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Effect of canopy leaf distribution on sand transport and abrasion energy

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ABSTRACT

During times when crop canopies are short or sparse, wind erosion can uncover plant roots, deplete the soil resource, and damage plants by abrasion and desiccation. Few studies have considered the effects of position and number of leaves on sand transport and the distribution of the sand abrasion energy. The objectives of this study were to determine the effects of number and distribution of leaves on threshold velocities, sand transport rates, and relative abrasion energy among simulated dicotyledonous plant canopies. Six canopies were tested in a wind tunnel with two levels of leaf area index (LAI), two different maximum leaf heights, and either two or four leaves per plant with maximum freestream wind speeds from 12 to 17 m s^{-1}. The leaf heights were selected to position the lowest leaves to be either intercepting saltating sand or largely above the saltation layer. The wind tunnel was a 1.52 W × 1.82 H × 15.3 L m push-type recirculating tunnel with the floor covered with a layer of sieved sand. Sand discharge and relative abrasion energy were measured during 3-min duration test runs. For canopies with two leaves, the experimental sand transport capacity was reduced most when the leaves were highest above the surface even though they were intercepting saltation when in their lowest positions. As expected, canopy LAI was directly related to threshold velocity and inversely related to sand transport capacity. Total abrasion energy impacting the target soil channel containers located vertically in the canopy increased with wind speeds above the threshold. Within canopies, high wind speeds increased height of maximum abrasion but often still caused less total abrasion per unit sand discharge than over a bare, sandy surface. When leaves were located nearest the surface, they modified the vertical abrasion profiles by deflecting a portion of the sand impact energy upward in the wind stream. Overall, the canopies modified both the profiles and normalized abrasion energy of the sand discharge when compared with a bare, sandy surface. Hence, it may be important to place test plants within a canopy of similar plants—to allow development of a fully developed velocity profile in the canopy by using a minimum upwind fetch of about 70 canopy heights in a wind tunnel—when conducting plant abrasion tests using sand to achieve results representative of plants in the interior of a field. In contrast, abrasion on inter-row flat soil containers was independent of wind speeds, but was higher without a canopy compared with measurements in the canopy for a given sand discharge.

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1. Introduction

During times when crop canopies are short and/or sparse, wind erosion can damage plants by abrasion and desiccation. Standing biomass controls wind erosion by reducing the friction velocity under the biomass to lower levels at the soil surface and intercepting a portion of the mobile particles to further reduce transport capacity. Young plants can provide thin, standing biomass canopies but are susceptible to damage from the wind and from mobile particles they intercept during a wind erosion event. Current information on the effect of canopy and aerodynamic variables is limited.

In laboratory wind tunnel tests seedling green beans suffered severe damage under various treatments of wind and sandblasting (Skidmore, 1966). Wind speeds of 13.4 m s^{-1} and higher with any tested sand flux above zero resulted in high plant damage levels. Duration of exposure, from 5 to 15 min, resulted in a linear increase in damage score, with scores assigned based on visual inspection. In a similar study (Armbrust, 1972), soybean seedlings sustained changes in metabolic processes due to sandblast injury before there was any visual damage.

Erosion also may uncover plant roots as well as deplete the soil resource. Several studies have reported sand transport among standing stalks (Lyles et al., 1974; Lyles and Allison, 1981; Van de Veen et al., 1989; Hagen, 1996). Plant abrasion studies,

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however, typically have not considered effects of position and number of leaves on sand transport and the distribution of the sand abrasion energy within a plant canopy (Fryrear, 1971; Baker et al., 2009). Because of the effect of the plant canopy on the velocity profile in the wind stream, and thus on the particle transport, results from studies with a few plants rather than a large area of plant canopy likely only apply at the edge of a field. The plants in the interior of the field will be subject to different velocity profiles and different abrasion characteristics than those at the edge of the field.

Wind erosion control by low populations of standing real or simulated biomass has often been measured in wind tunnels as a soil loss ratio (SLR), defined as the ratio of tray soil loss with standing biomass to tray soil loss at the reference condition of the tray surface (Lyles and Allison, 1976, 1981; Armbrust and Lyles, 1985; van de Veen et al., 1989). Mendez and Buschiazzo (2008) measured SLR under field conditions and found good agreement with the form of existing relationships between SLR and flat residue cover, but observed a 37% difference in measured coefficients compared with wind tunnel results because SLR is a function of wind speed. The SLR is a particularly strong function of wind speed near the threshold wind speed of standing biomass. To avoid this difficulty, the ratio of soil surface to above-biomass friction velocity and a particle interception coefficient were proposed as variables for use in physically-based erosion models (Hagen and Armbrust, 1994). When many leaves or stalks intercept the saltating sand, the interception tends to reduce discharge by increasing the effective threshold for transport capacity from the dynamic towards the static threshold friction velocity. The response of growing crops in a wind stream is particularly complex and, currently, direct measurements of these variables are not available. However, indirect calculations that were based on earlier SLR measurements (Armbrust and Lyles, 1985) have been reported for a few growing crops (Armbrust and Bilbro, 1997). That study showed that the effective plant area index (PAI), defined as the sum of silhouette area index and effective leaf area index, was highly correlated with reduction in the transport capacity of the wind, leading the authors to conclude that PAI can serve as an indicator of the soil protection afforded by growing plants.

