three treatments were selected: (1) 6-year *A. halodendron* plantation; (2) 6-year *C. microphylla* plantation; and (3) natural restoration area as a control (shifting sand patches without planting shrubs). Each treatment had three replicates, which were distributed on three sand dunes with more than 50 m distance from each other. For each replicate of each treatment, we marked a 10 × 15-m area as sampling plot. Each plot had a similar topographical trait.

Vegetation Investigation and Soil Sampling

Vegetation investigation and soil sampling was carried out in August 2003. Within the center of each plot of *C. microphylla* plantation, five neighboring *C. microphylla* individuals in the same belts were identified, and the height, crown diameter, and shoot numbers were recorded.

Fifteen 1 × 1-m^2 herb quadrates in the control plot and in the alleys of both *C. microphylla* and *A. halodendron* plantations were established randomly in each plot. Within each quadrate, the number of invaded species and the height of each species were surveyed.

Soil samples from two depths (0–5 cm and 5–20 cm) were taken from 15 random sampling points and mixed in each depth within each plot in the control treatment. In each plot of both *C. microphylla* and *A. halodendron* plantations, samples were taken from three shrub belts, and two sampling locations in each belt were distinguished: under the shrub canopy and in the midrow location (alley). At each location, a composite soil sample from two depths (0–5 cm and 5–20 cm) was collected from 15 sampling points. Soil samples were taken from 0 to 5-cm depth using a shovel, and from 5 to 20-cm depth using a 5-cm diameter soil auger. Soil was collected under the shrub canopies as close to the center of the shrub as possible.

Soil samples were air-dried and passed through a 2-mm sieve. Particle size analysis was done by pipette method (Gee and Bauder, 1986). Soil pH and electrical conductivity (EC) were measured in a soil–water suspension (1:1 and 1:5 soil–water ratio, respectively) (Multiline F/SET-3, Germany). Part of the air-dried and sieved samples was ground and passed through a 0.1-mm sieve for C and N analysis. Organic C was determined by dichromate oxidation of Walkley-Black (Nelson and Sommers 1982), and total N was measured by the Kjeldahal procedure (UDK140 Automatic Steam Distilling Unit, Automatic Titroline 96, Italy) (ISSCAS 1978).

Soil bulk density was determined using soil cores (stainless steel cylinders with a volume of 100 cm^3) taken at two depths (0–5 cm and 5–20 cm) at each sampling point (ISSCAS 1978). The same cores were kept intact and used for the determination of the maximum water-holding capacity of soil (Öhilinger 1996). The soil cores were closed as one end with a fine mesh and open at the other end, and saturated with water for 6 h. The surplus of water was sucked off using a sand bed; the remaining water in the soil represented the maximum water-holding capacity (WHC).

Statistical Analysis

Comparisons of soil parameters among the treatments were restricted by depth. Because there are two sampling locations (under the shrub canopy and in the mid-row location) for the two shrub treatments and only one for the control, analysis of variance and comparison of means were made among the five locations and did not adopt the analysis of split-plot design. One-way analysis of variance and least significant difference (LSD) were carried out using the SPSS package. LSD values were reported at the 5% level of significance. Soil organic C and N pools at the 0–20-cm depth were gained through calculating and summing those of the 0–5-cm and 5–20-cm depth. Paired *t*-test was performed to compare changes in organic C and N pools among before and after the establishment of shrub forest.

Results

Morphological Trait of *C. microphylla* and *A. halodendron*

The two shrub species differed considerably in their growing conditions and morphological traits. *C. microphylla*, a leguminous shrub, occurs as defined clumps of stems and is relatively tall. Investigation shows that the mean height, mean number of shoots, and mean crown diameter of *C. microphylla* individuals are 82 cm, 22, and 85 cm × 90 cm, respectively, exhibiting a luxuriant growth, whereas *A. halodendron*, a composite subshrub, is smaller and occurs as diffuse sets of stems, because of extensive sprouting from rhizomes and from decumbent or lateral stems that touch the ground. Investigation shows that 75% of 5-year-old main stems wither away, but they seed or revegetate through clonal propagation depending on well-developed perennating buds on stem bases near the soil surface.

