

A Comparison of Different Measures for Stabilizing Sand Dunes in the Horqin Sandy-Land, Inner Mongolia, China

Zhang Tonghui¹, Zhao Halin¹, Li Fengrui¹, Yasuhito Shirato², Toshiya Ohkuro² and Ichiro Taniyama²

¹ Cold and Arid Regions Environmental and Engineering Research Institute, CAS, China

² National Institute of Agro-Environmental Sciences, MAFF, Japan

Abstract: Some measures for preventing moving sand dunes in the Horqin Sandy Land were examined in this study. The results indicated that although all measures significantly increased plant diversity and biomass, but the wheat straw checkerboard and transplanting *Artemisia halodendrom* were the most effective. During transition from moving to fixed sand dunes, the successive order of vegetation was *Agriophyium quarrosum*, *Artemisia halodendrom*, *Setaria viridis* and *Artemisia scolaria*.

Key words: Horqin Sandy-land, desertification, vegetation succession, biomass, sand dunes.

In recent years, Horqin Sandy-Land has become one of the most severely desertified areas in China. Although a number of factors are responsible for the desertification in the region, the most important are overgrazing and deforestation for fuel-wood (Zhu and Chen, 1994). When the vegetation on fixed sand dunes is destroyed, stabilized dunes turn into semi-stabilized sand dunes, and then turn into semi-moving dunes and finally turn into moving sand dunes. During windy seasons, these moving sand dunes spread outward, and bury grasslands and croplands. At the same time, sandstorms occurring in spring have a negative influence on growth and development of crops and cause yield reduction in this region (Liu and Zhao, 1993). Over last several years, a series of experiments to stabilize moving sand dunes have been carried out. In this paper, we present some results of these experiments conducted during 1998 and 1999.

Materials and Methods

Study site description

The experiment was conducted at Naiman Station of Desertification Research, Inner Mongolia, China. The Station is located in the southern part of Horqin Sandy-land, (42°55"N, 120°42"E, 385 m above sea level). The region has a temperate and continental monsoonal climate. The climate is characterized by dry and windy spring, hot summer, cool and short autumn, and winter with no-rainfall. The annual mean temperature is 6.3°C. The annual mean sunshine is 2951 hours. The annual accumulated temperature >10°C is 3161°C. The annual frost-free period is between 140 and 151 days. The annual mean rainfall is 365 mm, which mostly occurs during three months from June through August. Based on the data for the last 40 years the annual mean rainy days are 37.2 for the rain more than 5 mm, 12.7 days for

above 10 mm, and 2.4 days for 50 mm and above. The annual mean evaporation of open-pan is 1935 mm.

The most part of this region is characterized by flat to gently rolling topography, with alternate moving sand dunes, sandy grasslands and croplands. The major soil type of the region is aeolian sandy soil with low organic matter and low productivity. The main vegetation is an *Artemisia halodendrom*-weed community.

Experiment design and methods

This experiment included five treatments: (1) control plot was on a moving sand dune without adoption of control measure; (2) fenced plot at moving sand dune with 10 to 15 cm high corn stalk at 80 cm spacing having north east to south west orientation across the wind directions; (3) *Artemisia halodendrom* plot was on the moving-sand dune; with one-year-old shoot of *A. halodendrom* transplanted in the rainy season; (4) checkerboard plot (1 x 1 m) with wheat straw on the moving-sand dune; and (5) the fixed sand dune plot was on a fixed sand dune near the moving-sand dune without adoption of any measure. Once the experiment began all treatment plots were enclosed to keep domestic livestock out. The size of the plot was 2000 m².

Methods

A 1 x 1 m permanent quadrat and five 1 x 1 m random quadrat were placed in the center of each plot. Soil moisture and temperature were recorded at 10-day interval using a TDR (TRIME-FM, IMKO) and thermocouple, respectively, in the permanent quadrat. The soil moisture was

measured at a depth of 0 to 20 cm and temperature was measured at 5, 10, 20 and 30 cm depths. Plant species and number of each species in the quadrats were recorded. The above-ground biomass was measured with a harvest method and under-ground biomass for each plot was measured in early September every year using samples obtained with a soil drill (500 cm³) (Zhao *et al.*, 1998) in the random quadrat. Three samples were taken to estimate root biomass in the random quadrat, with a total 15 samples for each treatment. To record plant biomass, samples were dried at 80°C for 48 hours and then weighed.

