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A comparison of different measures for stabilizing moving sand dunes in the Horqin Sandy Land of Inner Mongolia, China

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Abstract

An experiment was implemented in 1997 in the Horqin Sandy Land of Inner Mongolia, China to evaluate the effects of different measures of stabilizing sand dune on vegetation restoration. The measures included (1) building corn straw fencing, (2) placing wheat straw checkerboard, and (3) planting *Artemisia halodendron* on the dunes. The preliminary results from the first 2 years (1998 and 1999) demonstrate that all the three measures could result in significant increases of plant species diversity, vegetation cover, above-ground biomass and below-ground biomass on the moving sand dunes relative to the naturally restored plot (without taking any measures). However, both placing wheat straw checkerboard and planting *Artemisia halodendron* performed best and thus are considered to be the most promising techniques for the restoration of vegetation on desertified sandy lands in this area.

Keywords: Desertification; Fixed sand dune; Moving sand dune; Sand dune stabilization; Vegetation restoration

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1. Introduction

The Horqin Sandy Land, located in the north-eastern part of China, has undergone severe desertification since the mid-1970s primarily due to improper management of natural resources. Overgrazing and over-collection of fuel-wood are thought to be the major factors leading to desertification in the Horqin (Zhu and Chen, 1994). Desertification usually experiences the following three stages: (1) conversion from the fixed sand dune to semi-fixed sand dunes due to removal of vegetation, (2) conversion from the semi-fixed dunes to semi-moving dunes, and (3) conversion from the semi-moving dunes to moving sand dunes (Li et al., 2003). Desertification and frequent sand storms in the spring strongly affect growth of the grassland vegetation and crops and usually give rise to large losses of their yields as a result of wind erosion and sand dune movement (Liu and Zhao, 1993; Zhu and Chen, 1994). To bring desertification under control and reduce its influence on grassland and farmlands, we should take some critical measures to restore vegetation on desertified sand dunes. Both removal of grazing via fencing and growing of indigenous plants adaptive to sand dunes are accepted as common measures in the Horqin region. However, development of some techniques, which are effective but inexpensive, is generally essential in the desertification controlling practice. For this reason, we implemented an experiment in 1997 to evaluate which are the most proper measures in restoring vegetation in the desertified sand land in the Horqin region. In this paper, we present some preliminary results of the experiment.

2. Methods

2.1. Site descriptions

The experiment was conducted near the Naiman Station of Desertification Research, Chinese Academy of Sciences. The Station is located in Naiman County, Inner Mongolia, China (42°55′ N, 120°42′ E, 385 m a.s.l.; Fig. 1), at the southern part of the Horqin Sandy Land. The study area is characterized by sand dunes alternating with gently undulating interdunal lowlands. The surface sand deposits are 20–120 m thick. The soils are sandy in texture, light yellow in color and loose in structure; so they are particularly susceptible to wind erosion. The temperate, semi-arid and continental climate at the experimental site is mainly governed by the south-east monsoon, with windy and dry winters and springs, and warm and comparatively wet summers followed by short and cool autumns (Li et al., 2002). Mean annual precipitation is 366 mm, of which over 85% falls in the summer months (May–September). Mean annual pan-evaporation is around 1935 mm, five times greater than the annual precipitation. Mean annual temperature is around 6.4°C, and the lowest and highest monthly mean temperatures are -13.1°C in January and 23.7°C in July, respectively. Mean annual wind velocity ranges from 3.2 to 4.1 $\mathrm{m\,s^{-1}}$, and prevailing winds are north-west in winter and spring and south-west to south in summer and autumn (Li et al., 2002). The threshold wind velocity for sand

