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Spatial patterns of aeolian sediment deposition in vegetation canopies: Observations from wind tunnel experiments using colored sand

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ABSTRACT

In environments affected by wind erosion, plants act as traps for aeolian sediment, which leads to a small-scale mosaic of depositional and erosional sediment transport regimes. This wind tunnel study used colored sand to visualize spatial patterns of sediment redistribution within grass canopies. Wind tunnel experiments were performed with high-, medium- and low-density canopies of *Lolium perenne*, corresponding to vegetation covers of 47%, 16% and 4%, respectively. In the low and medium-density canopies, the wake areas downstream of the tussocks were the primary locations of sediment deposition. In the medium-density canopy, these wedge-shaped wake deposits overlapped with the adjacent downstream tussocks, while in the low-density canopy they did not, indicating that these vegetation densities respectively represented wake-interference and isolated roughness flow. In the high-density canopy, very few sand grains were entrained by the wind, and were mostly deposited within the disturbed zones surrounding the tussocks. The deposited grains were evenly distributed around the tussocks in the high-density canopy without pronounced accumulations on their upstream, downstream or lateral sides. We interpret the high-density canopy as a skimming flow aerodynamic regime. The fraction of the sand surface which was exposed to erosion was substantially smaller than the area not covered by grasses. It accounted for 67–78% of the non-covered surface in the low-density canopy, and for 44–77% of the surface in the medium-density canopy. This finding indicates that wind erosion models overestimate the sediment source area if they assume the erodible area is the entire exposed surface not covered by roughness elements.

1. Introduction

Vegetation affects soil erosion by the wind at multiple spatial and temporal scales. The above-ground parts of vegetation act as non-erodible roughness elements that modify the near-surface wind, while their roots help stabilize the soil. The effect of vegetation on aeolian sediment transport is attributed to three mechanisms (Wolfe and Nickling, 1993): (i) surface sheltering, (ii) momentum extraction from the wind, and (iii) trapping of windborne sediment.

Surface sheltering is provided both by covering a portion of the ground surface and limiting the area of bare ground available to be eroded and by the wakes of reduced mean wind velocity downflow from a plant. Morris (1955) defined three flow regimes depending on the wake development and the proportion of protected to total surface area: (i) isolated roughness flow, where there is no interaction between wakes and adjacent downstream roughness elements, (ii) wake interference flow, where wakes from upstream elements intercept downstream elements, and (iii) skimming flow, where wakes completely overlap and the entire ground surface is sheltered (Fig. 1). The flow regime depends on both the size and spacing of roughness elements and on the free-stream or mean wind speed, and is a critical factor in determining the amount of wind erosion a surface will experience (Morris, 1955; Lee and Soliman, 1977; Wolfe and Nickling, 1993; Breshears et al., 2009).

Momentum extraction from the wind by vegetation reduces the erosive force of the wind. By absorbing a part of the total shear stress of the wind, plants decrease the shear stress acting on the ground surface.

Trapping of sediment by vegetation occurs through two mechanisms. Windborne particles can be removed from the air stream when they hit plant surfaces, or when the wind velocity becomes too low in the immediate vicinity of plants. By these means, plants cause particles to settle from the flow, resulting in characteristic