The diversified index is calculated according to the Simpson formula (Li Bo, 2000):

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

where,

D is the Simpson indices, P_i is the proportion of species i in the community and s is the total number of plant species in the community.

To determine differences in physico-chemical properties of surface soil in moving and stabilized sand dunes, two samples were taken at 0 to 20 cm depths in September 1998. Soil samples were air-dried and sieved to pass through a 2-mm screen and analyzed for soil particle size by pipet method, and for total N by micro-Kjeldahl automatic analyzer using the Bremner method (Black, 1965). Available N was extracted with 2M KCl solution and determined by steam distillation by micro-Kjeldahl automatic analyzer using the Bremner method (Black, 1965). Phosphorus was determined

according to the method of Olsen and Dean (Black, 1965). Potassium was extracted with ammonium acetate and measured by atomic absorption spectrophotometer (Black, 1965).

Results and Discussion

A comparison of particle composition and nutrient content between moving and stabilized sand dunes is given in Tables 1 and 2. During dune stabilization there

and organic matter content in the stabilized sand dunes were about 5-fold, 1-fold, 6-fold higher than those of moving sand dunes, respectively. No differences were found in the content of total K between the moving and stabilized sand dunes. The available N and K in the stabilized sand dunes were 42% and 51% higher than in the moving sand dunes, whereas the content of available P was almost comparable in the fixed and moving sand dunes. In all these cases

Table 1 Soil particle composition of moving and stabilized sand dunes

Particle size mm	Moving dunes	Stabilized dunes
Sand		
1.00-0.25	19.5	8.8
0.25-0.05	76.3	65.4
Loam		
0.050-0.010	1.8	20.2
0.010-0.005	0.5	1.3
0.005-0.001	0.1	1.4
Silt <0.01	1.0	2.6

was considerable variation in the particle size and nutrient content of the surface soil layer (0 to 20 cm). The contents of sand, loam and silt for the moving sand dunes were 95.8, 2.5 and 1.0%, respectively, while in stabilized sand dunes these were 74.2, 23.7 and 3.1%. The soil texture of the former belongs to sand, whereas the latter belongs to loam sand (van Keulen, 1986). Furthermore, the total N, total P

differences result from erosion and deposition of soil on the moving and stabilized sand dunes, which are caused by strong and dry wind in spring (Liu, 1993).

The changes in soil moisture (0-20 cm) from 13 May to 14 September are given in Fig. 1. For each plot, soil moisture was lower in spring, and thereafter gradually

Table 2 Chemical properties for moving and stabilized sand dunes

Soil	pH	Organic matter g kg ⁻¹	Total N g kg ⁻¹	Av. N mg kg ⁻¹	Total P g kg ⁻¹	Av. P mg kg ⁻¹	Total K g kg ⁻¹	Av. K mg kg ⁻¹
Moving dunes	8.3	0.8	0.06	7	0.07	4	23.1	38
Stabilized dunes	8.4	4.4	0.27	10	0.11	3	27.5	74

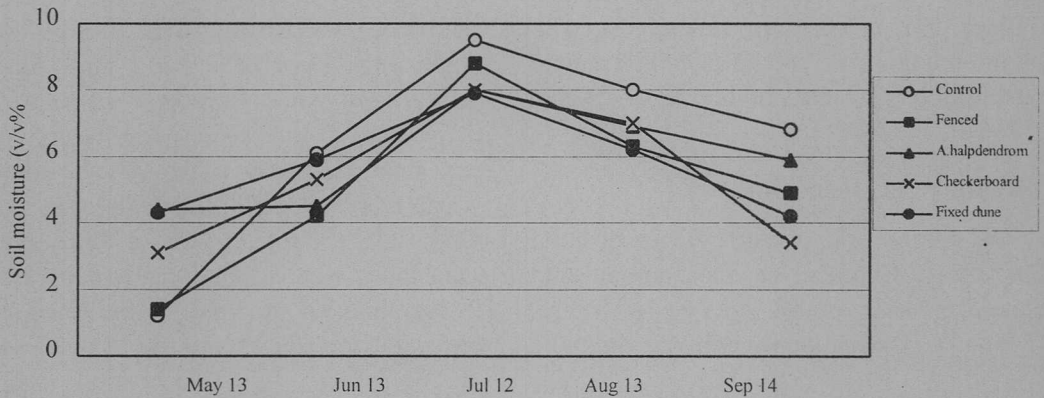


Fig. 1. Changes in soil moisture of each plot in 1998.

increased. In July the soil moisture content was maximum and there after it began to decline.