Soil Physical Properties

Soil physical analyses reveal significant changes in soil texture, bulk density, and WHC after establishment and development of both *A. halodendron* and *C. microphylla* compared to the nonvegetated sandy soil (Table 2). At the 0–5-cm depth, bulk density is significantly higher in the nonvegetated sandy soil than under *A. halodendron* and *C. microphylla* canopies and in their alleys. Medium-coarse sand content was lowest and very fine sand and silt contents were highest at 0–5-cm depth in soils under the canopy of *A. halodendron*. WHC increased at 0–5-cm depth from an average of 13.8% in the control site to average of 19.5% under *A. halodendron* and *C. microphylla* canopies and 16% in their alleys. In the subsurface layer of 5–20-cm depth, the effects of shrub establishment on soil physical properties improvement were less than those of the 0–5-cm topsoil. No significant differences were observed for parameters measured in the 5–20-cm depth among treatments, with exception of a significant lower bulk density under *A. halodendron* canopy.

Soil Chemical Properties

Soil organic C concentration at the 0–5-cm depth was 5.1 and 4.5 times higher, respectively, under the canopy of *A. halodendron* and *C. microphylla* than in the nonvegetated shifting sand dune. In their alleys, this increase was 2.9 and 2.5 times, respectively. Total N accumulation was relatively slower than organic C, and it was 3 and 2.6 times higher, respectively, under the canopy of *A. halodendron* and *C. microphylla* than in the shifting sand dune. Soil organic C and total N concentrations were also significantly lower in the alley than under the corresponding canopy of shrubs, but they were significantly higher than in the shifting sand dune (Figure 2). There were no significant differences in C and N concentrations of soils at the 0–5-cm depth between the same locations of the two shrub species, and slightly higher concentrations were found in *A. halodendron* plantation. Soil organic C and total N levels declined sharply at the 5–20-cm depth in both *A. halodendron* and *C. microphylla* sites. Except for a higher C concentration at the 5–20-cm depth under the canopy of *A. halodendron*, no significant difference was found among other microsites. For total N, there was significant higher concentration under the canopy of *C. microphylla* than under the canopy of *A. halodendron*, in their alleys, and in the nonvegetated sand dune. The C:N ratio in nonvegetated dune was very narrow, ranging from 3.9 to 5.2 at the 0–5-cm depth and 5.2–5.5 at the 5–20-cm depth. After *A. halodendron* and *C. microphylla* were established, the C:N ratio at the 0–5-cm depth increased.

Soil pH was lower in *A. halodendron* and *C. microphylla* treatments compared to the shifting sand dune. The EC was significantly higher in *A. halodendron* and *C. microphylla* treatments than in the shifting sand dune at the 0–5-cm depth, except for in the alley of *C. microphylla*.

Carbon and Nitrogen Dynamics

Averages for soil organic C and total N storages at the 0–20-cm depth for 1997 and 2003 are given in Table 3. The comparison of shifting sand dune between the 1997 and 2003 samples indicated no significant differences in organic C and total N concentration, suggesting that soil C and N had reached equilibrium of very low level on shifting sand dune. However, there was a significant accumulation for soil organic C and total N after establishment of both *A. halodendron* and *C. microphylla*. The highest and

Table 2. Average values ± SD for the physical properties of the three treatments after 6 years of shrub establishment, n = 3

