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Wind Erosion Control by Liquefied Corn Stalk as a Novel Sand-Fixing Agent

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Liquefied corn stalk was evaluated as a sand fixation agent for wind erosion control. Experiments were conducted in a wind tunnel on two representative soil samples, the severely eroded dune soil and the cultivated soil. Results showed that liquefied corn stalk application on the soil surfaces led to the formation of crust and the increase of soil threshold wind velocity and the decrease of the wind erosion rate. At an liquefied corn stalk cover density of 148 g/m^2, the threshold wind velocity improved from 6 to up to 20 m/s for the cultivated soil and from 4.8 to 14.6 m/s for the dune soil at an liquefied corn stalk cover density of 138 g/m^2. It was concluded that liquefied corn stalk is a promising sand fixation material for both cultivated soil and the dune soil for wind erosion control.

Key Words: Corn stalk, Liquefaction, Wind tunnel, Soil Wind erosion, Surfaces, Crust.

INTRODUCTION

Wind erosion is one of the major causes of soil degradation and desertification in semi-arid and arid regions where annual rainfall is scarce and the vegetation coverage is sparse, thus the soil surface lacks of effective protection. The direct results are severe ecological problems. For example, the soil productivity decreases resulting from the loss of fertile particles and depletion of organic matter[1], human health problems caused by large amounts of dust especially those PM10 (diameter of soil particles ≤10 μm) in the air[2] and water pollution problems. Wind erosion has gained increasing attention worldwide, especially in China where half of the country consisting of the north and northwest of semi-arid and arid farming and pastoral zone regions are threatened by wind erosion[3]. About 1.91 million square kilometers of soil have been degraded or even become desertification because of wind erosion[4]. Another consequence of wind erosion is the frequent and massive dust storms it causes in winter and spring. Therefore, it is significant to conduct a research to explore feasible practices to reclaim desertification lands and control wind erosion for sustainable development in this area.

Exposure to strong wind may cause dust emissions when soil particles can't resist wind forces. The dry particle size distribution has a decisive influence on the soil particle shear strength and the threshold friction velocities[5]. Thus, changing the particle size and/or decreasing the wind forces become effective ways for wind erosion control. Vegetation cover such as windbreaks can effectively decrease the wind strength and is an important method to protect the soil surface against the wind erosion[6,7]. Formation of soil crust is another approach to avoid wind erosion through binding small particles into large aggregates[5]. Large aggregate formation is strongly affected by soil texture and clay mineralogy. The synthesized polymer application is another way to strengthen the soil crust and improve soil structure and its resistance against wind erosion. Bitumen and modified bitumen have been researched extensively and sand fixation material to bind small particles into large aggregates on soil surface, now have been applied in the field of soil protect and garbage wrap in some countries[8]. Polyacrylamide, a chemical reagent, as a new sand fixation material used to protect the soil has also been widely studied[9-13]. It should be mentioned that the high cost of the synthetic polymer could prevent this technique from further practical application.

Biomass liquefaction has become a focus in biomass utilization in recent years and utilizing liquefied products to produce bio-oil or polymer have been increasingly investigated[14-17]. It is known that the liquefied biomass products are viscous reagents and easily solidified under air condition. The biodegradable, affordable and recyclable properties qualify the liquefied products as an alternative to bitumen or polyacrylamide as sand fixation agent. Additionally, the remains from the degraded liquefied biomass can increase the soil fertility which can intrinsically improve the soil structure. In this research, corn stalk was liquefied by thermochemical method, the feasibility of using liquefied corn stalk as a new sand fixation agent against wind erosion was investigated. The effects of liquefied corn stalk on anti-wind erosion were studied in a wind tunnel and the threshold wind velocity and wind erosion rate were chosen as the experimental responses.

EXPERIMENTAL

Corn stalk was collected from a local farm in suburb Beijing, China and stored in plastic bags with moisture content ranging from 8 % to 10 % by weight. The material was milled to 20-80 mesh for use in the liquefaction experiments. Ethylene carbonate and 97% sulfuric acid were used as the liquefying solvent and catalyst, respectively[17].

Two representative kinds of soils-cultivated soil and dune soil were investigated in this study. The top 0-30 cm layer of the cultivated soil sample was obtained from the farmland in Haidian district of Beijing. The top 0-20 cm layer of dune soil came from the Yongding river bed in Shijingshan district of Beijing. Residues whose diameters are larger than 2 mm such as leaves, agricultural stalks and large particles in the two soil samples were gently sieved before experiment. The particle sizes of the two soil samples were measured by means of dry sieving method for those whose diameters are larger than 0.05 mm and Malvern particle size analyzer (MS2000, England) for those smaller than 0.05 mm. Water content was measured by oven-drying method at 105 ºC for 24 h just before wind erosion test.

