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RESEARCH ARTICLE

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Regularities of wind-erosion of different land-use types in Yongding River sandy land, Beijing

Abstract The threshold wind velocity of a number of variables was studied in four different land-use types: farmland, forestland, wild grassland and a flood plain in the Yongding River sandy land in Beijing. The variables studied were transport of sand, underlying surface roughness, windblown sediment, wind-sand flow structure, soil mechanical composition and amount of wind erosion. The following conclusions were drawn: 1) The order of decreasing threshold of wind speed for sand displacement and surface roughness were forestland, wild grassland, farmland, sparse wild grassland and flood plain. 2) There were significant differences in sand flux among different ground covers. At a height of 0–20 cm, the height increased while the sediment discharge percent of sand flux decreased; there were significant differences in the sand flow formation under different land-use types. 3) The mechanical composition of sand particles consisted mainly of silver sand in the flood plain and sparse wild grassland, and of silver sand, particle silver sand and floury sand in other land-use types. 4) The amounts of wind erosion and sand sediment were different among different land-use types. Increased vegetation cover and change in farming techniques were suggested to prevent and control wind erosion of sand and soil.

Keywords Yongding river sandy land, land-use types, wind erosion

1 Introduction

Wind erosion of soil is one of most important processes among land degradation or desertification processes in arid, semi-arid and part of the sub-humid regions of China. The total land area experiencing wind erosion approaches 1.61×10^6 km^2, i.e. 16.7% of the national territory of China. This is recognized as a major threat to land utilization and sustainable social and economic development. Wind erosion of soil is the process of detachment and transport of soil particles and soil parent material by wind. Essentially, wind erosion is the interaction between wind and surface such as deflation and abrasion, a two-phase gas-solid airflow over surface material (Chen, 1991; Dong and Li, 1995; Wu, 2002). Much research in wind erosion involves wind erosion dynamics (Dong et al., 1995; Liu, 1995), blown sand flow structures (Huang et al., 2001, 2002) and factors influencing wind erosion (Liu et al., 1992; Dong and Chen, 1997; Wang and Wu, 1999; Chen et al., 2003). Wind erosion measurements, which are of great significance, are utilized in understanding the mechanism for preventing wind erosion of sand and soil.

The Yongding river sandy land is the largest of the five wind-sand resource regions in the Beijing area. Owing to long-term exploitation and utilization of the land, most of the region is badly affected by anthropogenic activities. Different types of land use result in remarkable differences in soil properties; factors affected by wind erosion show marked and distinctive regularities of wind erosion. For this paper, we investigated by field observations, a number of variables affected by wind erosion in the Yongding river lands of Beijing area under four different types of land use: farm field, forestland, wild grassland and flood plain. The

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variables studied are the threshold wind velocity for transport of sand, surface roughness, windblown sediment, wind-sand flow structure, soil mechanical composition and the amount of soil eroded by wind.

2 Study area

The study area is in Sangmafang Village, Daxing District, Beijing, located in the diluvium-alluvial plain of the Hai river system. The climate is that of a sub-humid warm temperate zone with an average annual temperature of 11.5°C and average annual rainfall of 568.9 mm, 65% of which falls in July and August. It is dry in spring and winter, often with winds of 8 m/s for 23.3 days every year, mainly from the northwest. The soil is mainly aeolian sand, which has a bad soil structure, low organic content and is vulnerable to wind erosion. There is little natural vegetation in the study area; it is mainly artificial vegetation in the form of agricultural crops and plantations.

3 Materials and methods

3.1 Study area and material

The study area is a typical flood plain sand strip in the Beijing Yongding river area. Most of the sand layers have a thickness of 2 m or more; soil properties are those of lean and arid soils, and the near-surface layer makeup is uniform. According to land-use classification criteria, there are four land-use types in the research area: farmland, forestland, grassland and flood plain. The farmland and forestland belong to first-grade agriculture lands, which are the major land-use types. Grassland and the flood plain form part of the unused land and are typical land-use types in the research area. According to the degree of cover, we divide wild grassland into two types: sparse wild grassland and wild grassland.

Farmland: The farm field land is flat with bits of corn (*Zea mays*) stubble and covers about 2.5% of the land area. Coarse sand soil accounts for more than 80% of the area. It easily becomes arid and is vulnerable to wind erosion. It is low in soil nutrients. A protection forest surrounds the area. It has the largest bare area in winter and spring, and presents a severely wind eroded landscape.

