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In situ effect of combined utilization of fly ash and polyacrylamide on sand stabilization in North China

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ABSTRACT

A field experiment was conducted to investigate the resistance to wind erosion of consolidated soil layer (CSL) on the edge of Ulan Buh Desert in Inner Mongolia, China under natural conditions during Aug. 2015–Apr. 2016. The CSLs consisted of sandy soil, fly ash (FA) (5%, 10% and 15% (w/w) soil) and polyacrylamide (PAM) (0.05% and 0.1% (w/w) soil). The experimental site was divided equally into Regions A and B where dry FA and PAM powder were applied in two ways in mid-Jul. 2015. In Region A, FA and PAM were mixed homogeneously with the 0–0.3 m depth topsoil. In Region B, FA alone was mixed homogeneously with the 0–0.3 m depth topsoil. PAM was then scattered uniformly on top of the surface layer. Finally, CSLs were formed by spraying an appropriate amount of water onto the surface to dissolve PAM fully and being equilibrated for one week to achieve a moisture content close to the initial soil moisture content (0.6%). It was found that during 2–26 Aug. 2015, the wind erosion rate (WER) was reduced most significantly by 77% in CSL (10%FA + 0.05%PAM) in Region A and by 58% in CSL (10%FA + 0.1%PAM) in Region B compared with control (CK) (WER = 10.2 kg/m^2). However, during 3–27 Sep. 2015, there was no significant difference in WER between treatments in Regions A and B compared with CK (WER = 1.4 kg/m^2). Whereas, during the following longer period of wind erosion (*viz.* 27 Sep. 2015–21 Apr. 2016), the WER was reduced most significantly by 69% in CSL (5%FA + 0.1%PAM) in Region A and by 32% in CSL (5%FA + 0.05%PAM) in Region B compared with CK (WER = 80.7 kg/m^2). The resistance to wind erosion of CSL in Region A was much stronger than in Region B. The WER of CSL was influenced by wind conditions including wind speed and direction. Precipitation also had an impact on the WER of CSL as the cohesive effect of PAM can be influenced by precipitation. The CSL as a mixture of sandy soil, FA and PAM is recommended for wind erosion control.

1. Introduction

China has some of the most serious desertification and sandification in the world. According to the 5th National Monitoring Survey of Desertification and Sandification, the desertified and sandified land area reached up to 4.33×10^6 km^2 across China (State Forestry Administration of the People's Republic of China, 2015). Wind erosion, as the main trigger for land degradation, not only hinders the sustainable development of agriculture, but also leads to the deterioration of ecological environment. Soil erosion by wind is a process consisting of deflation and abrasion of surface particles by airflow or gas-solid two-phase flow. The migration of soil particles under wind action can cause damage to soil structure and consequently result in soil loss (Zheng, 2010).

Mechanical sand barriers, vegetal sand fixation and chemical sand fixation are three main approaches for wind-sand's fixation (Chepil and Woodruff, 1963; Skidmore, 1986). The use of vegetative and non-vegetative mulches to control wind erosion is not new (Armbrust, 1999). Whereas, chemical sand fixation is featured by the quick sand-fixing effect using environmentally friendly chemical agents. Polyacrylamide (PAM) is among these chemical stabilizers for effective prevention of soil loss from wind erosion. For example, Armbrust (1999) and He et al. (2008) found that dry PAM solution on the surface of erodible soils improved the soil's resistance to wind erosion significantly. Genis et al. (2013) demonstrated that PAM solution application onto bare sandy soil in arid regions could reduce wind erosion amount significantly. He et al. (2008) also proved that the adhesive action and inter-particle binding of PAM could minimize wind erosion of soil.

Fly ash (FA) is the most abundant combustion residue of coal in

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thermal power plants (Usmani and Kumar, 2017). FA is a useful ameliorant that can improve the physical, chemical and biological properties of problem soils, and it is a source of readily available plant macro and micronutrients (Jala and Goyal, 2006). Therefore, FA has the potential to enhance sand-fixing plant growth in barren sand dunes. Moreover, the indoor wind tunnel experiment of Yang and Tang (2012) showed that there was a small but significant increase in the resistance to wind erosion of the dried mixture of sandy soil and FA compared with the untreated sandy soil. It was ascribed mainly to the pozzolanic action of FA and filling effect of fine FA particles that improved the structural stability of the soil (Yang and Tang, 2012). In addition, Yang and Tang (2012) demonstrated that the addition of PAM to the mixture of sandy soil and FA further increased the resistance to wind erosion.

A recent indoor wind tunnel experiment of Wang et al. (2016) found that the resistance to wind erosion of consolidated soil layer (CSL) which was a mixture of sandy soil, FA and PAM, was increased significantly compared with the untreated sandy soil. Consolidation of desert surface by mixing FA and PAM appeared to be an effective approach to prevent soil erosion by wind. Nevertheless, as suggested by Wang et al. (2016), it is necessary to further investigate the effectiveness of CSL in wind erosion control under natural wind conditions which are much more complex than indoor simulated wind conditions. Therefore, in this follow-up study, a field experiment was conducted to investigate the *in situ* effect of CSL on prevention of the loss of sand dunes from wind erosion in an arid region under natural wind and precipitation conditions.