Description of soil samples: The location of experimental soil samples. Beijing, located in the north of Huabei plain (39º56'N, 116º20'E), show typical sub-humid climate with mean annual rainfall of 507.7 mm, less than one-third of mean annual evaporation of 1800-2000 mm. Moreover, 70 % of the rainfall comes in June, July and August. In other words, drought often occurs in spring and winter due to insufficient rainfall. The annual average temperature of Beijing is 13 ºC, with a great variation from the minimum of -3.7 ºC in January to the maximum of 25.2 ºC in July. Mean annual frost-free period is about 180-200 days. Mean annual wind velocity is 3.4-4.5m/s, strong winds (more than 8 m/s) occurs in 23 days on the average and mainly occur during spring and winter. The predominant winds blow from the NW, N and S4. Therefore, the selected soil samples were from the typical wind erosion regions that are greatly affected by the drought and the sparse vegetations.

Preparation of liquefied corn stalk: Corn stalk was liquefied by using ethylene carbonate as liquefying solvent and 97 % sulfuric acid as catalyst at 170 ºC for 90 min. The liquefaction process parameters and the characteristic measurement of liquefied corn stalk such as acid number, hydroxyl number and moisture content were described previously[17]. The characteristics of the liquefied corn stalk used in this study were: acid number, 19.2 mgKOH/g; hydroxyl number, 137.3 mgKOH/g; moisture content, 1.5 %.

Wind tunnel: The wind tunnel experiment was carried out in a push-type wind tunnel, which consists of three sections, power section, stabilization section and work section, respectively. The work section of the wind tunnel is 9 m in length, 1 m in width and 0.75 m in height. Wind velocity can be adjusted continuously from 0 m/s to 30 m/s by an anemoscope (0.1 m/s precision) 10 cm above the tray surface. Soil samples were sun-dried and then filled into rectangular iron trays with dimensions of 45 cm in length, 24 cm in width and 4.5 cm in depth. The soil surface was gently smoothed with a wooden ruler to keep a similar surface roughness. Then different application rates of liquefied corn stalk were sprayed accurately onto the two samples surface for different cover densities. The weight change of sample tray was determined by an electronic balance (sensitivity 0.1 g) before and after spraying. After placed in room at 20-25 ºC for 3 days, the samples were set in the working section and their surfaces keep level with the tunnel floor. The cover density of liquefied corn stalk was calculated by following equation:

$$\eta = \frac{w_2 - w_1}{bd} \quad (1)$$

where, η is the cover density (g/m^2); w_2 is the weight of sample tray after sprayed (g); w_1 is the weight of sample tray before sprayed, g; b is the width of the tray (mm); d is the length of the tray (mm).

Measurement of threshold wind velocity: The threshold wind velocity is the wind velocity at which soil particles on the surface begin to move. In the experiment, the sample was blown with wind velocity at 3 m/s for 1 min and then the wind velocity increased gradually, meanwhile, the soil surface was observed through the glass window in the tunnel wall. Once the movement of soil particles in surface was detected by eye, the wind velocity was assumed as the threshold wind velocity of the sample. The wind velocity was measured by an anemoscope (0.1 m/s precision) 10 cm above the tray surface in a range of 0 m/s to 20 m/s.

Measurement of wind erosion rate: To observe the soil erodibility of different liquefied corn stalk cover densities, each soil sample was tested at wind velocities from 8, 10, 12 and 16 m/s, each for 5 min. Soil loss was measured by the electronic balance and the wind erosion rate was calculated by the following equation:

$$y = \frac{x_1 - x_2}{bdt} \quad (2)$$

where, y is the wing erosion rate, g/(m^2 min); x_1 is the weight of sample tray before a test, g; x_2 is the weight of sample tray after a test, g; b is the width of the tray, mm; d is the length of the tray, mm; and t is the time of sample blown, 5 min.

RESULTS AND DISCUSSION

Water content and particle distribution: After air drying, the water content of the dune soil and the cultivated soil were low, only 1.79 % and 1.17 %, respectively. The low water content is one of the major factors of wind erosion occurrence[18,19]. The existence of water can increase the connection strength between soil particles due to the electrostatic function of water[9]. Chepil[18] has indicated that the quantity of erodible soil particles decreases with an increase of water content.

The particle distributions of the two soil samples were shown in Fig. 1. The sand contents of particle sizes of 2-0.05 mm in the cultivated soil and the dune soil were 75.94 % and 82.78 %, respectively. Silt contents of particle sizes of 0.05-0.002 mm were 23.34 % and 16.42 %, respectively. Clay content of particle sizes of <0.002 mm were only 1.16 % and

0.78 %, respectively. Chepil[20] experimentally confirmed that as the sand content became higher, the formation of soil aggregates became more difficult and the resistance against wind erosion is weak. The optimal composition of the soil against wind erosion was 20-40 % sand, 40-50 % silt and 20-30 % clay. The higher content of silt and clay can promote the soil aggregation and strengthen the resistance against wind erosion. On the other hand, erodible particles (sizes < 0.1 mm) were susceptible to wind exposure[21]. Erodible particle contents of the two soil samples tested in this study were 38 and 35 %, respectively. Thus the cultivated soil and dune soil used in this study showed low resistance to wind erosion.