		Artemisia halodendron		*Caragana microphylla*				
Soil physical properties	Depth (cm)	Under canopy	Alley	Under canopy	Alley	Shifting sand dune	*F*-value	*P*
Soil particle size distribution								
Medium-coarse sand (1–0.1-mm)%	0–5	78.4 ± 1.7 d	88.5 ± 2.0 c	88.9 ± 0.9 c	92.5 ± 1.3 b	95.4 ± 0.5 a	64.39	<0.0001
	5–20	91.0 ± 2.4	93.5 ± 1.2	91.9 ± 1.9	93.9 ± 0.6	94.0 ± 0.8	2.74	0.089
Very fine sand (0.1–0.05-mm)%	0–5	13.3 ± 1.7 a	8.2 ± 1.6 b	6.7 ± 0.5 b	4.2 ± 0.8 c	2.3 ± 0.3 c	44.09	<0.0001
	5–20	4.3 ± 0.8	3.4 ± 1.3	4.3 ± 0.8	3.1 ± 0.2	2.6 ± 0.4	2.75	0.089
Silt (0.05–0.002-mm)%	0–5	5.9 ± 0.5 a	2.2 ± 0.9 b	2.7 ± 0.6 b	2.1 ± 1.0 b	1.5 ± 0.4 b	17.48	<0.0001
	5–20	3.1 ± 1.2	1.8 ± 0.3	2.3 ± 0.7	2.0 ± 0.2	1.6 ± 0.8	2.22	0.14
Clay (<0.002-mm)%	0–5	2.5 ± 0.6 a	1.1 ± 0.4 bc	1.7 ± 0.6 b	1.2 ± 0.2 bc	0.9 ± 0.2 c	8.87	0.003
	5–20	1.6 ± 0.4	1.3 ± 0.3	1.5 ± 0.6	1.1 ± 0.2	1.3 ± 0.5	0.94	0.481
Bulk density (g cm^{-3})	0–5	1.44 ± 0.05 c	1.57 ± 0.06 b	1.54 ± 0.02 b	1.57 ± 0.04 b	1.65 ± 0.03 a	24.73	<0.0001
	5–20	1.55 ± 0.04 b	1.62 ± 0.04 a	1.60 ± 0.03 a	1.59 ± 0.03 a	1.63 ± 0.02 a	10.11	<0.0001
Water-holding capacity(%)	0–5	19.7 ± 0.9 a	16.5 ± 0.8 b	19.2 ± 1.2 a	15.3 ± 0.9 bc	13.8 ± 1.3 c	18.15	<0.0001
	5–20	15.6 ± 0.7	14.4 ± 1.4	14.2 ± 1.3	13.6 ± 1.0	13.4 ± 0.4	2.2	0.143

Means in row with different letters (a, b, c, d) indicate significant differences at $p < 0.05$.