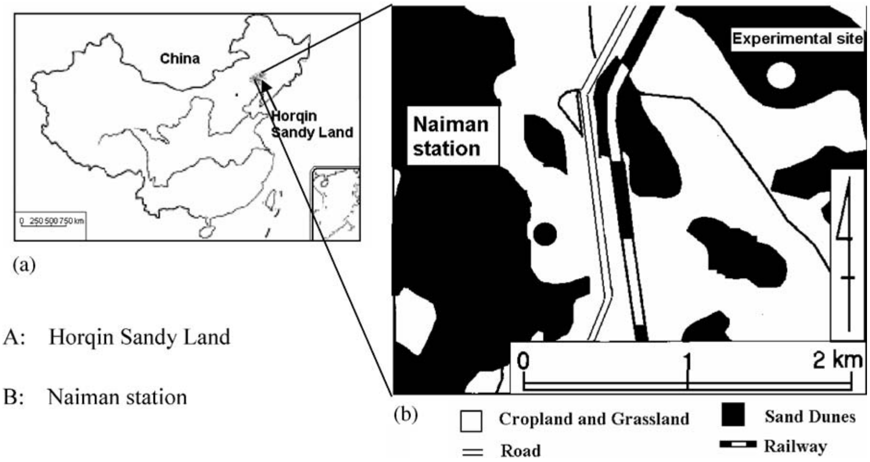


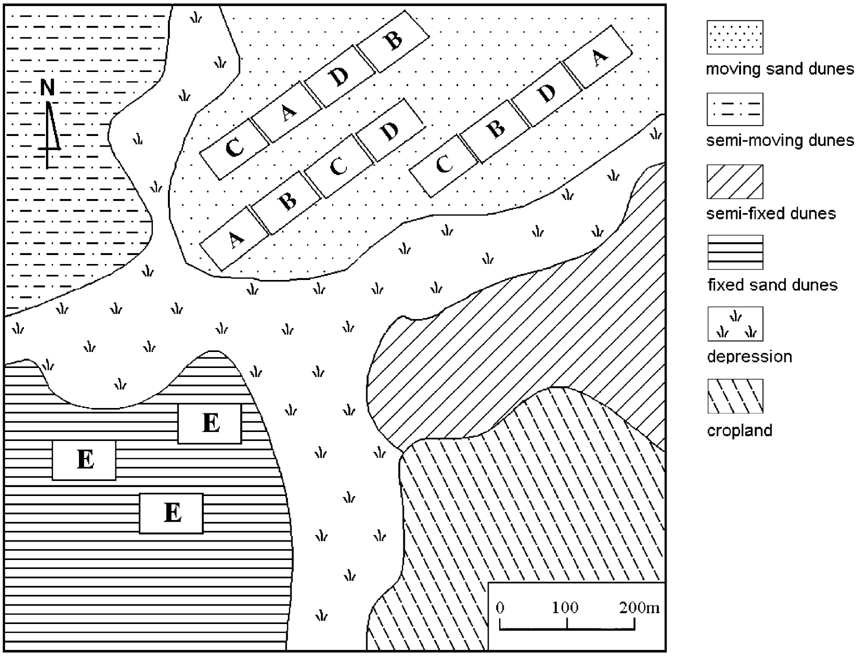
Fig. 1. Location of the experimental site.

movement (5 m s^{-1}) is exceeded during more than 200 days per year (mainly in spring and winter) (Zhu and Chen, 1994). Gales (wind velocity $\geqslant$17 m s^{-1}) occur 17–24 days per year. A wind erosion period often occurs from April to mid-June before the rainy season arrives (Li et al., 2003).

