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25 Biological Soil Crusts and Wind Erosion

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25.1 Introduction

Wind is an important erosive force in deserts, where limited cover of vascular plant material offers little soil-surface protection. Dust deposition by wind often exceeds that of fluvial deposition in these drier regions (Goudie 1978; Williams et al. 1995). Sediment production from soil surfaces occurs when wind forces exceed soil threshold friction velocities (TFV: the wind velocity needed to detach particles from soil surfaces). Decreased TFVs are directly associated with increased sediment movement. Soil fine particles are preferentially lost over larger sand particles (Leys 1990; Williams et al. 1995). Increased sediment movement can result in many direct and indirect problems for semiarid and arid ecosystems. Soils weather slowly from parent rock in deserts, often taking 5000–10 000 years (Webb and Wilshire 1983). Much of the soil fine material found in these regions is from atmospheric deposition (Danin and Yaalon 1982). Soils from the Colorado Plateau deserts show that most fine particles are derived from surrounding igneous mountains. Current deposition rates in these regions are low and when soils are disturbed, loss rates may far exceed deposition (Gillette et al. 1980; Offer et al. 1992; Belnap and Gillette 1997,1998; Reynolds et al. 1998).

Most of the soil photosynthetic productivity and nitrogen (N) fixation in desert soils is concentrated within 3 mm of the surface (Garcia-Pichel and Belnap 1996; see Chap. 16). Thus, only a little soil loss can significantly reduce C and N inputs from these organisms (see Chaps. 18, 19). In addition, the top few mm of soil contain a much higher percentage of soil fine particles than underlying soils (Danin and Ganor 1991; Verrecchia et al. 1995). Loss of soil fines can reduce site productivity, as plant-essential nutrients are often bound to these particles. Burial of nearby biological soil crusts from windblown sediments generally means death for the photosynthetic components of the soil crusts, further reducing fertility. Reduced fertility of systems is one of the most definitive, and problematic, aspects of desertification. Worldwide increases in windborne sediments are amply documented (Goudie 1978; Kovda 1980; Tsoar and Pye 1987).

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Both plant and soil characteristics influence wind erosion. In deserts, vascular plants are generally short with sparsely vegetated stems, and very large spaces occur between individuals. Plant litter cover is also very low. Thus, plant materials in semiarid and arid regions offer limited protection to soils from wind erosion. In such environments, biological soil crusts can play a critical role in soil stabilization.

25.2 The Influence of Undisturbed Biological Soil Crusts on Wind Erosion

Soil characteristics that reduce wind erosion include rock cover, high salt or calcium carbonate content, high clay/silt content, physical crusts, and extensive biological soil-crust cover. Where rocks form a pavement, soils are completely armored from wind erosion. However, many desert soils are not covered by pavement, and any soil between rocks is still vulnerable to wind erosion (Gillette et al. 1980; Musick 1998). Undisturbed, fine-textured desert soils have many of the above characteristics and are most often stable until disturbed (Gillette et al. 1980). When disturbed, however, the physical crust crumbles into tiny particles and most soil-surface protection is lost until the next rain storm reforms the crust. However, when biological crusts are disturbed, large aggregrates are left, bound together by unbroken filaments (Gillette et al. 1980; J.E. Herrick and J. Belnap, unpubl.). Coarse-textured soils are inherently more erodible than fine-textured soils, as they have less salt, clay and other characteristics that lead to significant surface physical crusting. Therefore, coarse soils are generally dependent on rocks and biological soil crusts for surface protection (Williams et al. 1995; Leys and Eldridge 1998). When different surfaces are tested under naturally occurring wind speeds, ranking of the inherent resistance of soils to erosion is: desert pavements=lichen/moss biological soil crusts > playa centers > playa edges > cyanobacterial soil crusts >disturbed clay soils > alluvial and aeolian sandy soils > sand dunes = disturbed sandy or silty soils (Gillette et al. 1980; Belnap and Gillette 1997, 1998).