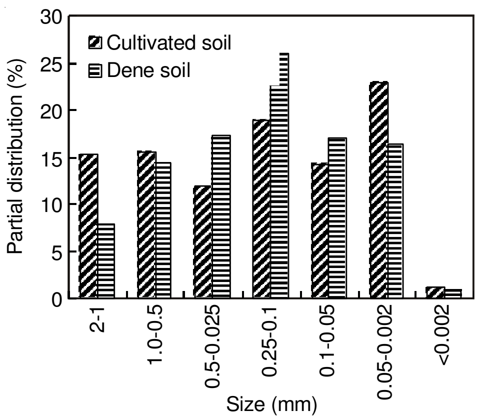

Fig. 1. Particle size distribution of the cultivated soil and dune soil samples

Effect of liquefied corn stalk on cultivated soil: The effects of liquefied corn stalk on threshold wind velocity and wind erosion rate of the cultivated soil are listed in Table-1. The initial threshold wind velocity was only 6.0 m/s without liquefied corn stalk addition. It means that the wind erosion didn't occur until the wind velocity reaching 6 m/s. With the cover density increased from 0 g/m^2 to 105 g/m^2, the threshold wind velocity increased significantly from 6 m/s to 11.5 m/s. At the cover density of 148 g/m^2, the threshold wind velocity was more than 20 m/s. Table-1 showed that at the same cover density, the wind erosion rate increased with the increase of wind velocity from 8 m/s to 16 m/s. The wind erosion rate changed conversely with the cover density. However, under the condition of low cover density and the high wind velocity, the difference of wind erosion rate between the liquefied corn stalk covered soil and the original soil was small. The high wind velocity may cause liquefied corn stalk dysfunction for anti-wind erosion. The low mechanical strength of liquefied corn stalk crust formed on the surface of soils resulted in the weak soil aggregate structure which is subjected to higher wind forces and led to the start of wind erosion.

TABLE-1
EFFECT OF LIQUEFIED CORN STALK ON CULTIVATED SOIL

Cover density (g/m^2)	TWV (m/s)	WER at different wind speed/g/(m^2 min)			
		8	10	12	16
0.00	6.0	37	101.8	848.2	1370.4
95.29	9.2	-	37	809.3	1333.3
105.76	11.5	-	-	101.5	1107.4
148.15	-	-	-	-	-

"- "TWV (threshold wind velocity) is up to 20m/s, or WER (wind erosion rate) is zero

Fig. 2 showed the appearance of soil particles after spray with the liquefied corn stalk. It was noticed that the small and large soil particles on the surface cohered to form a protective crust on soil surface after spray with the liquefied corn stalk. When the cover density was lower, soil crust was thin and the soil strength was weak, so that the soil crust cannot withstand high wind forces. The threshold wind velocity was only 11.5 m/s at the cover density of 105 g/m^2, whereas the threshold wind velocity was up to 20 m/s at a cover density of 148 g/m^2. With the increased cover density, the thickness and intensity of the soil crust became greater.

As seen in Fig. 2(a), some cracks in the soil crust were observed due to the dryness and shrink of liquefied corn stalk[22]. The wind erosion usually occurs from the crannies. Firstly, the soil under the crust is blown off gradually from the crannies and then the crust loses its support and breaks into little slices. When the wind force is strong enough, the broken crust slices are blown off.

Effect of liquefied corn stalk on dune soil: The effect of liquefied corn stalk on the threshold wind velocity and wind erosion rate of dune soil are listed in Table-2. The threshold wind velocity of dune soil increased from 4.8 m/s to 14.6 m/s with the cover density increased from 0 g/m^2 to 138 g/m^2; at the same cover density, the wind erosion rate increased with the wind velocity increased from 8 m/s to 16 m/s; at the same wind velocity, the wind erosion rate decreased gradually with the increase of cover density. It was also the same with the cultivated soil that, under the condition of low cover density and high wind velocity, the protective influence of liquefied corn stalk on dune soil disappeared gradually from weak mechanical strength of liquefied corn stalk crust.