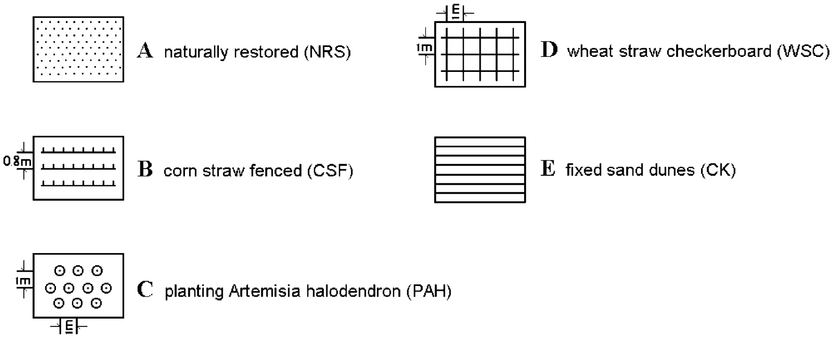
Original vegetation in the area was composed of *Stipa grandis*, *Leymus chinensis* and *Agropyron cristatum* communities with sparsely scattered woods (mainly *Ulmus pumila*). However, the original vegetation has been greatly altered over the past several decades, primarily due to long-term overgrazing and over-cutting. Vegetation in degraded sandy grassland is dominated by *Artemisia halodendron* communities. Main fuel wood species are *Ulums pumila* and *Prunus sbirica* (Li et al., 2003).

2.2. Experimental design

The experimental site was about 2 km away from the Naiman Station and was composed of moving sand dunes before the experiment. An area of c.100 ha (1000 × 1000 m) was fenced in the summer of 1997 with cement piles and barbed wires as the experiment field to compare the effectiveness of different measures of stabilizing sand dunes and restoring vegetation on the sand dunes. Those measures (treatments) included (A) natural restoration of sand dune vegetation without taking any artificial measures (NRS); (B) building corn straw fence belt (CSF, fence height was 10–15 cm above the ground surface, fence depth was 20 cm beneath the ground, belt spacing distance was 80 cm, belt orientation was perpendicular to the major wind direction); (C) planting of *Artemisia halodendron* seedlings (PAH, current year twigs of *A. halodendron* were taken in the rainy season from nearby fixed dunes and were transplanted at a depth of 15 cm in a row array with a row spacing of 1 m and a seedling spacing of 0.5 m); (D) placing of wheat straw checkerboard (WSC) (the checkerboard was composed of 1 m × 1 m squares made by the wheat straw, the



(a) Landscape of the experimental site



(b) Methods for each treatment

Fig. 2. Field array of the experimental treatment plot.

straw was put into sand about 15 cm and its mean height above the soil surface was about 10–15 cm); and (E) a plot near the above treatments was regarded as a control (CK) to monitor the vegetation dynamics after removal of grazing. The field array of the experimental treatments (plots) is shown in Fig. 2. Each treatment had three replicas each with a size of 2000 m^2 (Fig. 2). The size of the moving sand dunes averaged 5–8 m in height relative to the interdunal depression and about 400–600 m in length and 20–40 m in width (Fig. 2). *A. halodendron* was planted in the end of July in 1997 and the corn straw fence and the wheat straw checkerboard were built in autumn of 1997. The pre-experiment vegetation cover on the moving dunes was less than 5% and dominant species was *Agriophyllum squarrosum.* During the experiment, grazing was prohibited inside the experimental field.

Field investigation of vegetation and soil sampling were carried out in the growing seasons of 1998 and 1999. The climatic conditions during the experiment period are presented in Table 1. One permanent quadrat of 1 × 1 m and 10 random quadrats (1 × 1 m) were placed in the center of each plot for vegetation investigation and soil sampling. Soil moisture at a depth of 20 cm was measured in each permanent quadrat at 10-day intervals using TDR (Time Domain Reflectometry) (TRIME-FM, IMKO, GmbH, Ettlingen, Germany). Soil temperatures at four depths of 5, 10, 20 and 30 cm were monitored using thermocouples (HH82, Exphil Calibration Labs, Bohemia, NY, USA).

In each random quadrat, species composition, vegetation coverage, above- and below-ground biomass of each species were measured in early September. Above-ground biomass was determined with a harvest method. Soil cores were taken from three soil depths of 0–10, 10–20 and 20–30 cm at the quadrat and water-washed to determine below-ground biomass (Zhao et al., 1998). Biomass samples were dried at 80°C for 48 h and then weighed. We calculated community diversity index using the Simpson index (D) (Simpson, 1949) as

$$D = 1 - \sum_{i}^{s} (P_i)^2,$$

where P_i is the proportion of the ith species in the community containing s species.