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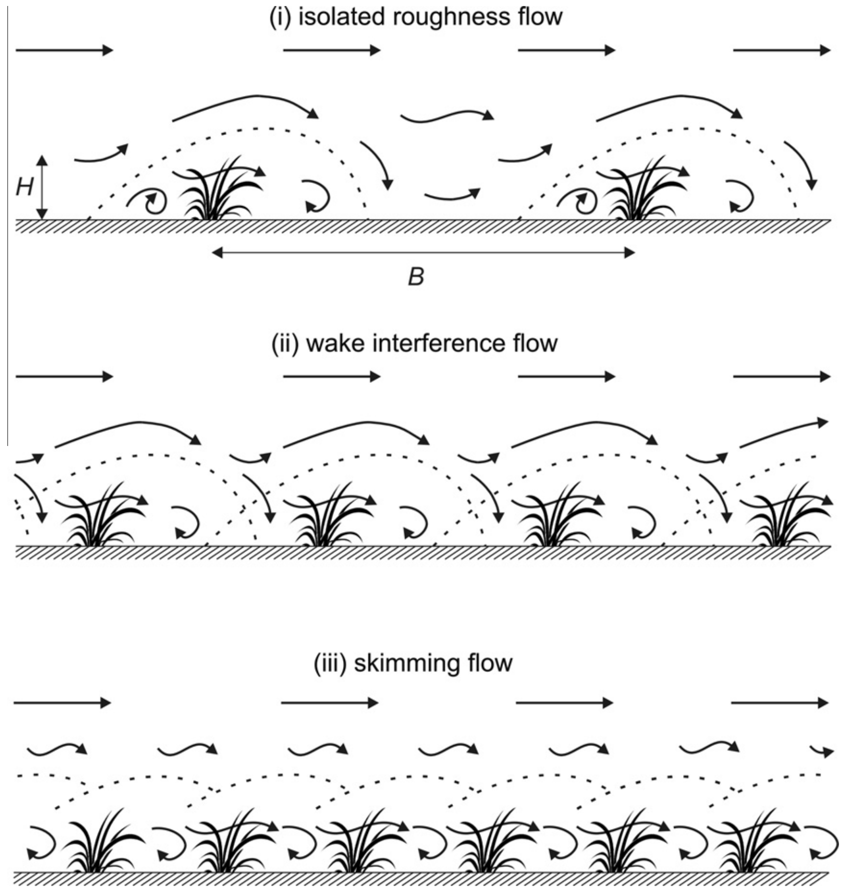

Fig. 1. Schematic representation of the three flow regimes defined by Morris (1955). Figure modified after Oke (1988) and Gromke (2008).

deposition patterns within vegetation canopies. A landscape experiencing wind erosion is thus a small-scale mosaic of depositional and erosional areas (Okin et al., 2006). These sediment redistribution processes have important implications for the development of a landscape's surface morphology and for soil resource availability. Wind erosion also depletes nutrients from plant interspaces and accumulates them within and around plants, a process known as the resource island phenomenon (Bielders et al., 2002; Li et al., 2007).

Several methods have been used to study small-scale spatial patterns of aeolian sediment deposition. Udo and Takewaka (2007) used a laser displacement sensor to measure wind-induced bed elevation changes in flexible artificial plant canopies in a wind tunnel setting. They found that canopies of low height, high density and high flexibility promoted bed accumulation and reduced sand transport downstream of the canopy. In several field studies, small-scale erosion and deposition processes have been monitored by marking the changing level of the soil surface on steel rods driven into the ground (Wiggs et al., 1995; Hesse and Simpson, 2006; Li et al., 2008). Other field studies have measured windborne sediment mass fluxes in heterogeneous plant canopies, indirectly providing information about deposition and erosion processes at the bed (Gillette and Pitchford, 2004; Gillette et al., 2006). Another approach to investigate aeolian sediment transport is the use of fluorescent tracer sand, but it has only been used on unvegetated surfaces to date (Berg, 1983; Willetts and Rice, 1988; Cabrera and Alonso, 2009).

More detailed information on deposition processes and wake development comes from wind tunnel experiments with model canopies of solid roughness elements (Sutton and McKenna Neuman, 2008a,b; Gillies et al., 2006). Various methods have been used to visualize bed-level flow and erosion patterns around solid roughness elements in wind tunnel experiments. Flow visualization techniques include ink and oil methods (Langston and Boyle, 1982; Bullard et al., 2000; Sutton and McKenna Neuman, 2008b) and a method based on the ammonia–manganese chloride reaction (Donat and Ruck, 1999). Sutton and McKenna Neuman (2008a) examined sediment transport initiation downwind of solid roughness elements by placing strips of sand across the wind tunnel floor and observing where they had eroded after exposing them to a wind event.

However, results from experiments with solid roughness elements do not necessarily apply to live plant canopies (Walter et al., 2012). Since live plants are porous and flexible, they affect the wind flow and sediment flux differently than solid, rigid objects. Plants allow the wind and sediment particles to pass through them, and they have larger drag coefficients than solid objects, i.e. they can produce greater overall flow resistance because they have a larger surface subject to skin friction (Gillies et al., 2002; Gromke and Ruck, 2008).

The study presented here differs from previous wind tunnel research in two respects. First, we used live vegetation instead of artificial roughness elements. Second, we used colored sand to visualize spatial patterns of sediment deposition within those vegetation canopies. The objective of this study was to identify and locate areas experiencing net deposition in three canopy densities of Perennial Ryegrass (*Lolium perenne*). Following a visual determination of net deposition patterns in different flow regimes, we estimate the fractional areas of sheltered and erodible ground surface within these grass canopies.