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Comparison of Erodibility on Four Types Biological Crusts in Gurbantunggut Desert from Wind Tunnel Experiments

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Abstract: Experiments of wind erodibility on four types biological crusts (moss crust, lichen crust, algal crust and algal-lichen crust) obtained from Gurbantunggut Desert were conducted in wind tunnel. The results showed that biological crusts and its destructive percentage had considerable influences on surface erosion. There was no sand grain movement and ground surface erosion occurred on the four types biological crusts even wind speeds reached to 25 m s^{-1} while the relative wind erosion rate (WER) on bare sand reached 1214.82 g m^{-2} sec^{-1}. Under the same destructive percentage, the threshold wind velocity (TWV) over the moss crusts was the highest, followed by lichen crusts, algal crust and algal-lichen crusts was the lowest. The WERs increased exponentially with increasing of destruction percentage of crust cover and wind velocity.

Keywords: Biological crusts, Dune surface stability; Gurbantunggut Desert, Threshold wind velocity, Wind erosion rate

1. Introduction

Biological soil crust, formed by different combinations of mosses, lichens, liverworts, algae, fungi, cyanobacteria and bacteria, is a common and widespread phenomenon in desert areas all over the world (West, 1990; Evans and Johansen, 1999). Despite its unassuming appearance, biological soil crust plays a significant role in the desert ecosystem and has received increasing attention in recent years for their outstanding contribution in control land desertification in the world (e.g. Anderson *et al*., 1982; Li *et al*., 2001). Most studies agreed that destruction of biological crusts can significantly decrease the threshold wind velocities for sand moving, increase soil erosion (e.g. Mackenzie and Pearson, 1979; Belnap and Gillette, 1997; Williiams *et al*., 1999) and make the organic matter losses (West, 1990). More than 80% area of Gurbantunggut Desert, the second largest desert in China, is covered by biological crusts and the sand surface as a whole is relative stable, while mobile area confined to the crest and the upper part of dune slopes. However, the frequency of wind erosion events in the desert tends to increase with frequent human activities in resent years. A detailed study on soil erodibility of different crust type and their disturbance is required. The aims of the research reported here were to determine typical TWVs and WERs on four biological soil crusts at different destruction percentage by wind tunnel experiments.

2. Study area and methods

Gurbantunggut Desert, with an area of 4.88×10^4 km^2, is located in the hinterland of the Junggar Basin in northwest China (44˚11′-46˚20′ N, 84˚31′-90˚00′ E) as shown in **Figure 1**. Main morphological dune type is longitudinal dune with a few hundred meters to more than 10 km in length, 10-50 m in height and orientated north-south. Interdune and middle to lower part of slope are stabilized but the crest often has 10-40 m wide mobile zone. Interdune and middle to lower slope are covered by *Ephedra distachya* communities and beneath them are ephemeral plants and biological crusts. Biological crusts in the study area contain moss crusts, lichen crust, algae crusts and algal-lichen crusts (Zhang *et al*., 2004). These four types biological crusts and pure sand samples were collected from different position on a typical longitudinal dune surface in the southern part of Gurbantunggut Desert as shown in Figure 1. Each type crusts contain 10 samples. In order to keep completeness of crust samples in fields, the soil surface we aimed at was uniformly sprayed with water prior to sampling. Till water seeped down to 15 cm or so, we

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dug a groove by its side and drove a 30cm×20cm×10cm (length×width×height) dustpan-like iron box into the soil. Then used a sharp knife to cut it apart and take out the undisturbed soil and closed the side door as shown in Figure 1. To avoid the influence of soil moisture on the experiment, each sample was air-dried under the natural condition for three weeks and kept their moisture content to no more than 0.6%.

The tests were carried out in the straight-line, blow-type wind tunnel at the Laboratory of Blown Sand Physics and Desert Environment, Cold and Arid Regions of Environmental and Engineering Research Institute, Chinese Academy of Sciences. The wind tunnel has a total length of 37.8 m. Its working section is 16.2 m long, 1.0 m wide and 0.6 m high. The experiment point was located at 12 m downwind from the entrance of the working section. Wind velocity can be changed continuously from 2-40 m s^{-1}. Detailed descriptions of this facility and related instrumentation were given by Dong *et al*. (2001). For the experiments, the samples were placed in the lift trough at the end part of working section and the crust surface was kept even with the floor of the wind tunnel. The impact area of each sample was 30 cm×20 cm. In designing the experiment, six levels of destruction rates of biological crusts cover (10%, 20%, 30%, 50%, 80% and 100%) were conducted, which are expressed by the percentage of damaged area out of the whole impact area. To obtain TWVs for the disturbed crusts and loose sand surface, wind speed in the tunnel was gradually increased until consistent forward sand particle movement was observable across the soil surface. The corresponding wind velocity, which was measured by standard Pitot tube at 20 cm above the floor, was defined as the threshold velocity in wind tunnel. Since >25 m s^{-1} wind velocities are rare in the desert, the tests for soil erodibility were conducted at six levels of wind speed (6, 10, 14, 18, 22 and 25 m s^{-1}). Each experiment was run for 10 min. The quantity of soil erosion at different conditions was calculated from changes in weight of samples (with a 0.01 electronic balance) before and after each experiment. The rate of erosion (WER) was calculated in g m^{-2} sec^{-1} by using quantity of wind erosion materials per unite area in per unite time.