To determine the differences in physical and chemical properties of surface soils on the moving and fixed sand dunes, two samples were taken from each plot at the 0–20 cm layer in September 1998. Soil samples were air-dried and sieved to pass a 1-mm screen. Soil particle size was determined by the pipet-method (Gee and Bauder, 1986). Total N was determined using an automatic micro-Kjeldahl analyzer

Table 1
The climatic conditions during the experiment period

Climatic variable	Multi-year mean (1961–1999)	1998	1999
Air temperature (°C)	6.4	8.1	7.7
Accumulated temperature of >10°C (°C)	3161.0	3140.0	3157.0
Rainfall (mm)	365.6	416.1	372.8
Rainfall between May and September (mm)	319.0	372.8	323.2
Day of rainfall >5 mm (d)	21.2	21.0	18.0
Frost-free period (d)	145.0	174.0	165.0
Sunshine hour (h)	2951.0	2957.0	2964.0
Wind velocity at 2 m ($\mathrm{m\,s^{-1}}$)	3.4	3.0	3.2
Annual pan-evaporation (mm)	1935.0	1726.0	1758.0

following the Bremner method (Black, 1965). Available N content was extracted with 2 M KCl solutions and determined using the automatic micro-Kjeldahl analyzer. Phosphorus content was determined according to the method recommended by Olsen and Dean (Black, 1965). Potassium content was extracted with ammonium acetate and measured by the atomic absorption spectroscopy (Black, 1965). Differences in vegetation characteristics among treatments were tested using one-way ANOVA and least significant differences (LSDs) with SPSS 11.0 data analysis software.

3. Results and discussion

3.1. Variations of soil physical and chemical properties

Considerable differences in the particle composition and nutrient contents of the surface soil layer (0–20 cm) between the moving sand dune and the fixed sand dune were observed (Fig. 3 and Table 2). For example, average contents of sand, silt and clay were respectively 95.6%, 2.5% and 1.9% at the moving sand dune while they were 74.2%, 21.5% and 4.3% on the fixed sand dune, respectively. Some other studies have also reported considerable differences in soil physical properties between moving and fixed sand dunes (Liu and Zhao, 1993; Li et al., 2003). Significant differences in total N and organic matter content were also found between the fixed and moving sand dunes, which were 5- and 6-fold higher in the fixed than the moving sand dunes. This was the same for available N and K contents, which were significantly higher (42% and 51%) in the fixed sand dune than in the moving sand dune. These differences can be explained by the different extent of surface wind erosion and aeolian dust deposition occurred in the moving and fixed sand dunes. Several other studies (Liu and Zhao, 1993; Cao et al., 2000; Li et al., 2003) also suggested that there were greater losses of soil erosion in the moving sand

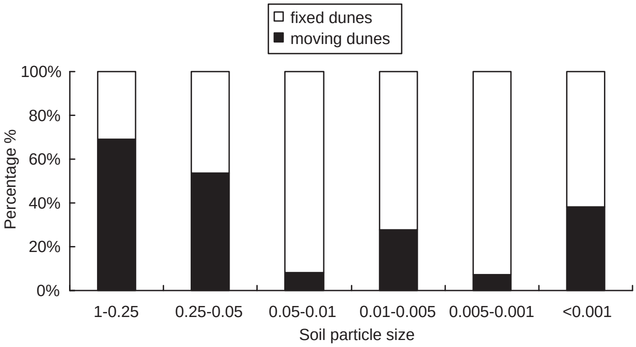


Fig. 3. Soil particle composition of moving and fixed dunes.