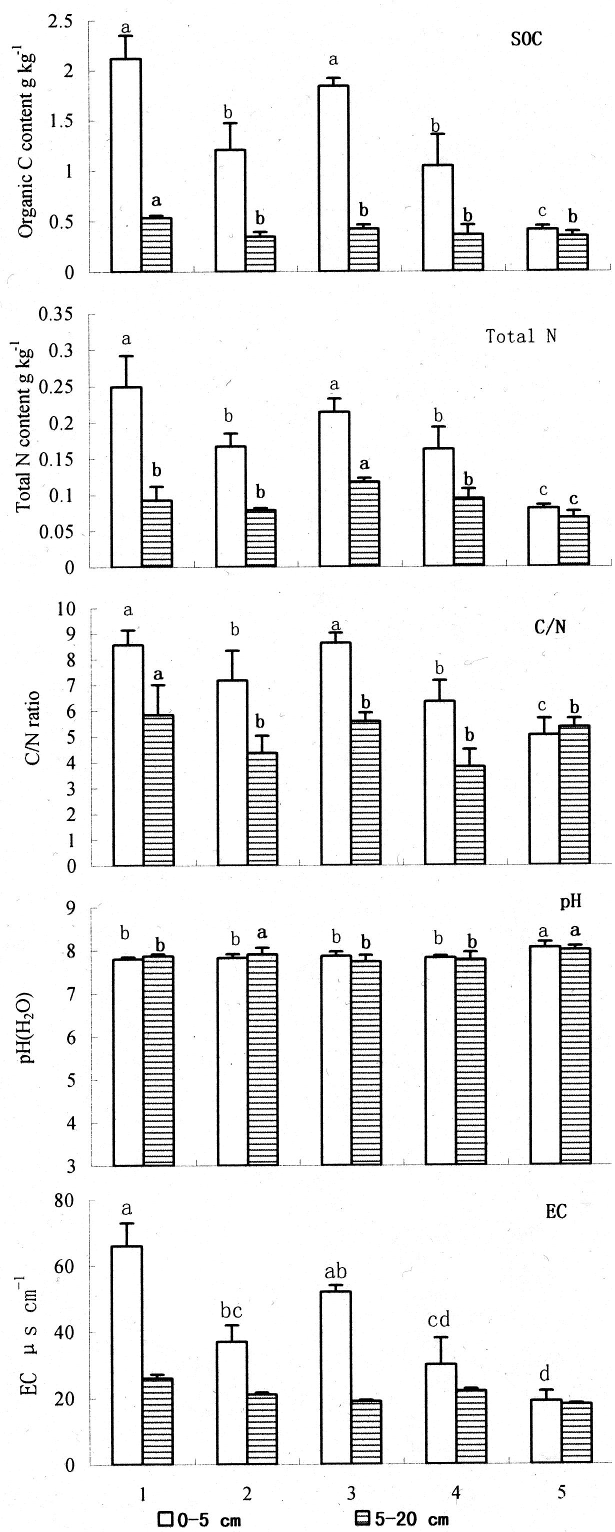

Figure 2. Average values for soil organic C (S0C) and total N concentrations, C:N ratios, pH, and electrical conductivity (EC) for the three sites. Bars show standard deviations. The different letters within a category are significantly different ($p < 0.05$). 1, under *A. halodendron* canopy; 2, in the alley of *A. halodendron*; 3, under *C. microphylla* canopy; 4, in the alley of *C. microphylla*; 5, on shifting sand dune.

lowest soil organic C accumulation was observed under the canopy of *A. halodendron* and in the alley of *C. microphylla*. In contrast, the highest and lowest total N accumulation was found under the canopy of *C. microphylla* and in the alley of *A. halodendron*.

Development of Plant Species

On the shifting sand dune, the total number of species and plant individuals per 1 m^2 was three and four (Table 4). *Agriophyllum squarrosum* is the dominant species. *Setaria viridis* and *Inula britanica* occur only in the leeward. The vegetative cover was less than 10%. With the establishment and development of *A. halodendron*, large numbers of *A. halodendron* seedlings occurred in the alleys through sprouting from rhizomes and from decumbent or lateral stems that touched the ground, and the sand surface was gradually stabilized. Some pioneer annual species including *Eragrostis poaeoides*, *Salsola collina*, *Bassia dasyphylla*, and *Setarria viridis* invaded in the alley from nearby fixed sandy land. The total number of species and plant individuals per 1 m^2 was 16 and 21, and the vegetative cover in the alley reached about 30%. After establishment and development of *C. microphylla*, the total number of species and plant individuals per 1 m^2 was 11 and 19. *Salsola collina* and *Bassia dasyphylla* were major species, but they occurred in the canopy of *C. microphylla*, and the vegetative cover in the alley was only about 12.

Discussion

Changes in Soil Characteristics After *A. halodendron* and *C. microphylla* Establishment

Overall, planting both *A. halodendron* and *C. microphylla* has a pronounced effect on sand stabilization, amelioration of surface soils (0–5-cm depth), and vegetation restoration. Relative to the nonvegetated sand dunes, soils in both *A. halodendron* and *C. microphylla* sites were more finely textured in the 0–5-cm soil surface and had higher organic C and total N contents, especially under the canopies of shrubs. The effects of soil amelioration can firstly be ascribed to the significant protective role of artificially established vegetation

Table 3. Average value of soil organic C and total N contents and their accretions before and after establishment of *A. halondedron and C. microphylla*, n = 3

Treatment		Soil organic C (g cm^{-2})	C accretion (g cm^{-2} 6 yr^{-1})	Total N (g cm^{-2})	N accretion (g cm^{-2} 6 yr^{-1})
Before establishment of shrub (1997)		1.30		0.24	
After establishment of shrub (2003)					
A. halondendron	Under canopy	2.76	1.47*	0.40	0.15*
	Alley	1.78	0.49*	0.32	0.08*
C. microphylla	Under canopy	2.43	1.13*	0.45	0.20*
	Alley	1.69	0.39*	0.35	0.11*
Shifting sand dune		1.22	−0.08	0.23	−0.01

*Significant difference between 1997 and 2003. ($p < 0.05$).

Table 4. The colonization of herbaceous species after *Artemisia halodendron* and *Caragana microphylla* establishment for 6 years