Seedlings are most prone to erosion damage, so accurate information during this crop stage is critical. Kinetic energy of impacting sand grains has been suggested as a main factor causing seedling damage (Fryrear and Downes, 1975). However, some preliminary data show that the kinetic energy for a given sand discharge varies, because standing biomass modifies the near-surface wind profile. Burri et al. (2011) found that various densities of vegetative canopies of Perennial Ryegrass (*Lolium Perenne*) strongly affected the vertical profile of particle mass flux in a wind tunnel compared with a bare surface. In agricultural fields flat residue cover also is often present along with growing biomass, but controls erosion somewhat differently than standing biomass (Hagen, 1996). In addition, preliminary tests demonstrated that moving leaves vertically along the stem without changing leaf area can affect threshold and other flow properties (Hagen and Armbrust, 1994). Thus, threshold velocities, interception coefficients, transport capacity, and kinetic energy measurements are needed for typical surface conditions with small seedlings.

The objectives of this study were to determine the effects of number and distribution of leaves on threshold velocities, sand transport rates, and relative abrasion energy among simulated dicotyledonous plant canopies such as typical varieties of beans.

2. Materials and methods

A series of wind tunnel experiments was conducted using sand alone and sand covered by thin canopies of simulated standing leafy biomass protruding above the sand surface. The form of the simulated biomass was selected to resemble young dicotyledonous plants (Fig. 1). The stem height remained constant at 170 mm, while the leaf height and number varied. The four-leaf plant configurations maintained the same 70 mm spacing between the top and bottom leaf pairs for both the 130 mm and the 170 mm top leaf heights. This was done to mimic typical growth patterns for dicotyledonous plants and resulted in the bottom leaves being at different heights when the top leaf heights differed. The maximum leaf heights are referred to as *canopy height* hereafter. The fixed stem height is only referred to as stem height. The tunnel test configurations and biomass characteristics are summarized in Table 1. The leaf area index (LAI) was calculated using the average measured leaf area per plant and then dividing by the total tunnel floor area occupied per plant. The test area in the downwind section of the wind tunnel with the biomass and sensors is illustrated in Fig. 2.

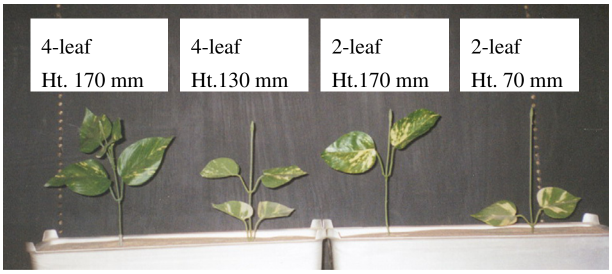

Fig. 1. Four variations of the simulated standing biomass used in wind tunnel tests showing height of top leaf.

In the experiments, quartz sand 0.29–0.42 mm diameter was placed 50 mm deep over the entire floor of a push-type, recirculating wind tunnel with a 1.52 W × 1.82 H × 15.3 L m working section. The free-stream wind velocity as well as wind velocity profiles at four locations near the downwind end of the tunnel, 14 m downstream from the fan section, were measured from near the sand surface to a height of 471 mm. Pitot tubes measuring the velocity profile were located at heights of 20, 31, 41, 61, 86, 111, 140, 151, 161, 181, 206, 231, 260, 271, 281, 301, 326, 351, 380, 391, 401, 421, 446, and 471 mm above the sand surface. The free-stream velocity was measured at 1.3 m above the tunnel floor centered between the tunnel sidewalls, while the velocity profiles were measured at both 0.3 and 0.4 m from the sidewall with two profiles immediately upwind and two profiles immediately downwind of plant rows. The profiles were measured at two different wind velocities below the threshold for sand movement using pitot-static tubes. Electronic transducers were used to measure temperature, barometric pressure, and differential pitot-static tube pressures. The latter transducer had 0–25 mm water pressure range with 0.03% linearity and 0.05% repeatability. The pressure measurements were corrected for barometric pressures and temperature. Finally, simultaneous measurements of the freestream wind speed were used to mathematically eliminate any offset differences among the pressure transducers. The aerodynamic roughness (Z_0), the displacement height (D) and the friction velocity above the biomass (U_{*v}) were calculated from the wind velocity (U) profiles contained in the well-known log-law of the form (Greeley and Iversen, 1985).

$$U = \left(\frac{U_{*v}}{0.4}\right)\ln\left(\frac{Z-D}{Z_0}\right) \tag{1}$$

where Z is height above the sand surface.

For the bare sand surface, D was set equal to zero, and the surface threshold friction velocity (U_{*0t}) for initial sand movement