Many studies worldwide have shown that biological soil crusts can be a critical factor in reducing soil erosion by wind (Dulieu et al. 1977; Van den Ancker et al. 1985; Tsoar and Møller 1986; Danin et al. 1989; Pluis 1994; Williams et al. 1995; Belnap and Gillette 1997, 1998; Marticorena et al. 1997; Leys and Eldridge 1998). Polysaccharides extruded by cyanobacteria and microfungi entrap and bind soil particles together, creating larger soil aggregates. Polysaccharides also then link these larger aggregates together (Belnap and Gardner 1993). These larger, linked aggregates require greater wind velo-

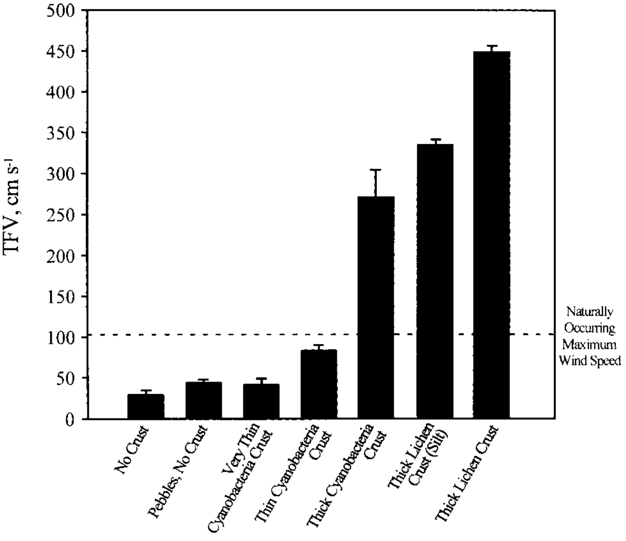

Fig. 25.1. Threshold friction velocities (*TFV*) of soil surfaces with different levels of biological soil-crust development. (After Belnap and Gilette 1998)

city to move than single grains (Gillette et al. 1980; Marticorena et al. 1997); this can be seen vividly with SEM photos (see Chap. 15; Van den Ancker et al. 1985; Danin et al. 1989; Chartes 1992; Belnap and Gardner 1993; Eldridge and Greene 1994). In laboratory wind-tunnel trials, cyanobacteria appear better able to protect soil surfaces than green algae. Cyanobacteria are generally longer and larger than green algae, and thus better able to connect soil particles together (McKenna-Neuman et al. 1996).

Soil resistance to wind erosion increases with biological crust development on all substrates tested (Fig. 25.1). While any level of biological crust development reduces soil loss by wind, both silt and sandy soils with the greatest erosion resistance are those with the most well-developed biological crusts. Even undisturbed, chemically-killed crusts (leaving the polysaccharide material intact) continue to protect the soil surface from erosion, at least temporarily (Williams et al. 1995). In most cases, well-developed crusts can withstand winds well above those recorded at field sites, and so offer complete protection from wind erosion, even in coarse soils (Leys 1990; Williams et al. 1995; Belnap and Gillette 1997,1998; Leys and Eldridge 1998).

25.3 Crust Disturbance and Wind Erosion

Biological soil crusts are highly susceptible to disturbance, especially in soils with low aggregate stability such as sands (see Chap. 27; Webb and Wilshire 1983; Belnap and Gardner 1993). Cyanobacterial filaments, lichens, and

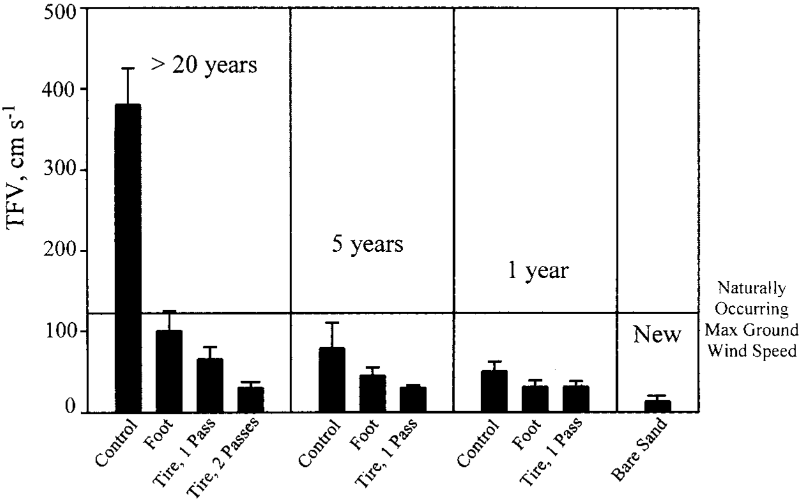

Fig. 25.2. Threshold friction velocities (*TFV*) and sediment production of control (undisturbed) and vehicle-disturbed (two passes) surfaces in Joshua Tree National Park, CA. Seven of eight control sites have TFVs above maximum field-recorded wind speeds; seven of eight disturbed sites have TFVs below recorded wind speeds. Sediment production is increased 2–36× with disturbance. (J. Belnap, unpubl.)