		Shifting sand dune			*Artemisia halodendron*			*Caragana microphylla*		
Species name	Life form	N	H (cm)	p %	N	H (cm)	p %	N	H (cm)	p %
Agriophyllum squarrosum	AF	2	32	40						
Setaria viridis	AG	0.13	18	30	2.7	12.4	33	1.8	18	66
Salsola collina	AF				0.4	4	26	2	8.8	47
Bassia dasyphylla	AF	0.07	5	6	5	9.4	80	5.5	12	73
Eragrostis poaeoides	AG				0.6	5	13	1.6	5	13
Artemisia halodendron	PS				7.2	12.6	100	0.2	8	13
Caragana microphylla	PS				0.13	60	6	0.3	25	20
Chloris virgata	AG				0.07	4	20	1	6	20
Corispermum macrocarpum	AF				0.13	15	6	0.07	16	6
Artemisia scoparia	AF				0.2	3.5	13			
Euphorbia humifusa	AF				3.1	1.5	90	2.2	1	26
Inula britanica	AF	0.13	13	26						
Erodium stephabianum	AF				0.07	8	6			
Ixeris chinensis	PF				0.3	3	13			
Lespedeza bicolor	PL				0.06	5	6			
Melissitus ruthenicus	PL				0.06	7	6			
Chenopodium glaucum	AF				0.13	7	13	1.5	14	13
Cynanchum thesioides	AF				0.9	6	53			
Portulaca oleracea	AF							3	3	6
Total number of individuals		3			21			19		
Total number of species		4			16			11		
Coverage %		8			30			12		

N, numbers of individuals per 1 m^2; H, height of species; p%, frequency; AF, annual forbs; AG, annual grass; PF, perennial forbs; PL, perennial legume; PS, perennial shrub.

against wind erosion. The protective effect of shrubs against wind erosion has been suggested by numerous studies (Dong and others 2000, Li and others 2002). In a previous study in this region, Li and others (2002) reported that establishment of *A. halodendron* on severely desertified sandy land affected significantly wind regimens by altering surface roughness; consequently, erosion was avoided in the vegetated surface. Also, the established *A. halodendron* and *C. microphylla* trapped wind-blown fine materials and dust that were rich in nutrients and were deposited in the surface soils under their canopies (Su and others 2004). As a result, the percentage of very fine sand and silt contents were significantly higher in *A. halodendron* and *C. microphylla* sites than on the shifting sand dunes, and under the canopies than in the alleys (Table 2). This is very important because the increased fine fractions can not only enhance the formation of soil crust that stabilize sand surface (Li and others 2002), but also improve soil physical properties such as WHC and bulk density, and accumulate organic C and nutrients. Then, with the development of shrubs, C fixation through photosynthesis and its transfer via leaf litter to the soil contributed to C accumulation. Nitrogen release by litter decomposition resulted in an increase in soil N content. In line with other research in arid and semiarid regions (Charley and West 1975, Schlesinger and others 1990, Wezel and others 2000, Su and Zhao 2003), our results show that higher levels of organic C and total N were found under the shrub canopies in comparison with their alleys, exhibiting the classic ''fertility of islands.'' This suggests that soil amelioration was initiated under the shrub canopy. While evaluating the changes in soil properties, it was found that the effect of shrub planting on soil amelioration was not appreciable in the 5–20-cm depth, except for organic C under *A. halodendron* canopy and for total N under *C. microphylla* canopy. This is probably due to relatively slow root turnover within a short plantation age. The reduction in the 0–5-cm soil pH was probably related to vegetative cover because the extensive secretion of organic acids and the release of CO_2 from litters, roots, and microorganisms can lead to decrease in pH (Tornquist and others 1999). The significant higher EC values in the 0–5-cm soils were observed after establishment of shrubs, especially under the shrub canopies, which reflects the accumulation and deposition of soluble salts in litters (Charley and West 1975). However, this effect of salt accumulation in litter could not induce soil salinization due to relative very low EC values, ranging between 18 and 66 $\mu s\ cm^{-1}$. In a previous study (Su and Zhao 2003), the highest EC value was only 102 $\mu s\ cm^{-1}$ under the canopy of 28-year-old *C. microphylla*.

The establishment of shrub plantations on shifting sand dunes initiates the soil amelioration process, but the degree of amelioration varies with the kind of species planted. Of the two shrub species in this present study, *A. halodendron* has been recognized to be more tolerant to a windy and sandy environment, and occurs as a pioneering species on mobile and semimobile sand lands. *A. halodendron* has a strong ability to produce offspring through clonal propagation, mainly depending on its well-developed perennating buds on stem bases near the soil surface (Li 1991). The establishment of *A. halodendron* and the subsequent spread of their offspring over a large area can stabilize the mobile sand surface rapidly. Also, the morphological traits with more dense foliage are favorable to aeolian sand and dust trapping (Wezel and others 2000). In comparison with *A. halodendron*, *C. microphylla* is relatively tall without a densely foliated crown. During the 6 years of growth, its crown has not spread over the midrow location. Therefore, the effects of *C. microphylla* on sand stabilization and soil amelioration are smaller in the initial establishment and development stage, relative to *A. halodendron*.

