MICROPHYTIC CRUST INFLUENCE ON WIND EROSION

J. D. Williams, J. P Dobrowolski, N. E. West, D. A. Gillette

ABSTRACT. *Wind is a persistent force in arid and semiarid lands. Microphytic crusts have been attributed with the ability to reduce wind erosion because of soil binding qualities. The purpose of this research was to determine if microphytic crusts contribute to soil stability in an arid land setting. Threshold friction velocity is the wind speed necessary for the initiation of soil erosion and, thus, is a measure of soil surface stability. A portable wind tunnel was used to determine threshold friction velocity on soil surfaces consisting of microphytic crusts living and undisturbed (control), chemically killed microphytic crusts but otherwise undisturbed (chemically killed), and microphytic crusts mechanically removed from the soil surface (scalped) to approximate conditions of absence. Significantly lower threshold friction velocities were measured within the scalped treatment than in the control or chemically killed treatments. Threshold friction velocities were not significantly different among control and chemically killed treatments. Significantly more wind-eroded material, entrained in the airstream and trapped by an inline filter, was obtained from the scalped treatment than from chemically killed or control treatments. Additionally, wind erosion occurred at significantly lower wind speeds in the scalped treatment. Microphytic crusts helped contribute to soil stability by binding soil particles, mainly by linked strands of cyanobacteria. Additional designed experiments are warranted to determine how the stabilizing influence of microphytic crusts are affected by type, degree, frequency, and season of disturbance and to answer pragmatic questions of concern to managers, such as determining acceptable levels of crust disruption and the wind speeds associated with erosion.*

Keywords. Wind erosion, Soil stability, Microphytic crusts, Cryptobiotic crusts, Microbiotic crusts, Aridland processes.

Wind is generally considered a major erosive agent in arid and semi-arid regions where the soil is typically loose and has minimal microtopography or vegetation cover. Wind blown deposition is greater than fluvial deposition in many regions, including such diverse areas as the western United States and Sahara Desert (Goudie, 1978) and might be the most important geomorphic process in many of the earth's arid regions, such as the Qattara Depression of northern Egypt and Rub' al Khali (the Empty Quarter) of the Arabian Peninsula (Watson, 1989). Understanding effects of airflow on the earth surface at small scales can begin to reveal mechanisms of wind erosion on larger spatial and temporal scales, e.g., measuring the force of wind needed to initiate wind erosion, the threshold friction velocity (Gillette, 1981; Watson, 1989).

Microphytic crusts occur in open shrub and grass communities in arid and semi-arid environments around the world. The term microphytic (West, 1990) is synonymous with cryptogamic (Kleiner and Harper, 1972), microfloral (Loope and Gifford, 1972), biologic (Danin, 1978), biocrusts or biogenic (Thomas and Tsoar, 1990), and cryptobiotic or microbiotic (Belnap, 1993). These crusts develop at the soil surface through growth of algae (brown and green), cyanobacteria, lichens, mosses, liverworts, fungi, and bacteria or some combination of these nonvascular microphytes (West, 1990). Physical and chemical process in the Aridisol soil order often create crusts or crust-like conditions that are not biologic in origin. These features, however, often occur in association with microphytic crusts and include vesicular porosity, rain crusts, salt crusts, gypsum crusts, or silica crusts.

Microphytes entangle and glue soil particles, binding particles to form a crust that should resist wind dislodgment and redistribution (Campbell, 1979; Pluis and de Winder, 1989; Belnap, 1993). This stabilizing mechanism might be particularly important in arid and semi-arid areas where vascular plant cover is sparse and large open intershrub areas are unprotected from wind. Young et al. (1986) speculated that microphytic crusts in the Great Basin (U.S.) would act to stabilize shrub interspaces against wind erosion if they were not periodically washed away by thunderstorms. When wetted cyanobacteria, *Microcoleus vaginatus*, filaments partially extrude from colonial sheaths, after which the filaments produce new sheaths and leave the abandoned sheath behind (Belnap, 1993). The abandoned sheath material continues to contribute to soil aggregate stability and, thus, should contribute to soil stability against wind stress (Belnap and Gardner, 1993). Despite these intuitively appealing arguments, microphytic crusts' ability to hold soil in place has not been examined directly.

