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# Deceleration efficiencies of shrub windbreaks in a wind tunnel

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ABSTRACT

Artemisia and Salix are dominant shrub species for windbreaks in arid areas of China, and they show similar features to shrubs in other arid areas of the world. We compared the mean velocity fields and shelter effects of two shrub windbreaks with different layouts. For a single plant of Artemisia, the higher the free airflow velocity is, the more the wind velocity around two sides of the plant increases. The velocity gradient around a single plant of Salix is smaller than that around an Artemisia plant due to the difference in the plant shapes. Seven new velocity zones in the horizontal direction appear when airflow passes through an Artemisia windbreak, including four deceleration zones and three acceleration zones. The mean velocity field that is affected by a Salix windbreak can be divided into a deceleration zone in the front, an acceleration zone above, a vortex zone behind and a restoration zone downwind of the vortex zone. Shelter effects of the shrub windbreaks vary with the wind velocity and are influenced by the construct of the windbreaks. Shrub windbreaks that have a complex construction have better shelter effects than simple ones. The shelter effects of plant windbreaks are also influenced by the growth features of the plants. Considering the plant characteristics and the shelter effects of Salix and Artemisia windbreaks, it is optimal to plant these two windbreaks together in a sand-control system. This research is intended to be useful for sand movement control in arid areas.

## 1. Introduction

China is one of the most severely desertified countries in the world, with up to 3.3 million km$^2$ desertified lands (Decai, 1998; Zhong and Qu, 2003). Recently, desertification has become a major environmental problem and has attracted widespread attention in China, especially in the arid, semi-arid and dry semi-humid climatic zones. The desertification process is generally accompanied by soil and vegetation degradation, water and wind erosion (Dregen, 1998). In China, 50% of the desertified lands lies in the agro-pastoral transition zone of northern China (Zhao and Masayuki, 1997; Zhu and Cheng, 1994). This desertified transition region serves as the main source of sand that was carried aloft by windstorms and ultimately distributed throughout the country's eastern regions as heavy layers of dust (Zhang and Shi, 2003). The Mu Us Sandland located in the agro-pastoral transition zone is typical sandland in semi-arid China in terms of its vegetation, its high frequency of blown-sand disasters and its sand-control counter-measures.

Shrubs have been observed to be an important biological measure to control desertification and soil erosion (Li et al., 2013), and usually shrubs that live locally are considered to be the best materials to cover and stabilize the sand because they are effective, persistent and low-cost (Yang et al., 2006). In areas where water availability limits the plant coverage, desert shrubs might form fertility islands (an accumulation of resources around individual plants) (Perroni-Ventura et al., 2006; González-Ruiz et al., 2007). Furthermore, local shrubs, in the long run, can enforce the stability of deposition (Burylo et al., 2011, 2012a). Therefore, local shrubs are effective at both controlling sand movement in desert areas and reducing soil erosion in farmlands. The local vegetation in the Mu Us Sandland is composed chiefly of shrubs in sandland, and its canopy coverage is usually especially low (Li, 1990; Zhang, 1994). The previous report indicated that the original vegetation in this sandland is mainly dominated by *Artemisia ordosica*, which is a low-growing shrub species (Wu and Yang, 2013). Therefore, we surveyed wild fields to search local vegetation species in the Mu Us Sandland. The survey revealed that Artemisia (*Artemisia sphaerocephala*) and Salix (*Salix psammophila*) are the dominant species in the Mu Us sandlands. In addition, both species have a

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high percentage of survival, grow well and are effective in reducing sand storms (Shi, 2009). Artemisia and Salix are easily available, inexpensive materials for windbreaks in the sandlands. Furthermore, both shrubs have similar dimensional characteristics to those of other shrubs in other semi-arid and arid areas, to reduce desertification and soil erosion. For example, *Hedysarum fruticosum*, *Artemisia halodendron* and *Caragana microphylla* have been planted as sand binders on moving and semi-moving sand dunes since the 1980s in the Horqin Sandy Land, which is located in the northeastern part of China (Zhang et al., 2013); Mediterranean legume shrubs, including *Colutea arborescens*, *Dorycnium pentaphyllum* and *Medicago strasser,* have been used to control soil erosion in Guadalajara in Central Spain (Garcia-Estringana et al., 2013). *Aloe secundiflora* shrubs act as facilitators in degraded semi-arid rangelands in Kenya (King, 2008). Thus, based on wind-tunnel simulations, we measured airflow field and calculated the shelter effect of these two shrub windbreaks. Scientific understanding of effective windbreaks could aid sand movement control there and can provide experience for similar arid areas in the world.