Restoration of Plant Species After *A. halodendron* and *C. microphylla* Establishment

The establishment of artificial shrubs facilitates the colonization and development of herbaceous plant species. Generally, extreme temperatures, high winds, limited moisture, and the infertile sandy soils make natural recovery of vegetation on mobile sand dunes very slow. However, the vegetation restoration in the presence of shrub plants was achieved by creating benign microclimatic conditions and improved soil environments (Holmgren and Scheffer 2001, Su and others 2004, Li and others 2002). In the present study, artificially established *A. halodendron* and *C. microphylla* act as seed accumulators by shielding wind-dispersed seeds of other species beneath their canopies, enhancing the possibility of the colonization of these species (Su and others 2003). In addition, even when plant recruitment does not occur in bare mobile sand, seeding establishment is often possible under the shade of existing ''nurse'' shrub plants, allowing the colonization and rejuvenation of some herbaceous species (Shumway 2000, Holmgren and Scheffer 2001). Furthermore, reduced soil erosion and improved soil properties associated with the development of shrubs created a nutrient-rich, water-retaining substrate, thus providing a better environment for germination of seeds and establishment of seedlings. At the same time, the development of herbaceous species also has an important role in soil development through the greater accumulation of organic litter to the soil, which can further improve the physical and chemical properties of soil in a significant way (Mun and Whitford 1998).

Because *A. halodendron* plantation has a better effect on sand stabilization and soil amelioration compared to *C. microphylla* plantation, the vegetation restoration is better in *A. halodendron* alleys than in *C. microphylla* alleys.

In Horqin sandy land, some artificial measures for stabilizing moving sand dunes and recovering vegetation were widely performed, such as building corn straw fencing, placing wheat straw checkerboard, and planting *A. halodendron* and *C. microphylla*. Among these measures, planting *A. halodendron* was considered to be the most proper way from an ecological viewpoint (Zhang and others 2004). Also, our results show that the performance of planting shrub species on shifting sand dunes has a profound effects on soil amelioration and vegetation restoration. From a cost–benefit point of view, planting shrubs is a cost-effective and environmentally sound measure, because the shrub seedlings can be taken from nearby fixed sandy land and it is easy for them to live and grow on sand dunes. Furthermore, as the sand surface was stabilized and vegetation was restored after planting shrubs, rehabilitated sandy land was able to be used for proper grazing.

However, to maintain the long-term stability of artificial vegetation in this semiarid region, the soil–water–plant relationships must be considered. Generally, the 0–300-cm sand layer in shifting sand dunes in the semiarid Horqin region sustains a relative stable water content of 3.0–4.0%, which could maintain the shrub growth in the early period after shrubs were established with the supplement of rainfall (Zhang 2003). However, with the development of artificial vegetation, the water consumption of shrubs by transpiration increased. In addition, the formation of soil crusts and the development of herbaceous plants promoted water evaporation from the shallow sand layer, which affected the soil infiltration. Zhang (2003) reported that 10 years after *A. halodendron* and *C. microphylla* establishment, soil water content at the 0–300-cm sand layer decreased from 3.4% to 3.0% and 2.1%, respectively. This indicates that the long-term stability of artificial vegetation could be affected by water condition.

Conclusions

The establishment and development of both *A. halodendron* and *C. microphylla* during the 6 years of the experiment resulted in significant changes in soil properties including increased silt and clay contents, WHC, organic C and total N, and decreased bulk density and pH at the 0–5-cm depth, as well as facilitating the colonization and development of other plant species. *A. halodendron* plantation may be a better practice than *C. microphylla* plantation from the soil amelioration and vegetation point of view. The results of this study imply that severe desertification in the semiarid Horqin Sandy Land can be reversed by reestablishing artificial vegetation on a large spatial scale. However, from the point of view of the long-term stability of artificial vegetation, soil–water–plant relationships and the regional water balance must be considered for establishing vegetation in the semiarid Horqin Sandy Land.

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