mosses are brittle when dry, and crush easily when subjected to compressional or shear forces incurred by activities such as trampling or vehicular traffic. Such disturbances break apart soil aggregates and the connections between them. Thus, TFV decreases significantly when the soil crusts are disturbed. Belnap and Gillette (1997) showed soil surface TFV in a sandy soil decreased by 73–92 % when moderate disturbance was applied (Fig. 25.2). Leys and Eldridge (1998) reported that moderate disturbance reduced soil TFV by 57 % in a loamy soil and by 40 % in sandy soils. Williams et al. (1995) found removing crust from silty soils decreased TFV by 50 %. Two passes with a vehicle decreased TFV in silty soils up to 96 % in coarse sandy and silty soils (J. Belnap, unpubl.). Belnap and Gillette (1998) applied the same moderate disturbance to a range of adjacent soil types. Physically-crusted playa soils with no biological crust showed the greatest impact with disturbance, as crushing of the mineral crust left the surface with virtually no erosion protection. Silty and coarse-structured soils covered with varying types of biological soil crusts showed an intermediate response, with gravel soils being the least compromised (Fig. 25.1). Severe disturbances show greater decreases in TFV than moderate disturbances (Leys and Eldridge 1998).

As TFV decreases, sediment production increases; thus, sediment loss is increased on disturbed surfaces. In Australia, Leys (1990) showed a fivefold increase in sediment production when a crusted surface was disturbed. Leys

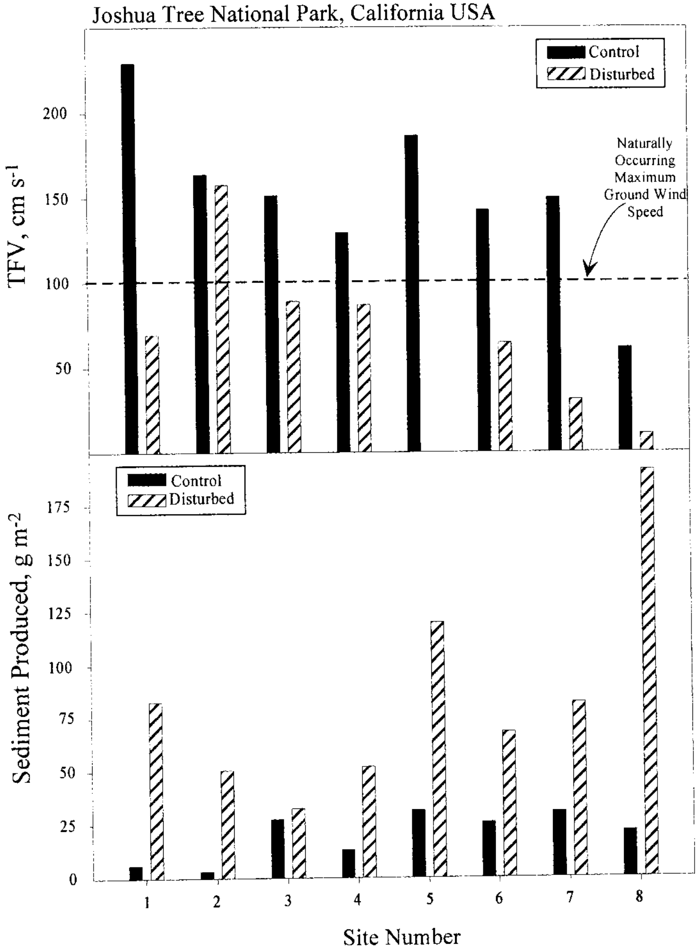

Fig. 25.3. Threshold friction velocities (*TFV*) of soil surfaces. Experimental disturbances were applied to four surfaces in SE Utah with different disturbance histories: undisturbed (>20 years), lichen-moss soil crusts; crust vehicle-disturbed 5 years previously (currently cyanobacterially dominated); crust vehicle-disturbed 1 year previously (currently cyanobacterially dominated) and newly disturbed lichen-moss crust. These soils were then walked and driven over, except for controls. All differences within a soil type are significantly different ($p<0.05$). TFVs of undisturbed crusts are above maximum field-recorded wind speeds, while those for all other surfaces are below recorded wind speeds, and thus subject to wind erosion. (After Belnap and Gilette 1997)