Forest land: It is wholly a *Populus semori* plantation, 240 m long from north to south and 125 m wide from east to west with a density of 4 m×4 m, an average height of 18 m, an average diameter at breast height of 32 cm, a canopy diameter of 3.5–4.25 m and a height below the first branch of 3 m. The main cover under the tree layer is blasted weed with an average coverage of 30%. The plantation is surrounded by open, barren farmlands.

Wild grassland: It is distributed over a very large area; the main grass species are *Digitaria sangurinalis* and *Chloric virgata*, and the average height is 5–10 cm. The distribution is uniform and the average degree of cover is about 26%–35%. The sand surface is hard and part of it has a sand crust.

Sparse wild grassland: The main grass species are *Setaria viridis*, *Digitaria sangurinalis* and *Chloric virgata*, which are distributed in clusters. The average height is 5–10 cm and coverage ranges between 5% and 12%. The sand surface is not entirely hard and the sand particle structure below the surface is loose; part of the sandy land appears to have different sized crevasses. The land-use type is severely affected by human activity.

Flood plain: It is distributed mainly in the channel of the Yongding river where it is flat and the sand surface denuded. Some grass species, such as *Setaria viridis, Digitaria sangurinalis*, *Chloric virgata* and *Agriophyllum squarrosum* are scattered around. The average height is 5 cm and coverage less than 10%. The agglutinating power between sand particles is low, and hence their fluidness is high.

3.2 Experimental data

The experimental data were obtained with a revised anemoscope during March to May in 2002–2004. Based on fixed and semi-fixed experimental observations, data were obtained simultaneously and recorded. The experimental observation index includes threshold wind velocity, velocity, amount of wind erosion, windblown sediment, vegetation cover, surface roughness and mechanical composition. The average value was taken from 50 sets of observations.

Observation of wind-sand flow: The amount of sand transported was obtained from a sand collector placed at a height of 0–20 cm; wind velocity was measured with the revised DEM-6 three-cup anemoscope. We managed two replications. Each sand collector group was divided into 10 height layers, each 2 cm apart. The width of the sand collector was 2 cm. The anemoscope was placed at a distance of 1.5–2 m from the sand collector in order to measure the wind velocity at a height of 2 m. The experimental data were recorded at the same time.

Surface roughness: Roughness can be calculated by using measured wind velocity at any height within the 2 m turbulent boundary layer; our measurements were made at a height of 0.5 m. The formula used for calculating roughness was $\lg Z_0 = (\lg u_2 - \lg u_1 \times u_2/u_1)/(1 - u_2/u_1)$, where Z_0 is the surface roughness, u_1 and u_2 are the wind velocities at two different heights at the same time. In this study, the two heights were 0.5 and 2.0 m.

Sand particle size analysis: The sandy particle samples taken at a depth of 0–10 cm were analyzed with a sieve in the lab.

Measurement of amount of wind erosion: In the experiment we used a scaled iron bar for measurements. Part of the bar was buried vertically in the sandy land. We subtracted the observed level from the level at which the bar was originally buried.

4 Results and analysis

4.1 Threshold wind velocity

As shown in Table 1, when soil water content at the depth of 0–10 cm is unmarked on the whole and the incipient motion of the same size of sand particale, the surface of different land use types causes obvious different threshold wind velocities. The order of the threshold wind velocity is forestland > wild grassland > field land > sparse wild grassland > flood plain. The reason is that wild grassland has some vegetation cover, which increased the frictional resistance to airstreams and reduced part of the airstreams' energy. Because the sand particles must gain enough energy to move, the threshold wind velocity of wild grassland was the largest. The reasons for a higher threshold wind velocity of the farmland were the bits of corn (*Zeal mays*) stubble left on the farmland, the protective forest belt around the field and the higher sand particle cohesion in the farm field than elsewhere. The flood plain surface was bare and largely devoid of vegetation cover. As the sand surface was structurally composed of loose particles, it needed only the smallest threshold wind velocity for its denudation. The forestland surface layer was protected by the forest, which increased the near-surface layer threshold wind velocity. When the measured wind velocity was 7.21 m/s in the experiment, the sand particle incipient motion did not occur. Our research results indicated that the threshold wind velocity of forestland was the highest. According to a relevant document (Chen, 2003), bare lands in the Yongding River are found mainly in winter in the flood plains, farm fields and wild grasslands of low coverage. These bare lands are prone to soil erosion under the influence of strong winds during winter. This result is in tune with our research conclusion.