Table 2
Soil chemical properties (mean ± S.D.) for moving and fixed sand dunes ($n = 12$)

Sand dune type	Organic matter ($g\,kg^{-1}$)	pH	Total N ($g\,kg^{-1}$)	Total P ($g\,kg^{-1}$)	Total K ($g\,kg^{-1}$)	Available N ($mg\,kg^{-1}$)	Available P ($mg\,kg^{-1}$)	Available K ($mg\,kg^{-1}$)
Moving dune	0.8 ± 0.21	8.3 ± 0.5	0.06 ± 0.01	0.07 ± 0.02	23.1 ± 3.2	7 ± 3.2	4 ± 2.1	38 ± 8.1
Fixed dune	4.4 ± 0.82	8.4 ± 0.6	0.27 ± 0.06	0.11 ± 0.05	27.5 ± 5.5	10 ± 4.1	3 ± 3.4	74 ± 11.2

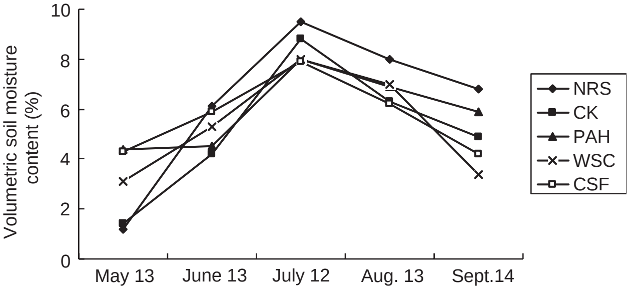


Fig. 4. Volumetric soil moisture content (mean ± S.D.) at each treatment in 1998.

dune than in the fixed sand dune because of a greater surface wind speed over the moving sand dune than over the fixed sand dune. Also these studies found higher rates of aeolian dust deposition and larger amount of litterfall on the fixed than the moving sand dunes. However, there were no significant differences in available P content and total K content between the fixed and moving sand dunes.

3.2. *Variations of soil moisture and temperature*

Fig. 4 shows a marked trend of seasonal changes in surface soil moisture from May 13 to September 14 in different treatment plots. Soil moisture in all the treatments showed a similar seasonal variation pattern (Fig. 4). It was consistently lower in spring (May 13), increased over time and peaked in July. After that time, it tended to decrease. In spring, soil moisture content was significantly lower in the NRS plot than in the CSF, PAH and WSC plots, whereas in autumn it became higher in NRS as compared with those in CSF, PAH and WSC plots. This was caused by higher soil evaporation in spring and lower evapotranspiration in summer and autumn at the NRS plots relative to other three plots.

Fig. 5 shows seasonal variation in soil temperatures in the different treatment plots. There were similar variation patterns for soil temperature among treatments, i.e. it increased from May to July and reached the maximum in July, and then tented to decrease with time. Despite somewhat differences in soil temperatures among treatments, but these differences were not statistically significant.

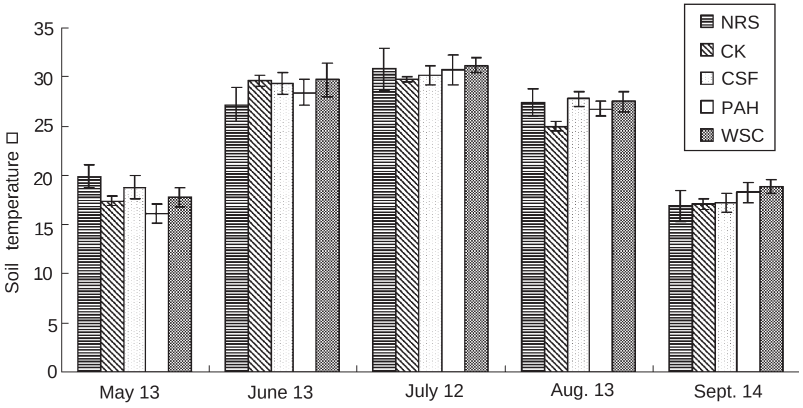


Fig. 5. Variation of soil temperature at the depth of 5 cm (mean ± S.D.) in each treatment plot in 1998.