Circumstantial evidence exists that microphytic crusts reduce wind erosion and soil redistribution. In Australia, Andrew and Lange (1986a) examined microphytic crusts around a piosphere-a site where water is the controlling factor of livestock distribution and disturbance decreases with distance from the water source. Trampling by sheep

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apparently destroyed the microphytic crust and led to redistribution of soil surface nutrients by wind, thereby decreasing the site's cover and stability. However, the degree of disturbance is not clearly related to the amount of measured dustfall (Andrew and Lange, 1986b). Comparisons of soil properties in opportunistic or space for time substitution studies, the comparison of adjacent plots with different landuse as opposed to interspersed manipulated plots observed through time (Pickett, 1989), are also used as evidence of the influence undisturbed microphytic crusts have on wind erosion, e.g., differences in soil texture (Bond and Harris, 1964), greater concentrations of soil Ca, P, K, and organic matter (Kleiner and Harper, 1977), and soil K, Zn, Fe, Mn, Na, and SAR (Johansen and St. Clair, 1986).

Wind erodibility of soil surfaces not covered by shrubs or grasses is influenced by surface characteristics such as roughness, soil texture, pebble cover, and physical or chemical crusting (Gillette, 1978; Gillette et al., 1980). The purpose of the present research was to quantify microphytic crusts' ability to hold soil in place against wind stress.

Because many other types of soil crusts might influence results (West, 1990), we searched for a research site with only microphytic crusts present. Such a site was found in Capitol Reef National Park (CARE), Utah, wherein no apparent vesicular horizon and physical or chemical crusts were present. The microphytic crust was predominately composed of *Microcoleus vaginatus* and is typical of the crusts found in the Colorado Plateau biogeographical province (Belnap and Gardner, 1993; Belnap et al., 1994).

MATERIALS AND METHODS

STUDY SITE

The study site was in the Hartnet Draw within CARE, south-central Utah, approximately 60 km west of Hanksville, Utah, at an elevation of 1750 m. A meteorological station at the site during the study period from 1989 through 1991 recorded between 333 mm and 607 mm annual precipitation, a maximum wind speed of 14.8 m•s^{-1} at 1.5 m, maximum and minimum temperatures of 46.0° C in July and - 27.5°C in February, with the median annual temperatures ranging from 8.0° to 12.0° C. Long-term records at CARE headquarters, 15 km to the south at 1000 m, registered snowfall during all months but June, July, August, and September with a maximum depth of 356 mm.

Hartnet Draw is an alluvial valley characterized by alternate broad and open basins with canyon sections on an anticlinal fold (Billingsley et al., 1987). An ephemeral stream cuts through Jurassic period (135 to 180 mybp) deposits, specifically the Brushy Basin Shale member of the Morrison and Summerville Formations (Billingsley et al., 1987). The study site is on an alluvial fan grading into a stream terrace consisting of gravel, sand, silt, and clay deposits. The overall slope varies from 0 to 2% with a northern exposure. An order 4 soil survey, as per USDA (1980) guidelines, was conducted and soil at the site was classified in the Begay Series (Ustollic Camborthid, coarse-loamy, mixed, mesic) and Semidesert Sandy Loam (Fourwing Saltbush) range site (Swenson and Jarman, 1991). The vegetation type is classified as a Greasewood-Rabbitbrush Phase of Intermittent Riparian Shrub Community (Romme et al., 1993).

LANDUSE HISTORY

Cattle and sheep have grazed CARE since the late 1800s (N.A.S., 1984). Since 1954, the Hartnet Draw and surrounding area has served as winter pasture for cattle; before that time its use was year-round. The livestock grazing allotment now consists of three paddocks totaling approximately 36 000 ha and is managed on a rest-rotation basis with use between November and June. The grazing allotment ranged from 1,008 to 1,500 animal unit months (AUM) or approximately 0.06 AUM•ha^{-1} (0.02 AUM acre^{-1}) during the study period.

Rabbits and rodents are the only other large herbivores present in the Hartnet Draw. Deer and elk do not inhabit the area, apparently due to the remoteness of a perennial water source.

A 6 ha (13 acre) exclosure was fenced in 1987 to 1988 to protect the experimental sites from human and livestock traffic. Small, bounded ephemeral drainage channels served as paths for human foot traffic.