In spring, the soil moisture of control plots was significantly lower than that of the fenced, *A. halodendrom* and checkerboard plots. In autumn, however, the soil moisture in control plot was higher than the fenced, *A. halodendrom* and Checkerboard plots. A possible reason is that moving sand dunes had higher evaporation losses in spring because soil surface was not covered.

In checkerboard, *A. halodendrom* and fenced plots, the soil moisture was higher in spring and lower in autumn than in

the moving sand dune. The cause for this may be that stabilized sand dunes had relatively lower evaporation in spring and relatively higher transpiration in summer and autumn because of a high vegetation cover.

Changes in soil temperature in each plot are given in Table 3. The trend of changes in temperature seemed to be similar in all the treatments, namely lower in May and highest temperature was recorded in July, but there after it began to decline. The differences in soil temperature were not significant among treatments. But there was considerable variation in soil temperature within each plot (Table 3).

Table 3. The changes of soil temperature ($^{\circ}\text{C}$) at 5 cm depth in each plot

Treatment	May 13	Jun 13	Jul 12	Aug 13	Sep 14	Mean \pm S.E.
Control	19.9	27.2	30.8	27.4	16.9	24.6 \pm 4.6
Fixed dune	17.4	29.6	29.8	25.0	17.1	23.8 \pm 3.9
Fenced	18.8	29.4	30.2	27.8	17.2	24.7 \pm 4.3
<i>A. halodendrom</i>	16.1	28.4	30.7	26.8	18.3	24.1 \pm 4.4
Checkerboard	17.8	29.7	31.2	27.5	18.9	25.0 \pm 4.1

Table 4. The distribution of plant species in each plot during 1998 and 1999

Plant species	1998					1999				
	Control	Fixed dune	Fenced	<i>A. halodendrom</i>	Check-board	Control	Fixed dune	Fenced	<i>A. halodendrom</i>	Check-board
<i>Agriophyium quarrosum</i>	+	-	+	+	+	+	-	+	-	-
<i>Artemisia halodendrom</i>	-	-	-	+	-	-	-	+	+	-
<i>Bassia dasyphylla</i>	-	+	+	-	+	-	+	+	+	+
<i>Melilotus suaveolens</i>	-	-	+	-	-	-	-	-	-	+
<i>Setaria viridis</i>	-	+	+	+	+	+	+	+	+	+
<i>Lespedeza bicolor</i>	-	-	-	-	+	-	-	-	-	+
<i>Populus pseudo-simonii</i>	-	-	-	-	+	-	-	-	-	+
<i>Inula britanica</i>	-	+	-	-	-	-	+	-	-	-
<i>Xanthicem sibiricum</i>	-	+	-	-	-	-	+	-	-	-
<i>Digitaria sanguinalis</i>	-	-	+	+	+	-	+	+	+	+
<i>Aristida adscensionis</i>	-	-	+	-	-	-	+	+	+	+
<i>Eragrostis pilosa</i>	-	-	-	-	-	-	-	-	+	-
<i>Euphorbia humifusa</i>	-	+	-	-	+	-	+	-	+	-
<i>Salsola collina</i>	-	-	-	-	-	-	+	+	-	+
<i>Artemisia scolaria</i>	-	-	-	-	-	-	-	-	+	+
<i>Ixetis denticulata</i>	-	-	-	-	-	-	-	-	+	-
<i>Chloris virgata</i>	-	-	-	-	-	-	-	+	-	-
Numbers of plant	1	5	6	4	7	2	8	8	9	9

The distribution of species in each plot (Table 4) indicated that the composition

of plant species was rather simple. Most of these plant species belonged to the

Table 5. Changes in the Simpson index in each plot

Treatment	1998	1999	Mean
Control	0.000	0.074	0.037
Fixed dune	0.570	0.695	0.632
Fenced	0.590	0.663	0.626
<i>A. halodendrom</i>	0.718	0.797	0.757
Checkerboard	0.467	0.738	0.602

families *Chenopodiaceae*, *Compositae* and *Gramineae* (Ohkuro, 1997).