and Eldridge (1998) showed a fivefold increase in sediment loss from a loamy soil and a fourfold increase from sandy soils when soil crusts were severely disturbed by raking (however, due to greater erodibility in sandy soil, much more total sediment was lost from the sandy site). Williams et al. 1995 showed a fivefold increase in sediment loss when crusts were scalped from a silty soil. Figure 25.2 shows 2- to 35-fold increases in sediment production at high spring wind speeds when crust-covered sandy loam soils in the Mojave Desert were disturbed by vehicle tracks. As disturbance increases in severity, more aggregates are crushed, resulting in greater soil loss with greater disturbance levels (Leys and Eldridge 1998).

Disturbance type can affect wind erodibility. Hoof and human footprints have less effect on soil TFV than vehicle tracks in sandy and some silty soils (Belnap and Gillette 1997, 1998). In other silty soils, hoof prints have more impact than vehicle tracks (Belnap and Gillette 1998). This response is probably dependent on the depth of the print in a given soil, as deeper, discrete prints would have greater protection from wind than shallow prints or continuous vehicle tracks.

The condition of the biological soil crust prior to disturbance can affect the wind erodibility of a surface after the new disturbance. Disturbance in well-developed, undisturbed lichen-moss soil crusts have less effect on TFVs than disturbance to crusts that are recovering from impacts (Fig 25.3; Belnap and Gillette 1997). Footprints and one pass with a vehicle in an undisturbed lichen-moss crust have less impact than the same disturbance on a crust disturbed 5 years ago, 1 year ago, or just recently, as undisturbed crusts have a buildup of soil-binding polysaccharide material both at and below the soil surface that is lacking in crusts that have recently been disturbed. Nearby disturbances can also have a detrimental effect on the stability of soil surfaces. Sediment produced from such disturbances can "sandblast" adjacent crusts and erode them at a much faster than normal rate. Thus, a small disturbance can trigger much larger impacts (Belnap and Gillette 1997; Evans and Johansen 1999).

25.4 Recovery of Wind Resistance

Because crustal organisms are only metabolically active when wet, re-establishment time is slow in arid systems. Recovery is faster under plant canopies than shrub interspaces (see Chap. 27), but soils in plant interspaces are more vulnerable to wind erosion. Experiments show that sandy soils can remain susceptible to monthly maximum winds for at least 5 years after disturbance, and to annual maximum winds for at least 10 years after disturbance (Fig. 25.2).

Although silty alluvial and sandy soils showed a similar response to new vehicle disturbance (83 vs. 74% TFV decline), silty soils show a much faster recovery rate than sandy soils. Silty soils are able to form a thin physical crust after even a light rain that increases TFV by 65%. In contrast, sandy soils with no physical crusting showed little TFV recovery after 5 years (Belnap and Gillette 1997).

25.5 Conclusions

All studies show that biological soil crusts play a significant role in reducing soil loss by wind. Degree of crustal development parallels amount of protection from wind erosion. As coarse soils are inherently more erodible than silt soils, and do not generally form physical crusts, the protection offered by biological soil crusts is especially important in coarse soils. Disturbance to crusts results in decreased TFV and increased sediment production. This response is related to the severity of disturbance; to the biomass, species composition, and physical structure of the soil crusts; and to soil characteristics such as texture, physical crusting, and vesicular horizons. However, with the limited number of data sets available, it is not yet possible to develop generalizations predicting the relative importance of these factors on a regional or global basis.

Recovery time of wind resistance is much faster in soils with inherent aggregate stability, such as clays and gypsum. Recovery is also much faster in soils where physical crusts reform after rain events. Thus, coarse soils have less inherent resistance to wind erosion, and take longer to redevelop protection from wind erosion once disturbed. This suggests that, while biological soil crusts play an important role in preventing wind erosion in all soil types, the protection offered by biological soil crusts is especially critical in coarse soils.

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