Table 3
Species composition for each treatment in 1998 and 1999

Plant species	1998					1999				
	NRS	CK	CSF	PAH	WSC	NRS	CK	CSF	PAH	WSC
Agriophyllum squarrosum	+		+	+	+	+		+		
Aristida adscensionis			+				+	+	+	+
Artemisia halodendron				+				+	+	
Artemisia scoparia									+	+
Bassia dasyphylla		+	+		+		+	+	+	+
Chloris virgata								+		
Digitaria sanguinalis			+	+	+		+	+	+	+
Eragrostis pilosa									+	
Euphorbia humifusa		+			+		+		+	
Inula britanica		+					+			
Ixetis denticulata									+	
Lespedeza bicolor					+					+
Melilotus suaveolens			+							+
Populus pseudosimonii					+					+
Salsola collina							+	+		+
Setaria viridis		+	+	+	+	+	+	+	+	+
Xanthium sibiricum		+					+			
Number of species present at the plot	1	5	6	4	7	2	8	8	9	9

NRS, CK, CSF, PAH, and WSC represents, respectively, Natural restoration of sand dune vegetation, control, corn straw fence, planting of *A. halodendron* and wheat straw checkerboard. Symbol + denotes the presence of species.

3.3. Variations in species composition and diversity

Species composition was simple and most plant species were from the families of Chenopodiaceae, Compositae and Gramineae (Table 3, Ohkuro, 1997). A greater inter-annual variation in the number of plant species was noted in the PAH plot, but such an inter-annual variation was not very pronounced in the other plots. The WSC

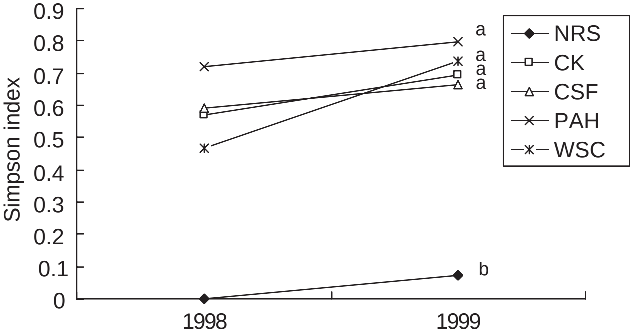


Fig. 6. Variation of the Simpson species diversity index in each treatment in 1998 and 1999. Different letters above the curve illustrate significant differences between the treatment at $p < 0.05$.

plot showed an increase of plant species in the first year of the experiment, probably because it trapped more plant seeds within the plots than living sand barrier (Li, 1992; Cao et al., 2000). The lower number of plant species in the NRS plot than in the other plots may be attributed to the following reasons. In spring, seeds of invaded plant species could not stay long enough to have a chance of germinating on the moving sand dune surface, whereas in plots with the adoption of artificial measures (e.g. erecting corn straw fence, wheat straw checkerboard and planting *A. halodendron*) seeds might be able to stay for a longer time to have an opportunity to germinate, thus resulting in a greater number of plant species in the treated plots than the NRS plots. Our data also showed significantly more number of plant species in the WSC and PAH plots than the NRS plots.

In the process of sand dune stabilization from the moving to fixed sand dunes, the order of invasion of plant species was firstly *Agriophyllum squarrosum*, then *Artemisia halodendron*, and followed by *Bassia dasyphylla*, *Setaria viridis* and *Digitaria sanguinalis* in the CSF and WSC plots. In the PAH plots, *Setaria viridis, Digitaria sanguinalis* and *Aristida adscensionis* firstly invaded, then *Salsola collina* and *Artemisia scoparia*. Liu (1985) reported that the order of restorative succession of plant community from moving to fixed sand dunes can be divided into four major phases, namely the phase dominated by *Agriophyllum quarrosum* phase, the pre-phase of *Artemisia halodendron*, the post-phase of *Artemisia halodendron* (dominant species was *Setaria viridis*), and the fixed dune phase (dominant species was *Artemisia scoparia*). Our results were consistent with the study of Liu (1985).