Previous researches on windbreaks are abundant. A windbreak is generally defined as any structure that reduces the wind speed (Rosenberg, 1974), and windbreaks are frequently natural vegetative barriers against wind. A windbreak can be a single element or a system of elements that, through their presence in the airflow, reduce the effects of the wind both in the immediate vicinity and within a given windward and leeward distance (Cornelis and Gabriels, 2005). The efficiency of a windbreak in terms of the reduction in the wind velocity and turbulence intensity and, hence, its efficacy on wind-erosion processes is determined by various factors (Cornelis and Gabriels, 2005). The shape, height, orientation, width and spacing all affect the wind-velocity reduction and turbulence intensity in the leeward areas of a windbreak. The free wind velocity and surface roughness of the surrounding area also affect the windbreak performance (Chepil and Woodruff, 1963; Hagen and Skidmore, 1971; FAO, 1978; Banzhaf et al., 1992). Calculating the "correct" characteristics of any specific shelter device would allow us to suggest an appropriate windbreak for any given application (Perera, 1981). Therefore, the objective of our scaled wind tunnel measurements is to design windbreaks that efficiently reduce the wind velocity and involve two shrubs (Artemisia and Salix). We compared the mean velocity fields and shelter effects of the different windbreak designs.

## 2. Simulation conditions

### 2.1. Wind tunnel measurements

The experiment was carried out in a straight-blowing wind tunnel at the State Key Laboratory of Earth Surface Processes and Resource Ecology. The test section of the wind tunnel is 24 m long, 3 m wide and 2 m high. The wind velocity could be controlled continuously from 2 to 45 m s$^{-1}$ and was measured using a multipoint anemometer (Wu et al., 2011). Its supporting system has a hook to connect with a three-dimensional positioning machine, by which the anemometer is transferred between the measurement points along the *X*, *Y* and *Z* axes (Wu et al., 2013). In this study, only the horizontal wind velocities were measured at heights of 1 cm, 3 cm, 5 cm, 7 cm, 10 cm, 15 cm, 20 cm, 25 cm, 30 cm, 40 cm, 50 cm and 60 cm. The wind velocity refers to the mean wind velocity of 120 values within 2 min. A wind tunnel simulation of the airflow around a windbreak is shown in Fig. 1.

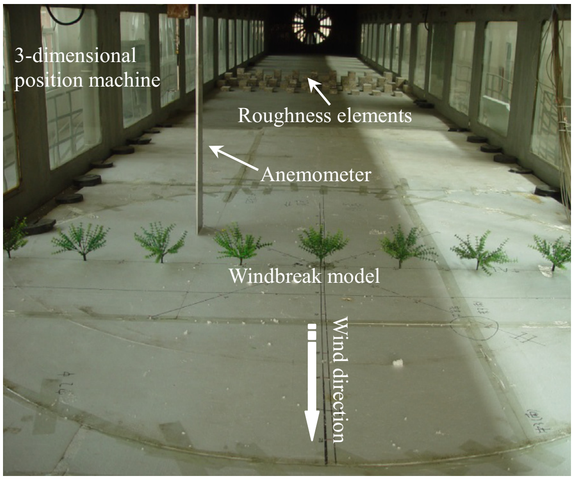

**Fig. 1.** Wind tunnel simulation of airflow around a single-row Artemisia windbreak.

Three types of windbreak were made: single plant, single-row and double-row. Measurement lines were set parallel to the incoming airflow, and measurement locations were placed from upwind to downwind, with the middle of the models as the origin, point 0. The position and measurement locations for the Artemisia and Salix windbreaks in the wind tunnel are shown in Fig. 2. For the single plant Artemisia and Salix windbreaks, we measured the wind velocities in eight directions around the windbreaks, including perpendicular directions, as shown in Fig. 2A and D.

### 2.2. Wind tunnel similarity

In this experiment, we measured the pure airflow around the models; therefore, geometric similarity, movement similarity and dynamic similarity are expected to be present (Wu et al., 2003) and have the same scale. The experiment conditions in this study are roughly in line with those in the previous research (Wu et al., 2013), except for some minimal differences. Elastic parameters (because of the bending and vibration of the plants) have not been accounted for in the study.

Geometric similarity here refers to the dimensional similarity between the models in the wind tunnel and the vegetative wind barriers in the field (Wu et al., 2013). We defined the cap as the diameter length and width of the canopy of a single plant; the "row and cluster" space refers to the distance between two adjacent rows and two adjacent plants in the same row, and "the number of clusters" refers to the number of plants per row. According to our field survey, the average dimensions for the Artemisia branches are 80 cm in height, with a 115 cm × 117 cm cap and 160 cm × 180 cm row and cluster space, whereas for Salix, the average dimensions are 220 cm in height, with a 160 cm × 170 cm cap and 180 cm × 350 cm row and cluster space. Their difference lies in that (1) the architecture for a cluster of Artemisia is similar to a reversed cone, while for a cluster of Salix, it is similar to a reversed pyramid; (2) the branches of Artemisia are rigid, while those of Salix are supple. We therefore chose plastic and elastic materials with a wider coverage of width and stiff twigs, which are similar to the field Artemisia plants, to make the Artemisia windbreak models. They were made at a scale of 1:5 and were 16 cm in height, with a 23 cm × 23.5 cm cap and 32 cm × 36 cm row and cluster space. We chose tall and thin dried plant materials with soft branches, which are similar to the field Salix plant, to make the Salix windbreak models. The Salix windbreak models were made at a scale of 1:10 and were 22 cm in height, with a 16 cm × 17 cm cap and 18 cm × 35 cm row and cluster space (Table 1). Thus, the requirements for geometric similarity are met in this study.