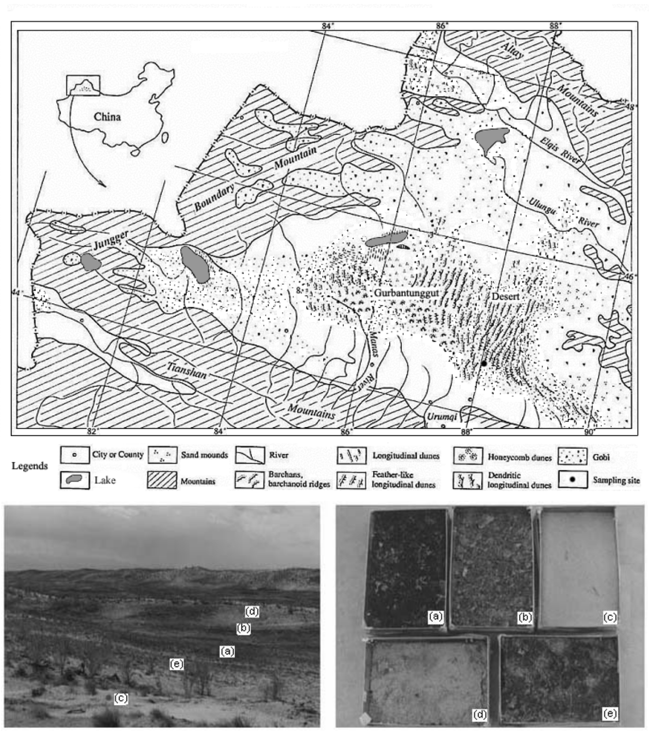

Fig. 1. The location of sampling site in Gurbantunggut Desert and four type biological crusts and loose sand samples. (a): moss crusts; (b): lichen crusts; (c): bare sand sample; (d): algal crusts; (e): algal-lichen crusts

3. Results and Discussion

3.1. Impact of biological crusts on threshold wind velocity (TWV)

The experiment demonstrated that no sand grain movement was observed on all undisturbed crusts surface at 25 m s^{-1} wind velocities, while we could identify the initiation of grain movement on loose sand surface only at wind velocity of 8.42 m s^{-1}. Under the same destructive percentage, the TWV over moss crusts was the highest, followed by lichen, algal and algal-lichen crusts, showing that moss and lichen crusts have stronger wind erosion resistance. Under 10% of destructive percentage, the TWVs over moss crusts were higher than 18.52 m s^{-1}. Under 30% of destructive percentage, the TWV reduced to 12.62 m s^{-1}. When destructive percentage reached 100%, sand grain could be observed in motion at a wind velocity of 9.90 m s^{-1}. TWVs of all crusts decreased rapidly from initial disturbance to 30% of destructive percentage. There were no obvious changes were observed when destructive percentage was over 50%. Comparatively, disturbed algal and algal-lichen crusts had poor erosion resistance. Their TWVs were 16.04 m s^{-1} and 11.78 m s^{-1} respectively under the destruction rate of 10% and they reduced to 12.27 m s^{-1} and 10.72 m s^{-1} as destructive percentage increased to 20%. The TWVs reduced to 8.6 m s^{-1} when the crusts were entirely destroyed, almost approximated to the bare sand surface. The curve of algal crusts in **Figure 2** had a great change at a destructive percentage of about 20%, which suggesting that smaller disturbance to algal crusts can cause sand moving. Algal-lichen crusts had a less significant variation and had the lowest TWVs among the four type crusts.

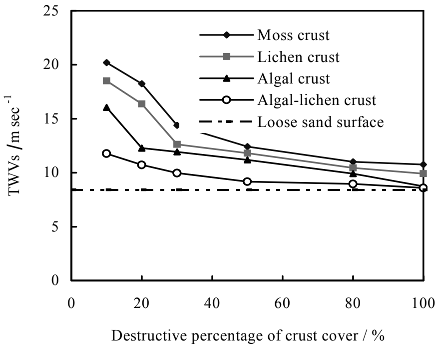

Fig. 2. TWVs for four type crusts at different destruction percentage of crust cover.