2. Material and methods

2.1. Study area

The experimental site is located in Dengkou County, Bayan Nur City, Inner Mongolia, China (N 40°39′, E 106°98′) (Fig. 1). Inner Mongolia is one of the provinces that face the most serious desertification and sandification in China. According to the 5th National Monitoring Survey of Desertification and Sandification, the desertified and sandified land area in Inner Mongolia was 1.09×10^6 km^2 in 2014, accounting for 6.35% of its total land area (State Forestry Administration of the People's Republic of China, 2015). The site is on the eastern edge of Ulan Buh Desert which has an area of about 1×10^5 km^2 (Fig. 1). Semi-fixed sandy land and semi-mobile and moving dunes spread across the northeastern part of Ulan Buh Desert (Peng et al., 2015). Wind erosion mainly occurs in this area between Mar. and May during which period west and southwest winds are prevalent, and 50.26% of the threshold wind speeds range from 5 to 6 m/s (He et al., 2013). According to the Chinese International Exchange Stations Surface Climate Standard Values Monthly Dataset (1981–2010) (weather station no.: 53419; name: Dengkou; location: N 40°2′, E 107°, 1055.3 m asl), the regional average maximum temperature is 15.8 °C, ranging from 31 °C in Jul. to −2.3 °C in Jan.; the regional average minimum temperature is 2.7 °C, ranging from 18.3 °C in Jul. to −14.4 °C in Jan.; the regional average annual precipitation is 143.4 mm, with average monthly precipitation ranging from 144.2 mm in Aug. to 0 in most of the year; and the regional average annual wind speed is 2.7 m/s, with average monthly wind speed ranging from 3.1 m/s in Apr. and Dec. to 2.1 m/s in Sep. (National Meteorological Information Center, 2005). *Artemisia desertorum*, *Artemisia ordosica* and *Sophora alopecuroides* L. are distributed sporadically in the area.

2.2. Soil, FA and PAM

The soil of the experimental site was strongly alkaline (pH 8.9) and had a bulk density of 1.5 Mg/m^3 and a specific gravity of 2.7. The FA was taken from the dry disposal site of the Bayan Nur Thermal Power Plant in Bayan Nur City, Inner Mongolia. The FA was extremely alkaline (pH 10.8) and had a specific gravity of 2.9. The particle size distribution of the soil and FA was determined by the laser diffraction method using a particle size analyzer (Mastersizer 2000, Malvern, Malvern, UK) (International Organization for Standardization, 2009). According to the international soil texture classification system (International Society of Soil Science, 1929), the soil was classified as a sandy soil with 97.9% (v/v) sand and 2.1% (v/v) silt. The texture of FA was the same as a silty loam with 27.1% (v/v) sand, 72.0% (v/v) silt and 0.9% (v/v) clay. The PAM was purchased from Xilong Chemical Co. Ltd. in Shantou City, Guangdong Province, China. It was anionic, a white powder with a solid content of 85% (w/w) and a relative molecular mass of ≥3 million.

2.3. Experimental design

The field wind erosion experiment was conducted at the experimental site during Aug. 2015–Apr. 2016. The experimental region of the site was levelled by a bulldozer to a size of 21 m long and 23.3 m wide, with sand slope in both the north and east. The northern sand slope (about 45° angle) was about 2 m high from the levelled ground,

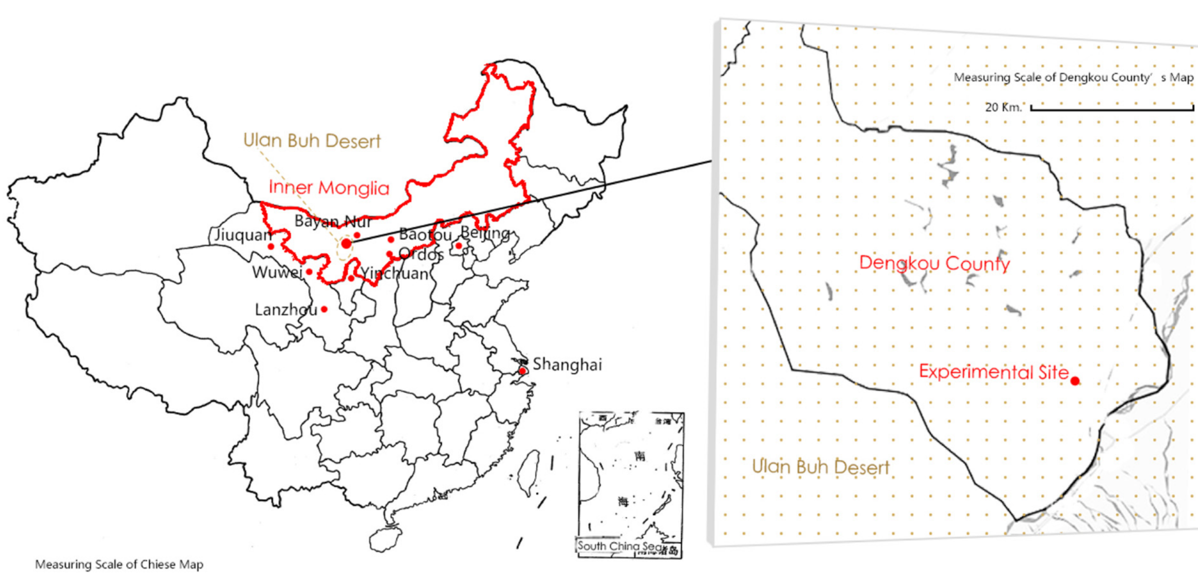

Fig. 1. Location of the experimental site.