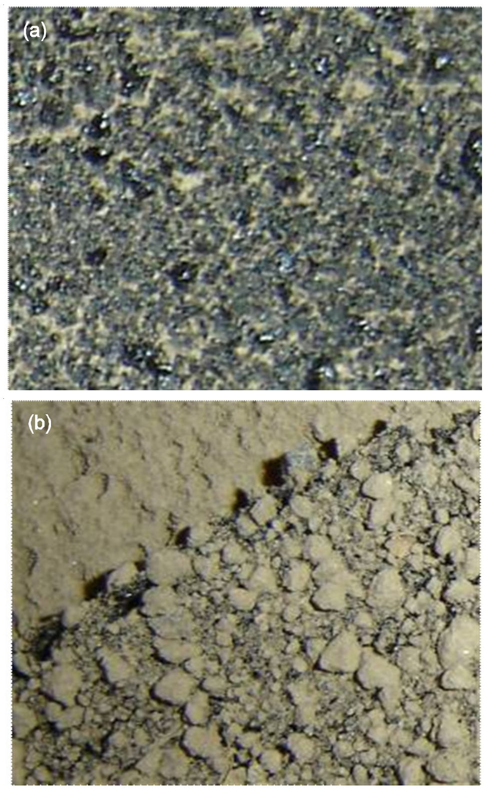

Fig. 2. Appearance of cultivated soil particles after sprayed the liquified corn stalk; a) surface appearance of sample after sprayed liquified corn stalk; b) appearance under the surface of sample

TABLE-2
EFFECT OF LIQUIFIED CORN STALK ON DUNE SOIL

Cover density (g/m^2)	TWV m/s	WER at different wind speed/g/(m^2 min)			
		8	10	12	16
0.00	4.8	140.7	522.2	1020.4	1835.2
65.40	7.5	100.3	485.8	848.3	1665.4
101.85	10.9	-	-	228. 9	1274.1
138.89	14.6	-	-	-	824.6

"- "TWV is up to 20m/s, or WER is zero

Fig. 3 showed the appearance of dune soil particles after sprayed liquefied corn stalk. It was similar to the appearance of cultivated soil particles that the small and large dune soil particles aggregated together and form the protective crust on dune soil surface. Some crannies formed due to dryness and shrink of liquefied corn stalk were also observed on the surface of dune soil crust. The wind erosion began from the crannies which were observed in experiment.

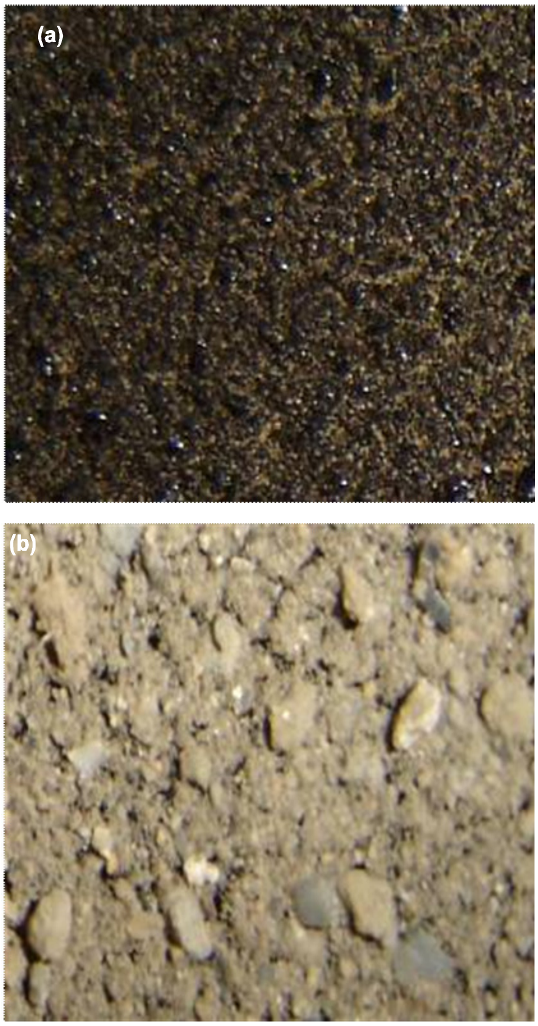

Fig. 3. Appearance of dune soil particles after sprayed the liquified corn stalk; a) surface appearance of sample after sprayed liquified corn stalk; b) appearance under the surface of sample

Conclusion

By spraying liquefied corn stalk on the surfaces of the cultivated and dune soil samples, soil-conserving crusts were formed. With the increased liquefied corn stalk cover density, the threshold wind velocity of two soil samples increased significantly and the wind erosion rate decreased. The threshold wind velocity of cultivated soil was up to 20 m/s at the cover density 148 g/m^2 and was 333 % higher than original cultivated soil. The threshold wind velocity of dune soil at the cover density 138 g/m^2 was 304 % higher than original dune soil. The wind erosion rate decreased with increased cover density for the two soil samples. Liquefied corn stalk was proved to be a potential sand fixation material for both cultivated soil and the dune soil for wind erosion control.

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