Table 1 Threshold wind velocity of different land-use types

Land-use type	Threshold wind velocity /$(\text{m}\cdot\text{s}^{-1})$	Sand particle size /mm	0–10 cm water content /%	Incipient motion
Flood plain	4.39	0.10–0.25	1.00	Rolling
Sparse wild grassland	4.91	0.10–0.25	1.10	Rolling
Farmland	5.1	0.10–0.25	1.21	Rolling
Wild grassland	6.73	0.10–0.25	1.26	Rolling
Forestland	7.21	0.10–0.25	1.43	No rolling

4.2 Roughness

Roughness Z_0 is defined as the height above the surface at which the average wind velocity assumes zero value. Roughness is an important variable in many surface studies and has been used effectively to assess the aerodynamic properties of different land-use type surfaces in desertification control. It can be seen from Table 2 that different land-use types result in a great deal of variation in roughness. The surface roughness of the five land-use types, i.e., forestland, wild grassland, farmland, sparse wild grassland and flood plain were calculated as 1.231, 4.456×10^{-2}, 1.463×10^{-2}, 2.282×10^{-3} and 2.692×10^{-5} cm respectively. The five different ground layers exerted variable influence in decreasing wind velocity. The surface of the flood plain was bare without any protective vegetation cover that might have had some effect on wind velocity at ground level. As it is, the present condition easily causes wind erosion. Forest vegetation can decrease aeolian velocity of the near surface layer and increase roughness of forestland, which in turn can control wind erosion.

Table 2 Roughness in different land-use types

Land-use type	Velocity/$(\text{m}\cdot\text{s}^{-1})$	Velocity /$(\text{m}\cdot\text{s}^{-1})$	Roughness Z_0 /cm
Flood plain	5.21	5.57	0.000,026,92
Sparse wild grassland	5.37	6.06	0.002,282
Farmland	3.22	3.86	0.014,63
Wild grassland	2.14	2.75	0.044,56
Forestland	2.59	5.46	1.231

4.3 Windblown sediment

It can be seen from Table 3 that different near surface layers of land-use types resulted in different amounts of sand being transported at a height of 0–20 cm at the same wind speed. At a wind speed of 7.45–7.5 m/s, at a 0–20 cm high airflow layer, the amount of windblown sediment was 3.32 g/(min·cm^2) above the flood plain and 2.51 g/(min·cm^2) above the sparse wild grassland with 15% cover. Our quantitative research results showed that different land-use types resulted in distinctly different amounts of windblown sediment. The bare sand surface layer with poor cohesion of sand particles on the flood plain, some vegetation cover, and a stable underlying surface (for example, grassland), can have great influence on the amount of windblown sediment. At a wind speed of 6.6–6.9 m/s and at a 0–20 cm airflow layer, the windblown sediment was 2.10 g/(min·cm^2) above the farmland, 1.65 g/(min·cm^2) above the 30% covered wild grassland and 0.73 g/(min·cm^2) above the forestland. This variation among the amounts of windblown sediment was mainly induced by the type of land-use and thus land-use proved to be a pronounced characteristic of soil wind erosion.

Table 3 Wind speed and weight of sand transported in 0–20 cm in different land-use types

Land-use type	Wind velocity /($m \cdot s^{-1}$)	Weight of transporting sands /($g \cdot min^{-1} \cdot cm^{-2}$)
Flood plain	7.45	3.32
Sparse wild grassland	7.5	2.51
Farmland	6.6	2.10
Wild grassland	6.32	1.65
Forest land	6.9	0.73

4.4 Wind sand flow distribution

As can be seen from Table 4, sand transport rates decreased as the height of the layer increased. Relative sand transport rates also varied with different ground covers, the velocity remaining the same. The major wind sand flows occurred at a height of 0–6 cm near the ground. When the wind velocity was the same, the wind sand flow distributions near surface were unequal over different land-use types. Of the gross sediment discharge, the discharge at 0–2 cm accounts for 43.09% over the flood plain, 43.10% on the sparse wild grassland, 34.46% over farmland, 37.40% over wild grassland and 29.8% over forestland. This indicates that wind sand flow is the process of sand transportation over different ground covers. Different ground characteristics lead to different relative contents of wind sand within the height of 0–20 cm. Consequently, if we change the wind sand flow structure, which can in turn reduce the intensity of sand movement, then we can obtain better control of soil erosion.