EXPERIMENTAL PROCEDURE

PLOT DESCRIPTION

Forty-eight plots were located within the exclosure in shrub interspaces. Plots were positioned to correspond with the direction of the prevailing winds.

The dimensions of each plot were 2.4 m x 0.15 m, constituting an area of 0.37 m^2. Visually determinable soil surface characteristics for each plot were recorded before treatment assignment and application. Percentage surface area occupied by microphytic crusts, pebbles, vascular plants, litter, cracks, or bare soil categories was determined from 48 points with a point frame (500 x 1000 mm) on legs that rested outside the plots (Floyd and Anderson, 1982). Soil surface microtopography was measured with a rill meter (McCool et al., 1976). Soil cores were collected at 0 to 50 mm and 50 to 100 mm depth from immediately outside all plots before tests. Gravimetric soil moisture and bulk density (Gardner, 1986) were determined from these soil cores. After wind tunnel tests we collected additional soil samples from plot surfaces, which were used to determine soil texture (Gee and Bauder, 1986), aggregate stability (Kemper and Rosenau, 1986), soil organic matter (revised Walkley-Blake; Jackson, 1955), and Mg, Ca, Na, and K concentrations (Rhoades, 1982: adapted for arid land soils by R. G. Gavlak, D. A. Horneck, and R. O. Miller, Utah State University Soils Laboratory, Logan).

TREATMENTS

Treatments were applied and wind tunnel tests conducted in June and July of 1990 and 1991. Each treatment was randomly assigned to one of three plots in each set. The treatments were:

1. Control, in which no disturbance was allowed to the soil surface.
2. Microphytes chemically killed to determine the contribution of nonliving microphytes to soil stability. Microphytes were killed by application of 0.61 mm (0.6 1 • m^{-2}) commercial grade calcium hypochlorite [65% Ca(OCl)$_2$ 35% inert material;

0.1 M $Ca(OCl)_2$ applied concentration], and crust left in place. Calcium hypochlorite is an oxidizing agent and disrupts cell wall integrity. Tests to determine the most suitable agent and concentration to kill the microphytes showed that microphytes treated with this oxidizing agent no longer photosynthesized even though the filament structure remained intact.

3. Scalped to approximate the absence of microphytes. The microphytic crust and approximately 10 mm to 20 mm of the soil surface were carefully removed using a small putty knife.

Control and scalped plots were treated with 10 mm of calcium chloride (0.1 M $CaCl_2$) solution to insure the same amount of calcium was applied to all treatments. Chemicals were applied from one to two weeks before wind tunnel tests. The addition of $Ca(OCl)_2$ and $CaCl_2$ to a calcium-rich environment would be less likely to affect soil conditions than the alternatives that contained greater concentrations of sodium, e.g., commercially available chlorine bleach.

WIND TUNNEL

A portable open-bottomed wind tunnel, 150 mm x 150 mm cross-section by 2.4 m length (fig. 1), was used to assess the influence of microphytic crusts on wind erosion (Gillette, 1978). The 5:1 contraction chamber, working section, and expansion chamber were designed to create a variable-speed turbulent boundary layer over soil surfaces with minimal roughness. Air was drawn through the wind tunnel by a suction-type turbine powered by a 30-hp engine. Wind speeds were determined by pressure readings taken of the wind stream profile from soil surface to top of the wind tunnel. The wind tunnel is capable of producing wind speeds up to 30 m • s^{-1}. An inline filter inserted at the end of the expansion chamber trapped and collected sediment. In preliminary tests, the filter trapped 15, 22, 99, and 100% of 0.10, 0.15, 0.54, and 1.77 mm diameter glass beads, respectively.

Wind speed was increased in the tunnel until particle movement was observable (U_{*t}) across the soil surface. The air-flow profile was measured and recorded. Next, wind speed was increased to full capacity of the machine, which was comparable to regionally recorded high wind speeds (table 1). The increase was done slowly to guard against hydraulic jump and concomitant disruption of the soil surface. The flow profile at maximum speed was then recorded. The elapsed time from initiation of particle movement to shut down was approximately 10 min.