The number of plant species in control plot was less than in other plots. In spring, seeds of invading species cannot stay long enough to germinate on the moving sand dune surface. After adoption of some control measures, including erecting fence, setting up checkerboard and transplanting *A. halodendrom* on moving sand dune, can help retain seeds longer. So the number of plant species in the fenced, checkerboard and *A. halodendrom* plots was much more than that of control plot. This study also revealed that the number of species on dunes having checkerboard and *A. halodendrom* were more than those in the fenced and stabilized dunes.

Different plants have different growth and development characteristics, thus have different abilities to adapt to micro-environment. *Agriophyium quarrosum* occurred mainly on moving sand dunes, while *Bassia dasyphylla*, *Digitaria sanguinalis* and *Aristida adscensionis* were seen mainly in semi-stabilized sand dunes during the process of sand dune stabilization.

Plant diversity is one of the important indicators that reflect the community structure and function characteristics. Also plant diversity was an indicator for reflecting

the changes of vegetation during the process of sand dune stabilization. Data in Table 5 indicate significant differences of plant diversity between plots. According to an average over two years, plant diversity was the highest in the *A. halodendrom* (0.797), followed by checkerboard and the fenced dunes. The indices of plant diversity in each plot followed an increasing trend with time. In 1999, plant diversity increased by 58% at checkerboard, followed by stabilized dune, fenced and *A. halodendrom* plots as compared with 1998. After taking these measures, the microenvironment on moving sand dune improved which resulted in the seeds of invaded species to stay longer, and to regenerate later.

The extent of changes in biomass is an important aspect of evaluating land desertification. The biomass production was significantly more in treated plots in comparison to control plots (Table 6). The aboveground biomass was maximum (81.19 g m^{-2}) in dunes having *A. halodendrom*, followed by checkerboard, stabilized dune plot, fenced plot and control plot. But the trend was not the same for under-ground biomass. The underground biomass was the highest in stabilized dunes; followed by checkerboard, fenced and *A. halodendrom* plots. The root mass in all treatments, except control plot, was distributed largely in the

Table 6. Changes in vegetation biomass (g m^{-2}) in each plot in 1999

Treatment	Aboveground	Underground				Total biomass
		0-10 cm	11-20 cm	21-30 cm	0-30 cm	
Control	ns	ns	ns	ns	ns	
Fixed dune	69.5	27.4	14.9	1.5	43.8	113.3
Fenced	51.6	28.7	6.7	3.3	38.7	94.5
<i>A. halodendrom</i>	81.2	13.3	5.9	0.5	19.8	91.0
Checkerboard	74.8	23.8	14.0	3.6	41.4	116.4

surface layers as most of the plants were annual. For example, the root mass in 0 to 20 cm surface layer was 42.3 g m^{-2} in the stabilized dune plot, which accounted for 96.6% of its total underground biomass.

Conclusions

The restoration of vegetation in moving sand dunes can be achieved by adopting different measures in the Horqin Sandy-Land. During transition from fixed sand dunes to moving sand dunes, the ecological environment also changed. For example, structure of plant community became simple and coverage of vegetation became low. As a result, the top soil became susceptible to wind erosion. Therefore, it was difficult for invaded seeds to stay on the surface of moving sand dunes. Similarly, it is difficult for vegetation to restore naturally. This study also indicated that fenced, checkerboard and *A. halodendrom* plots provided a shelter for invaded seeds, which was beneficial to increase of plant species. In addition, these measures promoted the reverse process from moving to stabilized sand dunes.

During the course from moving to fixed sand dunes, the order of invaded plant species in the fenced and checkerboard plots was *Agriophyium quarrosum* followed by *Artemisia halodendrom* *Bassia dasyphylla*,

Setaria viridis, and *Digitaria sanguinalis*. While in the *A. halodendrom* plot this order was *Setaria viridis*, *Digitaria sanguinalis* and *Aristida adscensionis* first, and followed by *Salsola collina* and *Artemisia scolaria*. Liu Shene (1985) reported that the order of changes from moving sand dunes to stabilized sand dunes could be divided into four phases, namely the *Agriophyium quarrosum* phase, the pre-phase of *Artemisia halodendrom*, the post-phase of *Artemisia halodendrom* (dominant species was *Setaria viridis*) and the fixed dune phase (dominant species was *Artemisia scolaria*). This study also obtained similar results.

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