Wind-sandy Environment and the Effects of Vegetation on Wind Breaking and Dune Fixation in Horqin Sandy Land, China

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1. Introduction

Horqin Sandy Land is located in northeast China (42°41'-45°15'N, 118°35'-123°30'E). The wind-sand topography in Horqin Sandy Land can be described as two series--sand deposition and wind erosion. Wind is the natural force for the formation of wind-sandy environment, under wind-sandy environment, the wind erosion processes such as sand drifting, dust-storm, etc. occurred frequently because of the frequent high wind speed and plenty of easy-eroded sand soil. To prevent wind erosion and fix the sand surface, several strategies are tested. Establishing vegetation on the sand dune is the most efficient method in reducing the wind speed and fixing the dune. The objective of this paper is to compare the sand transport rates, sand flow structures and the aerodynamic properties for the vegetation (planted) with the bare sand dunes.

2. Methodology

2.1 Measurement of windborne sand flow

The measured surfaces are classified as Vegetation (planted) and Natural dunes, the latter are divided into fixed dune (vegetation coverage >=60%), semi-fixed dune (30%-59%), semi-shifting dune (10%-29%), and shifting dune (0%-9%).

Windborne sand flow is measured by using Segment Dust Sampler, in which a serial vessels is arranged in 10 levels to collect the sand transported by wind. And the sand transport rate (STR) can be described as:

$$STR=C(d/D)^{-1/2}\cdot(\rho\cdot V^3/g)$$

Where d and D are the diameters of the observed sand particles and the 0.25mm standard sand particles, respectively, C is a coefficient constant, ρ is the density of sand particles ($g\cdot cm^{-3}$), V is the wind speed of 2m height ($cm\cdot s^{-1}$), and g is the acceleration of gravity ($cm\cdot s^{-2}$).

2.2 Meteorological Methodology

Measured elements and their setup

Measured elements and their setup heights are shown in Table 1.

Table 1 Measured elements and their setup heights (cm) over vegetation (V) and shifting dune(SD)

Elements	V	SD	Elements	V	SD
Solar radiation	120	120	Air temperature	50,160	30,140
Net radiation	115	115	Wind direction	520	500
Reflect radiation	91	91	Wind velocity	50,90,160, 270,520	30,70,140, 250,500
Soil heat flux	-1	-1			

Instrumentation was installed in the top of sand dune where the surface is relatively plain. The average height of dunes is about 4m, fetch distance upwind of instrumentation is more than 200m. Meteorological instrumentation arrangement in field is shown in Figure 1.

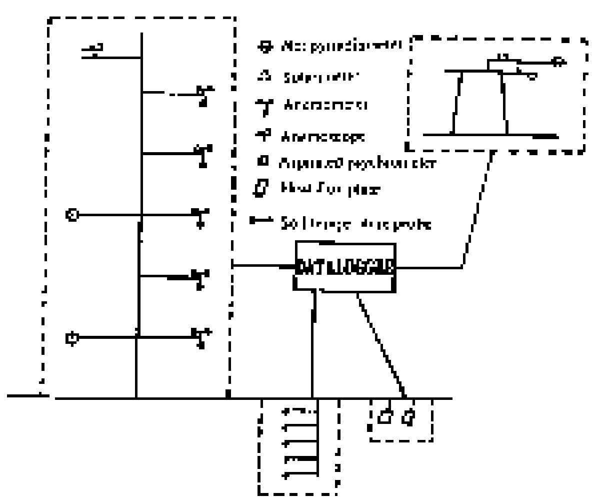

Fig. 1 Illustration of instruments arrangement in field

Analysis method

Under conditions of neutral atmospheric stability, the mean wind velocity profile over an open, rough surface can be described as (Rosenberg, *et al*., 1983, Y. Harazono, *et al*., 1992):

$$u(z)=\frac{u_*}{\kappa}\ln\left(\frac{z-d}{z_o}\right) \quad (1)$$

$$\ln(z-d)=a[u(z)]+b \quad (2)$$

Where **u(z)** is the wind velocity of height **z** ($cm\cdot s^{-1}$), $\mathbf{u_*}$ is the friction velocity ($cm\cdot s^{-1}$), $\mathbf{z_o}$ is the roughness height (cm), κ is the *von karman constant* (κ=0.4), and **d** is the zero plane displacement (cm).