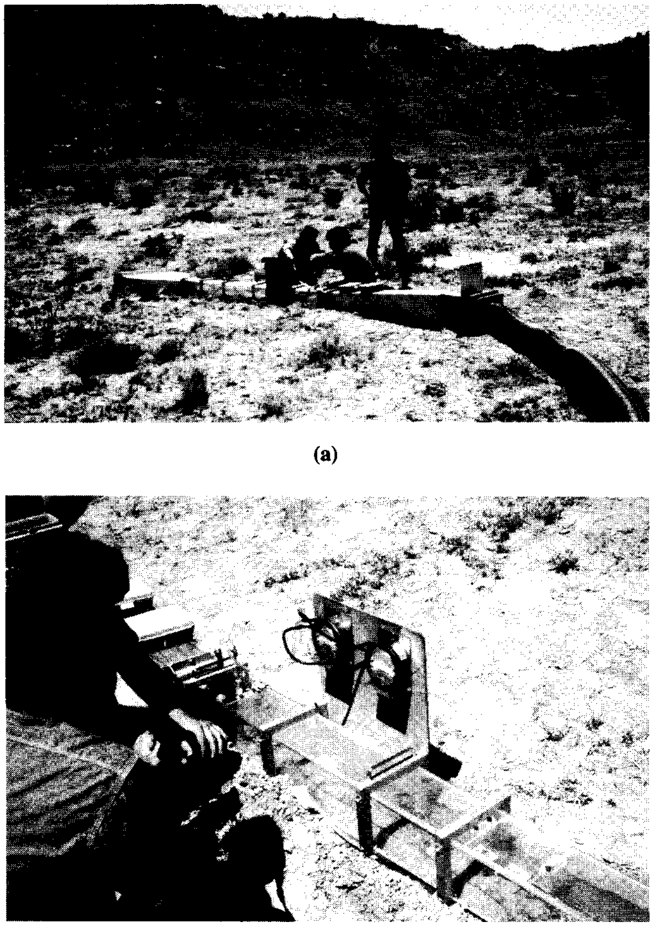
Wind profile data were fitted to the equation for aerodynamically rough flow:

$$U \quad k_{*t} \ \mathrm{In} \ _{Lz0} \Big| \qquad (1)$$

for $Z > Z_0$ and Z # 0, where U (m • s^{-1}) is the horizontal wind speed at height Z (mm), U_{*t} is threshold friction velocity and measure of soil stability, Zp is roughness characteristic of the surface height where U = 0 at Z = Z0, and k (-0.4) is Von Karman's constant (Priestly, 1959; Hsu, 1973; Gillette, 1978). The responses recorded for analysis were U_{*t} (m • s^{-1}) at the soil surface, maximum wind speed (U m • s^{-1}) at 100 mm above the surface during erosion tests, and total amount of wind-eroded material trapped in the inline filters.

DATA ANALYSIS

Data from 48 wind tunnel plots, divided evenly among three treatments and two years, were analyzed in a 3 x 2 (treatment x year) factorial experiment and analysis of



(a)

Figure 1-Open-bottomed wind tunnel: (a) NOAA portable wind tunnel; and (b) pitot tube and pressure gauges in working section.

lhble 1. Regional monthly recorded high wind speeds between 1982 and 1988

Month	Bullfrog m•s^{-1}	Moab m•s^{-1}
January	—	33
February	—	29
March	30	35
April	28	32
May	29	35
June	28	28
July	29	32
August	—	27
September	—	34
October	—	28
November	—	32
December	—	28

Data compiled by Brough et al., 1989.

variance (ANOVA). Scheffe's multiple comparison test was used for mean separations because it was considered the most conservative of the available tests (Ott, 1988). Rejection of the null hypothesis was at a <_ 0.05 (Neter et al., 1983). Analysis was conducted using Number Cruncher Statistical System (NCSS) (Hintze, 1991). Regression analysis was conducted to determine if a correlation existed between plot characteristics and test response variables.

RESULTS AND DISCUSSION

PLOT CHARACTERISTICS

With few exceptions, the research site and plot locations were homogeneous before treatment application. The difference in surface cracks (1.4%) between chemically killed and control plots did not correlate with, nor appear to affect, U*t or sediment production.