Table 4 Wind-sand relative content in different ground covers to 0–20 cm in different land-use types

Height /cm	The rate of sand transported in different land use types/%				
	Flood plain	Farmland	Forestland	Sparse wild grassland	Wild grassland
0–2	43.09	34.46	29.8	43.10	37.40
2–4	24.41	19.38	21.3	23.40	20.10
4–6	11.97	12.24	14	12.60	15.50
6–8	7.92	9.22	10	7.80	8.34
8–10	4.00	7.14	6	4.90	6.10
10–12	2.86	6.14	5	3.30	4.50
12–14	2.21	4.32	4.4	2.00	3.28
14–16	1.44	4.08	3.4	1.40	2.95
16–18	1.20	2.00	3.3	0.90	1.23
18–20	0.90	1.02	3.2	0.60	0.60

4.5 Mechanical composition

It can be seen from Table 5 that particles of size 0.05–0.5 mm formed the greater part of the mechanical composition of sand particles and make up from 68.68%–96.99% of the total amount in place below 1.25 mm above the surface. This indicated that soil particle size tended to be a wind erosion factor. The proportion of sand particles of size 0.1–0.25 mm on the flood plain increased and the soil of the surface layer had a high coarse component caused by wind erosion. The content of particles of size 0.05–0.1 mm remarkably decreased on both types of grassland and surface layer soil tended to be fine granules. Particle size of the farmland was very well proportioned and did not lead to a predominantly coarse texture due to vegetation cover. As a result, different land-use types resulted in various degrees of coarse components.

Table 5 Mechanical compositions of sand particles in different land-use types

Land-use type	Distribution of sand particle size/%					
	<0.05 mm	0.1–0.05 mm	0.25–0.1 mm	0.5–0.25 mm	1.25–0.5 mm	>1.25 mm
Flood plain	3.45	12.97	80.2	3.66	0.03	0
Sparse wild grassland	0.29	21.37	74.85	0.77	0.03	0.03
Farmland	14.64	17.11	44.29	20.34	1.94	1.68
Wild grassland	17.76	38	37.34	2.86	0.91	0.47
Forest land	29.54	32.05	30.89	5.74	1.12	0.67

4.6 Amount of wind erosion

Based on our fixed experiment observations, it was concluded that the amount of wind erosion was 18.5 mm from the flood plain, 11.9 mm from the 15%-covered wild grassland, 3.4 mm from the farmland, 2.1 mm from the 30%-covered wild grassland and the sediment of sand deposited on forestland was 2.8 mm. The results indicate that poor vegetation cover is one of the primary causes of serious soil erosion by wind. The dynamic change in total vegetation is inversely related to the amount of soil erosion.

Table 6 Wind erosion amount in different land-use types

Items	Different land-use types				
	Flood plain	Sparse wild grassland	Farmland	Wild grassland	Forest land
Sediment /mm	18.5	11.9	3.4	2.1	—
Erosion /mm	—	—	—	—	2.8

5 Conclusions

1) The order of wind speed threshold for the displacement of sand as well as for the roughness index was forestland, wild grassland, farmland, sparse wild grassland, and flood plain.

2) Different levels of wind speeds caused significant differences in sand flux among various types of ground cover. At a height of 0–20 cm, the height increased while the sediment discharge percent of sand flux decreased. There were significant differences in the sand flow formation over different land use types. The mechanical composition of sand particles consisted mainly of silver sand in the flood plain and sparse wild grassland, whereas the soil of other land use types was made of silver sand, particle silver sand and floury sand.

3）The amounts of wind erosion and sand sediment were different among different land-use types during our sampling period. The amount of soil erosion by wind was 18.5 mm in the flood plain, 11.9 mm in the 15%-covered wild grassland, 3.4 mm in the farmland, 2.1 mm in the 30%-covered wild grassland, and sedimentary deposition of sand was 2.8 mm in the forestland.

Some advice was advanced: 1) improve vegetation cover to control and prevent wind erosion of the soil, 2) change farming techniques.

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