By introducing wind velocities of different height into formula (2), and using Least Squares Regression Estimation analysis method, d, a, b can be calculated out, then:

$$u_*=\kappa/a,\ z_o=\exp(b) \quad (3)$$

According to *Monteith* (J. L. Monteith, 1975)

$$\tau=\rho u_*^{\ 2} \quad (4)$$

$$\tau=\rho u_1^{\ 2}C_D \quad (5)$$

Then $C_D=(u_*/u_1)^2$ (6)

Where τ is the momentum flux ($g\cdot cm^{-1}\cdot s^{-2}$), ρ is the air density ($g\cdot cm^{-3}$), u_1 is wind velocity of the highest Z($cm\cdot s^{-1}$), and C_D is the drag coefficient.

3. Wind-sandy Environment

Heavy wind and drought in spring are the main forces for the formation of wind-sandy environment in Horqin Sandy Land (Table 2). According to the Meteorological data in Naiman Banner (1970-1988), the windy day (10m wind speed >=17.2 $m\cdot s^{-1}$) is about 50-60% of a year in spring season, and only about 12% precipitation occurred during this period. In spring, ground surface is covered with less vegetation and the surface sand is loose and easily eroded because of freezing and thawing over winter. Therefore, strong activities of wind erosion and sand deposition frequently appear during spring season.

The movement of sand dune in Horqin Sandy Land trends to southeast because in spring the prevailing wind direction is northwest.

Table 2 Wind-sandy weather and rainfall distribution according to the data from meteorological observation station in Horqin Sandy Land

Observing station	Annual windy days	Windy days in spring and its ratio to annual		Dust-storm days in spring and its ratio to annual		Drifting-sand days in spring and its ratio to annual		Precipitation in spring and its ratio to annual	
Bayatuhushuo	78.0	31.0	39	2.9	85	3.5	59	41.3	9
Zhaluter	41.7	18.7	45	2.5	61	5.8	57	35.1	9
Kezhuozhong	31.8	20.8	65	5.9	97	10.0	81	52.2	12
Shebotu	21.0	14.1	67	5.8	70	7.3	59	37.8	11
Tongliao county	33.3	18.5	56	10.5	85	16.7	57	50.7	13
Kailu county	25.2	14.9	59	5.6	80	17.1	60	37.2	11
Tongliao city	28.5	17.5	61	6.4	65	16.8	47	47.7	12
Jinbaotun	46.0	26.6	58	8.1	84	10.2	68	66.8	14
Erlesun	18.5	11.2	61	6.6	80	8.4	62	50.4	13
Kezhuohou	31.9	20.8	65	3.2	76	9.1	75	57.0	13
Naiman	22.4	12.4	55	10.1	80	14.8	60	44.0	12
Kulun	36.4	19.9	55	7.3	78	22.3	63	50.4	11
Qinglongshan	52.0	29.0	56	3.9	80	5.8	71	59.3	13
Mean	35.9	19.6	57	6.1	79	11.4	63	48.5	12

4 Results and discussion

4.1 Windborne sand flow

Table 3 shows the percentage of sand content in 5 layers and the STR over the measured sites. The structure of windborne sand flow over vegetation has changed compared with those over the semi-fixed dune, semi-shifting dune, and shifting dune. For the shifting dune, the percentage of sand content decreased rapidly with height, sand transported by wind concentrated within 4 cm of the surface, for the fixed dune, the percentage of sand content increased with height, and most sand transport occurred above 8 cm, the amount of sand among different layers above 8cm has almost no differences. Also, the STRs changed a lot, they are two orders of magnitude lower for fixed dune and vegetation than for shifting dune. That means, the vegetation has reduced the STR, but its surface sand is not as steady as that of the fixed dune.

Tab. 3 Structure and sand transport rate (STR) of wind-sand flow over five surfaces and their corresponding mean wind speed (MWS)*.