Some plots differed (a <_ 0.05) in the following characteristics after treatments: soil organic matter between control and scalped, extractable Na between control and chemically killed, composition of soil surface by algal crust, and total cover between scalped and both control and chemically killed. A complete list of plot characteristics recorded is in table 2. None of the 39 characteristics were correlated significantly with U*t or wind eroded material and suggests these characteristics had little influence on the soil stability at this spatial scale.

As expected, treatments changed the extent of soil surface composed of algal crust, total cover, and soil organic matter. Soils in plots where microphytes had been chemically killed contained significantly more extractable sodium than did soils in the control plots. Because the treatments were interspersed, it is unlikely that the plots were located on sites of high sodium concentrations prior to treatment, thus the difference was apparently due to sodium contamination in the treatment solution. Gillette et al. (1980) reported a significant concentration of sodium, 20% by volume, in playa soil of the Mojave Desert. Sodium concentrations were correlated with soil moisture and the inhibition of wind erosion. At our site, there were no correlations between soil moisture, sodium concentrations, and U*t, so the differences in sodium content of soil did not appear to affect U*t.

THRESHOLD FRICTION VELOCITY (U*t)

Microphytic crusts that had been undisturbed for the previous two to three years contributed to soil stability by reducing wind erosion, as was evident by the significantly lower U*t (fig. 2) and the significantly greater volume of suspended sediment from the scalped plots compared to the control and microphyte-killed plots (fig. 3). The wind speed associated with erosion was significantly lower in the scalped plots than measured in the control and chemically killed plots. As the wind speed increased on the scalped plots, large volumes of soil were dislodged, entrained, and transported to the filter, which was quickly clogged. Nonetheless, the removal of the microphytic crusts not only increased soil loss, but caused soil loss to occur at significantly slower wind speeds (table 3). Threshold velocity values were not significantly different among control and chemically killed treatments. This result provides evidence supporting claims based on microscopic

Table 2. Results of mean separation tests for plot characteristics*

	Control	Microphyte-Killed	Scalped
Surface composition (%)			
Total cover	**91.4±1.8a**	**91.8±1.8a**	**12.6±1.9b**
Algalcrust	**76.5±3.6a**	**76.3±2.6a**	**0.030.0b**
Bare soil	**4.9±1.9a**	**6.8±1.9a**	**84.8±2.2b**
Litter	**9.0±1.9a**	**7.4t1.3a**	**7.3±1.3a**
Pebble	**4.6±1.2a**	**2.230.6a**	**1.7±0.8a**
Surface cracks	**3.7±0.5a**	**1.4±0.1b**	**2.6t0.6ab**
***Collema* sp. (lichen)**	**2.2t1.2a**	2.5±1.Oa	**O.o±0.0a**
Hilaria jamesii	**1.7±1.3a**	**1.6±0.7a**	**1.6±03a**
Sporobolus cryptandrus	**0.3±03a**	**0.8t0.5a**	**0.8±0.6a**
Oryzopsis hymenoides	**0.1±O.la**	**0.3±0.2a**	**0.8t0.6a**
Salsola kali	**0.3±0.2a**	**0.4±03a**	**0.1t0.la**
***Tortula* sp (moss)**	**0.4±0.4a**	0.0±0.0a	**0.330.2a**
Amsinckia sp.	**0.3±0.2a**	**0.3±0.2a**	**0.0±0.0a**
Gutierrezia sarothrae	**O.l+O.la**	0.0±0.0a	**O.I+O.la**
Lepidium sp	**O.0±o.oa**	**O.l±0.la**	**0.0±0.Oa**
Soil Characteristics			
Organic Matter (%)	**0.40±0.02a**	**0.26±0.02ab**	**0.31±0.03b**
Texture (%)			
Sand Fraction	**62.36t1.40a**	**60.15±1.56a**	**61.60±2.18a**
Silt Fraction	**31.76±1.17a**	**33.15±1.31a**	**31.79±1.86a**
Clay Fraction	**5.88±0.29a**	**6.73±0.44a**	**6.61±0.45a**
Soil Moisture (%)			
Gravimetric			
50 mm	**2.8±0.5a**	**3.0t0.5a**	**3.0±0.5a**
100 mm	**3.2±0.5a**	**3.2±0.5a**	**3.4±0.5a**
Bulk Density (Mg•m-3)			
50 mm	**1.6±0.1 a**	**1.6±0.1a**	**1.6±0.0a**
100 mm	**1.6±0.1a**	**1.6±0.l a**	**1.6±0.Oa**
Extractable Cations (cmol•kg-I)			
Sodium	**0.4+0.la**	**1.3t0.3b**	**0.930.2ab**
Calcium	**30.2t0.7a**	**30.831.la**	**30.9±1.0a**
Potassium	**0.530.oa**	**0.630.0a**	**0.6±0.0a**
Magnesium	**1.230.1a**	**1.230.1a**	**1.330.la**
Microtopography (8)	**7.7430.63a**	**7.84i0.61a**	**8.0330.63a**