There were significant differences in plant species diversity among the different experimental treatments (Fig. 6). We found that 2 year's mean plant species diversity was highest in the PAH plot (0.797), followed by the CSF plot (0.626) and the WSC plot (0.602). An increasing trend of plant diversity was observed for all the treatments. For example, the plant diversity index increased by 58%, 21%, 12%, and 11% from 1998 to 1999 in the WSC, CK, CSF, and PAH plot, respectively.

Table 4
Above- and below-ground biomass (mean ± S.D.) of the different treatment plots in 1999 ($n = 11$)

Treatment	Above-ground biomass (g m^{-2})	Below-ground biomass at different depths (g m^{-2})			
		0–10 cm	11–20 cm	21–30 cm	0–30 cm
NRS	1.3 ± 2.2^{a}	0.6	0.7	0.6	1.9 ± 3.1^{a}
CSF	51.6 ± 3.6^{b}	28.7	6.7	3.3	38.7 ± 10.2^{b}
PAH	81.2 ± 4.8^{b}	13.3	5.9	0.5	19.8 ± 12.3^{b}
WSC	74.8 ± 7.2^{b}	23.8	14.0	3.6	41.4 ± 10.5^{b}
CK	69.5 ± 5.4^{b}	27.4	14.9	1.5	43.8 ± 9.8^{b}

Different superscript letters within a column indicate statistically different values at $p < 0.05$.

Table 5
Vegetative cover (mean ± S.D., %) in the different treatment plots

Treatment	1998	1999
NRS	0.5 ± 0.8^{a}	4.0 ± 2.6^{a}
CSF	10.0 ± 4.6^{ab}	15.7 ± 4.1^{ab}
PAH	19.0 ± 6.5^{b}	26.7 ± 7.6^{b}
WSC	12.0 ± 2.8^{ab}	21.6 ± 10.4^{b}
CK	44.0 ± 5.0^{c}	46.6 ± 7.6^{c}

Values followed by the same superscript letters indicate there is no significant difference among the treatment at $p < 0.05$.

3.4. Variations in vegetation cover, above- and below-ground biomass

The amount of plant biomass is an important indicator for evaluating the extent of vegetation restoration (Chang and Wu, 1997; Roels, 2001; Li, 2003). Relative to the NRS plot, above-ground biomass was significantly higher in other treatment plots (Table 4). Largest above-ground biomass was observed in the PAH plot, followed by the WSC, CK, CSF and NRS plots. However, the below-ground biomass exhibited a different pattern in that it was greatest in the CK plot, followed by the WSC, CSF, PAH and NSR plots. In all the treatments, except the NSR plot, below-ground biomass is mainly distributed in the surface soil layer of 0–20 cm.This is because most species in the plant communities were annuals with shallow root system. For the CK plot, root biomass in the 0–20 cm soil layer was 42.3 g m^{-2} that accounted for 97% of the below-ground biomass.

Vegetation cover is also an important indicator for evaluating the extent of vegetation restoration on degraded sandy grasslands (Liu and Zhao, 1993; Zhu and Chen, 1994; Li, 2003). Table 5 shows changes of vegetative cover in the different treatments. Vegetation cover was significantly higher in the PAH than NSR plots in 1998. Likewise, vegetation cover was much higher in the PAH and WSC plots than in the NSR plot in 1999. In addition, no significant differences were found in vegetation cover among the PAH and WSC plots either in 1998 or in 1999. This suggests that the WSC and PAH is the best measures to restore vegetation on degraded sandy land.

4. Conclusions

The results of the present study show that it is possible to restore vegetation on the severely degraded sandy lands by developing and adopting different artificial measures in the Horqin Sandy Land. Our experiment shows that the performance of different restorative measures may vary appreciably. Among the three measures examined (i.e. corn straw fencing, wheat straw checkerboard and planting *Artemisia halodendron*), planting of *A. halodendron* was considered to be the most proper way for stabilizing moving sand dunes from ecological viewpoints.

Acknowledgements

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