3.2 Impact of biological crusts on wind erosion rate (WER)

As shown in **Figures 3** and **4**, the results of WER showed that the crust-covered surface has much stronger wind erosion resistance than loose sand surface, among them moss and lichen crusts are the strongest, followed by algal-lichen crust and the weakest is algal crust. Under 8.42 m s^{-1} wind velocity, the WER on bare sand surface was 0.09 g m^{-2} sec^{-1}, at 18 m s^{-1} the figure was 298.88 g m^{-2} sec^{-1} and at 25 m s^{-1} it could reached 1214.82 g m^{-2} sec^{-1}. For moss and lichen crusts, even being entirely destroyed (not removed), their WERs only accounted for 1.70% and 1.95% of that on loose sand surface respectively at wind velocity of 25 m s^{-1}, while algal and algal-lichen crusts had large values, which were 5.68% and 4.13% respectively. The WERs for four type crusts did not exceed 8.95% of that on the loose sand surface at the same wind velocity. With increase in destructive percentage of crust cover and wind velocities, the WERs of all type crusts increased exponentially. WERs could reach 0.18-0.25 g m^{-2} sec^{-1} only under the destruction percentage of <20%. At the destruction percentage of 50-80%, the WERs corresponding to the TWVs decreased to 0.07-0.15 g m^{-2} sec^{-1} and when the crusts were entirely destroyed, they increased to 0.41-0.58 g m^{-2} sec^{-1}. For algal crusts, the WERs varied between 0.11-0.19 g m^{-2} sec^{-1} at the destructive percentage of <50%, and it increased to 1.26 g m^{-2} sec^{-1} when entirely destroyed. The changes of WER with destructive percentage on algal-lichen crusts was not obvious, the maximum value

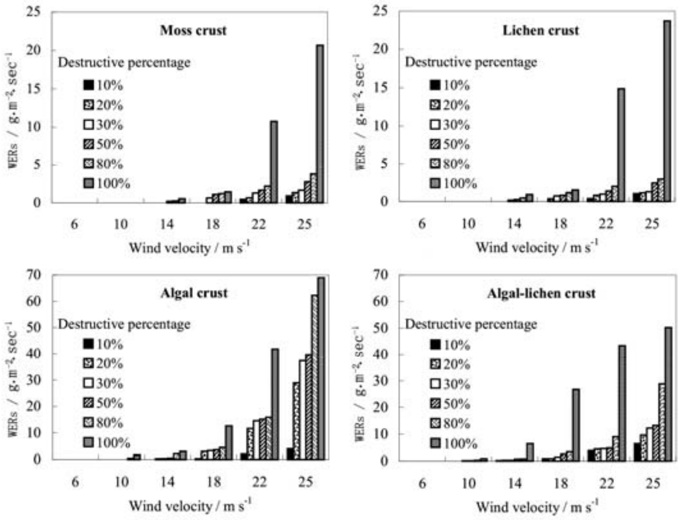

Fig. 3. Variation of average WERs for four type crusts with wind speed at different destructive percentage of crust cover.

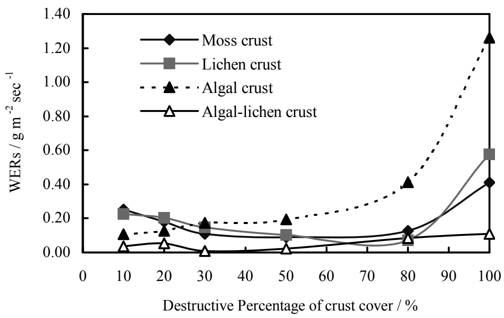

Fig. 4. WERs for four type biological crusts at different destructive percentage at corresponding TWVs.

did not exceed 0.11 g m^{-2} sec^{-1}. The reason for this is unclear now, which may be related to the biological characteristics of the crust type (Zhang, 2005).

4. Conclusions

Biological soil crusts extensively occur in Gurbantunggut Desert and their distribution exhibits obvious selectivity to landform. The wind tunnel experiments confirmed that the biological crusts greatly increase the TWVs. There is no sand grain movement and wind erosion was observed on the all undisturbed crusts under 25m s^{-1} wind, while the TWV on the bare sand surface was only 8.42 m s^{-1}. Under the same destructive percentage, moss crust had the highest TWV, followed by lichen and algal crusts, and algal-lichen crusts had the smallest one.

The WER on bare sand surface was 0.09 g $m^{-2}\cdot sec^{-1}$ at wind velocity of 8.42 m s^{-1} and it reached 1214.82 g $m^{-2}\cdot sec^{-1}$ at a high speed of 25 m s^{-1}. At the same wind velocity the WERs on four type crusts did not exceed 8.95% of that over the bare sand surface. The WERs increased exponentially with increasing of destruction percentage of crust cover and wind velocity. From its magnitude order and variation tendency, Moss and lichen crusts were similar, varying between 0-23.67 g $m^{-2}\cdot sec^{-1}$; algal and algal-lichen crusts were approximate, ranging from 0-69.00 g $m^{-2}\cdot sec^{-1}$. Moss and lichen crusts showed stronger wind erosion resistance. Their erosion rates were no more than 1.95% of that on bare sand surface even at wind velocity of 25 m s^{-1}. However, once wind velocity approached the threshold for sand moving, they reached 0.18-0.23 g $m^{-2}\cdot sec^{-1}$ and thereby caused a significant loss of organic matter even under low destruction percentage. When the destruction percentage was larger than 80%, the WERs on algal and algal-lichen crusts was close to that on bare sand surface and thus the sand stream may cause sandblast damages in the disturbed area.

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