Characteristics, by row among treatments, with same letter are not significantly different at the ot ± 0.05. **Mean t standard error presented.**

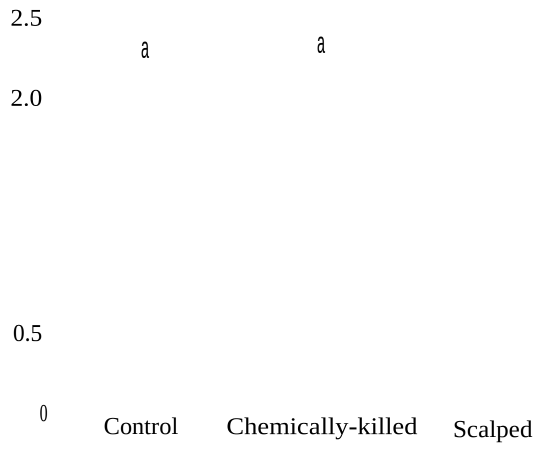


Figure 2-Treatment means and standard errors for threshold friction velocities. Different letters indicate significance at « <_ 0.05.

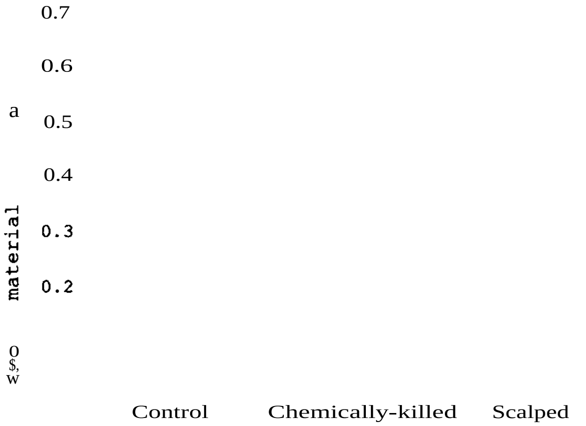


Figure 3-Treatment means and standard errors for wind-eroded material from within 2.4 m wind tunnel. Different letters indicate significance at « <_ 0.05.

observation (Belnap, 1993) that nonliving *Microcoleus* sheaths contribute to soil stability against wind stress.

We also conducted additional wind tunnel tests on four plots without any treatments applied to determine background conditions. Although the average U*t on these plots was lower than on the control and chemically killed plots (table 3), it was higher than on the scalped plots. At similar maximum speeds, there was slightly less (30.6 g) eroded material from untreated plots than either experimental control ($CaC1_2$) or microphyte-killed [$Ca(OCl)_2$] plots.

The threshold friction velocities (table 3) were comparable to those in other arid wildland ecosystems (Gillette, 1981; Gillette et al., 1980; Gillette et al., 1982). Threshold friction velocities measured on rain-crusted sandy loam soils (2.9 m - s^{-1}, Gillette, 1988) were similar to those on the control and chemically killed plots (table 4). Rain-crusts, as those examined by Gillette (1988), are ephemeral whereas microphytic crusts are present throughout the year, continuing to develop and perhaps persist for decades. Threshold friction velocities in sandy soil (90% sand) in the Mojave Desert (no microphytic crusts) between 0.2 and 0.6 m - s^{-1} (Gillette et al., 1980) are lower than the mean value of 0.9 m - s^{-1} on the scalped sandy loam soil.

The minimum wind speed needed to initiate soil movement in mixed size dune sand is 6 m - s^{-1} at 300 mm above the surface (Beasley et al., 1984). The maximum wind speed recorded at the site during our research was 15 m - s^{-1} (table 5). If one assumes 6 m - s^{-1} at 100 mm (anemometer height) produced 0.3 m - s^{-1}, from equation 1, or greater wind velocities at the soil surface then approximately 10% of the wind gusts recorded at the research site between 1989 and 1991 would have been sufficient to initiate erosion. However, soil surface development without microphytic crusts probably differ from the surface condition that resulted after scalping the plots.