Observation height (cm)	Fixed dune	Semi-fixed dune	Semi-shifting dune	Shifting dune	Vegetation
0-4	8.34	62.61	70.50	65.39	42.78
4-8	10.42	24.62	20.80	23.26	31.98
8-12	25.00	8.34	5.70	7.61	13.83
12-16	29.17	3.12	1.89	2.39	6.78
16-20	27.08	1.58	1.11	1.06	4.63
MWS(cm/s)	720	1080	980	760	1050
STR ($g.cm^{-1}.min^{-1}$)	0.008	2.834	3.173	2.516	0.035

* data followed Zili Cong *et al*., 1993, mean wind speed (MWS) was measured at the 2m heigh.

4.2 Meteorological factors

Albedo

Albedo decreased with the vegetation coverage. The mean albedo from sunrise through sunset is 19% at the vegetation, while it is 35% at the shifting dune, which indicates that the establishment of vegetation increased the utilization of solar radiation.

Wind velocity profile

Normalized wind profile above the vegetation is logarithmic all day long, but above the shifting dune, it is logarithmic only at night (Fig. 2). Thickness of surface boundary layer (estimated from the wind velocity profiles) is about 2.7 m in daytime over the vegetation, compared with the shifting dune, where it is less than 0.7 m. The wind velocity profile over the vegetation changed compared with over the shifting dune, which represents a smaller wind shear on the ground at the vegetation.

Friction velocity

Friction velocity u_* increased after the establishment of vegetation, which is about 0.21 cm and 0.69 cm for the shifting dune and the vegetation, respectively. The correlation between u_* and u_1 is closer at the vegetation than that at the shifting dune (Figure 3). And the ratio of u_*/u_1 is higher at the vegetation all day long (Figure 4). In case of u_1>2 m/s, u_*/u_1 is 5.7% and 4.6% for the vegetation and the shifting dune, respectively. In comparison with the interdune (where bushes well growing at an average height of 1.2m), where u_*/u_1 is 9% while u_1>2 m/s (Y. Harazono, *et al*, 1992).

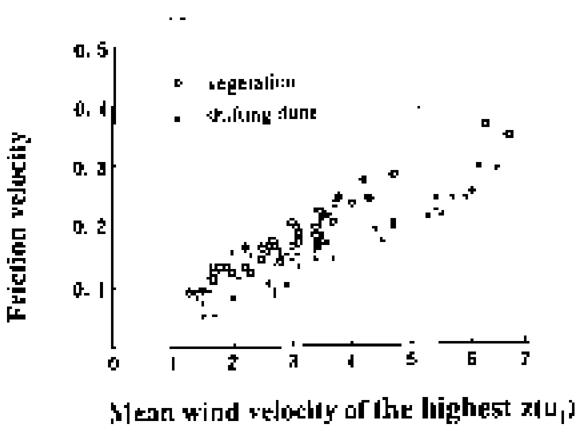

Fig. 3 Scatter plot of friction velocity (u_*) and mean wind velocity of the highest z (u_1)

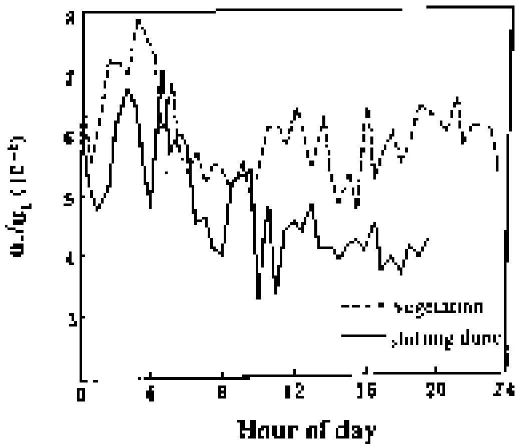

Fig. 4 Daily changes of the ratio u_*/u_1

Drag coefficient

Drag coefficient also reflected the efficiency of momentum absorbed by vertical factors. At the vegetation, the drag coefficient is 3.2×10^{-3}, which is 1.7 times of that at sand dune, but much less than that at grazing grassland (Miyata, *et al*, 1993).

5 Conclusion

After the establishment of vegetation, the sand transport rate reduced, that means there is less sand being moved because of the vegetation.

The meteorological observation indicates that the wind velocity profile over the vegetation has changed, which reduces wind shear at the ground surface, and the friction velocity becomes greater. Thus the drag coefficient is bigger compared with that for the shifting dune. The result is that the vegetation can efficiently absorb momentum, thus reduce the ground sand activities, and prevent sand movement.

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