Table 3. Maximum velocity recorded at 100 mm above soil surface for erosion test

Treatment	m*s^{-1}*
Control	28.34 t 2.21
Chemically killed microphytes	30.53 t 1.99
Microphytic crusts scalped	20.07 t 0.95

* Mean t standard error given for measured maximum velocities.

Table 4. Average threshold friction velocities

	m*s-I
Background plots	1.39 ± 0.07
Treatment	
Control	2.06 t 0.22
Chemically killed microphytes	2.09 ±0.22
Microphytic crusts scalped	0.93 ±0.11

* Mean t standard error.

Long-term wind data are scarce for most areas and nonexistent for remote areas like CARE. Maximum wind speeds reported by state or federal climatic stations nearest to the research site (Moab, 250 km and Bullfrog, 150 km distant, respectively) are given in table 1 (Brough et al., 1989). The frequency of wind speeds exceeding 22 m - s^{-1} was greatest during March, April, and May at Moab. If the wind speeds recorded at Bullfrog or Moab are typical for the region, the wind speeds used in our tests possibly occur at the CARE site.

Although algal crusts appear to help stabilize soil against wind, the results might depend on spatial scale and landscape dynamics. For example, Van den Ancker and Junerius (1985) and Pluis and de Winder (1989) found that algal crusts were quite effective in colonizing and stabilizing small dune blowouts in coastal dune areas of the Netherlands, but there were only small colonies of algae in larger blowouts due to wind and the influence from surrounding vascular vegetation.

The value of microphytic crusts in soil stabilization during drought also depends upon the frequency of dust storms and rate of erosion, which appears to be increasing in areas with increasing human activity, vegetation loss, and disturbance of protective soil surfaces (Goudie, 1983; Middleton, 1989). Vegetation is reduced with increasingly dry and often loose soils that accompany drought (Gillette and Hanson, 1989) and, thus, soil erosion potential increases. In clay rich soils, clay particles are able to form sand-sized aggregates (Gillette, 1981) called parma (Young et al., 1986). Unlike clay aggregates, however, the

Table 5. Mean*, median*, and maximumt wind speeds recorded at research site between January 1989 and September 1991 at 1.5 m

Year	Mean (m-s-1)	Median (M*s-1)	Month$	Maximum (m*s-1)
1989	1.11	0.58	June	14.81
1990	0.97	0.50	July	13.42
1991	1.03	0.53	March	13.67

* Mean and median values calculated from readings made of average wind speed during each one half hour period.

t Annual maximum speeds determined from maximum recorded each half hour.

$ Month when maximum speed was recorded.

microphytes appear to provide a structure that is nearly continuous and less erodible. We found that even dead microphytes help stabilize the soil surface. Dry microphytes can apparently survive months and years and begin photosynthesis when rehydrated in sunlight (e.g., Scherer et al., 1984), but it is not known how long dry crusts will continue to stabilize the soil surface before they deteriorate. If there is not enough moisture to maintain soil-stabilizing vegetation, but there is adequate moisture to initiate a minimal growth of algae in desert soils, the judicious protection of microphytic crusts might ameliorate the effects of long periods of drought and wind. In the United States, 3.6 million ha of rangeland are subject to some degree of wind erosion annually (Beasley et al., 1984). Microphytic crusts are potentially the last defense against extensive soil loss in these areas.

Although microphytic crusts appear to stabilize soil, our findings are site and scale specific and thus reflect local edaphic, climatic, and historic conditions. Killing microphytes with chemicals or removing them are not practices associated with normal land use, which would simply involve breaking part of the crust and leaving partially aggregated pieces in place.

CONCLUSION

We found that microphytic crusts helped stabilize soil against wind at our study site, which is consistent with previous work concerning the soil-binding mechanisms of microphytes and the resultant crusts. Microphytic crusts can enhance the stability of dry soil. Additional designed experiments are warranted to determine how the stabilizing influence of microphytic crusts are affected by type, degree, frequency, and season of disturbance.

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