MICROPHYTIC CRUST INFLUENCE ON INTERRILL EROSION AND INFILTRATION CAPACITY

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

ABSTRACT. *Microphytic crusts form at the soil surface in arid and semiarid rangelands. They bind soil particles together and purportedly influence hydrologic and stability responses to rainfall. We tested this influence in a designed rainfall simulation experiment conducted on a sandy loam site in Capitol Reef National Park, Utah, that had been protected from livestock and human traffic for two to three years. Treatments consisted of microphytic crust conditions: 1) living and undisturbed (control); 2) chemically killed to determine structural influence (chemically killed), and mechanically removed from the soil surface (scalped) to approximate conditions of absence. Microphytic crusts in control and chemically killed treatments significantly reduced ($\alpha \leq 0.05$) time to ponding and time to runoff, apparently due to structural and textural differences at the soil/air interface. Interrill erosion was greatest in the chemically killed treatment and lowest in the control treatment. Interrill erosion in the scalped treatment was significantly greater than in the control treatment at 45 and 90 min. Microphytic crusts did not significantly influence the infiltration capacity. We attribute these responses to textural differences and structural support contributed to the soil by the microphytes. In the control treatment, living microphytes' greatest contribution was to the stabilization of fine soil particles at the soil surface. Microphytic crusts' ability to contribute to soil stability should be considered in development of management plans.*
Keywords. *Raindrop impact, Soil stability, Microphytic crusts, Cryptobiotic crusts, Microbiotic crusts, Aridland processes.*

Considerable speculation has occurred in the last 50 years about the role of microphytes in hydrologic and stability properties of soil. Microphytes—mosses, lichens, and algae—contribute to the development of microphytic (synonyms are cryptogamic, cryptobiotic, or microbiotic) crusts on rangeland soils. In the following discussion, the crusts will be identified variously, as in the cited literature, as algal, cyanobacterial (known in older literature as bluegreen algae), or lichen crusts. In 1986, when this research began, studies purporting to show the importance of microphytic crusts were extensive, contradictory, and often the conclusions were reached by pseudoreplicated and/or post hoc experimental designs (Eberhardt and Thomas, 1991; West, 1990).

Undisturbed microphytic crusts reportedly enhanced infiltrability at some sites in the United States (Brotherson and Rushforth, 1983), Spain (Alexander and Calvo, 1990), and Australia (Greene et al., 1990). This enhancement was attributed to the ability of microphytes to reduce development of physico-chemico raincrusts in loessal-silt soils (Booth, 1941; Fletcher and Martin, 1948; Shields and Durrell, 1964). Soil surface structure, and thus macropores (> 0.75 mm diameter) might also be maintained by well developed microphytic crusts (Eldridge, 1993a).

Microphytic crusts are not always associated with superior infiltration capacity. For example, basidiomycetous fungi encase sand grains in organic material and create hydrophobic conditions in the interspaces between vascular plants (Bond, 1964). Under ponded conditions, infiltration increased after the hydrophobicity was overcome (Bond, 1964). Infiltration into sandy soils increased threefold after lichen crusts had been removed from plots in western New South Wales, Australia (Graetz and Tongway, 1986). Turgid and swollen lichens that fill soil pores apparently restrict the downward passage of water and the exchange of soil gasses (Graetz and Tongway, 1986). In the Negev, Israel, preliminary results indicate that removal of a thin microphytic crust increased infiltration capacity and reduced erosion of clays and silts (Yair, 1990).

Evidence is also presented that microphytic crust do not affect infiltration. Microphytic crusts dominated by cyanobacteria did not influence the infiltration capacity of three coarse sandy loam soils tested in Kansas, Oklahoma, and Texas (Booth, 1941). In a greenhouse study of silt loam and clay loam soils in Arizona, Faust (1970) found no significant differences in infiltration capacity between plots with (inoculated) and without algal crusts. On clay loams and loams in New South Wales, Australia, microphytes had less effect on infiltration than did other soil characteristics (Eldridge, 1993b).

The physics governing the passage of water between the interface between microphytic crusts and mineral soil might be similar to that in raincrust and mineral soil. Graetz and Tongway (1986) and Danin et al. (1989) have reported increased concentrations of clay and silt in developed microphytic crusts. These fines would be a discontinuity in soil texture and organic matter through which water must pass. Ahuja (1983) and Hillel and Gardner (1969, 1970) examined how fines affected

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infiltration into soils with raincrusts. Microphytic crusts potentially influence infiltration in a similar manner through a combination of concentrated fine soil particles and hydrophobic organic matter at the soil surface. However, any reduction in infiltration capacity might be offset by greater aggregation resulting from microphytes.

The uneven microtopography, characteristic of well-developed microphytic crusts, might either be the result of erosion around stabilized points or the uplifting and subsidence due to frost heaving as microphytes stabilize certain points (Eckert et al., 1989). The uneven microtopography effectively creates small detention dams that increase the tortuosity of overland flow, thereby reducing the site gradient (Abrahams et al., 1988). The reduction in flow velocity could increase the time water has to infiltrate before it runs off a site.

Although increased infiltration and reduced soil erosion are often related to enhanced soil aggregation associated with microphytic cover, studies of microphyte-induced aggregation have not made this claim (Anantani and Marathe, 1972) or only have inferred the possibility (Gifford, 1986). Numerous investigators have examined the microscopic binding mechanisms of soil particles (e.g., Fletcher and Martin, 1948; Campbell, 1979; Danin et al., 1989; Belnap and Gardner, 1993). Cyanobacterial crusts appeared to contribute to soil stability on micro-plots (≤ 2 m^2) at sites in Kansas, Oklahoma, and Texas (Booth, 1941) and in Arizona (Brotherson and Rushforth, 1983). Monoliths with surface areas from 240 mm^2 to 6400 mm^2 and covered with various microphytic life forms and degrees of development were removed from sites in Australia (Kinnell et al., 1990; Eldridge, 1993b) and Utah (Tchoupopnou, 1989), and were subjected to simulated rainfall in laboratories. Soil stability increased with cover and with associated changes in the dominant microphytic life form: bare soil < algal crust < lichen crust < moss-covered soils.

However, not all microphytic crusts reduce erosion potential. Graetz and Tongway (1986), for example, reported that removing microphytes from a sandy site in Australia increased infiltration to such an extent that runoff and interrill erosion were negligible. Eldridge (1993a) attributed their results to exposure of macropores with the removal of the microphytic crust.

Our primary objective was to determine, through a designed experiment, if microphytic crusts significantly influence infiltration or soil stability. Because many other types of soil crusts might influence these properties, we searched for and located a site with only microphytic crusts present. Vesicular horizons, physical, and chemical crusts were not apparent.

Materials and Methods

Study Area

We conducted the studies in the Hartnet Draw within Capitol Reef National Park (CARE), south-central Utah, approximately 60 km west of Hanksville, at an elevation of 1750 m (39°N Lat, 111°W Long). A meteorological station at the site during the study period from 1989 through 1991 recorded between 333 mm and 607 mm annual precipitation, maximum and minimum temperatures of 46.0° C in July and –27.5° C in February with median annual temperatures ranging from 8.0° to 12.0° C. The maximum rainfall intensity recorded was 48 mm•h^{-1}. Long-term park records at CARE headquarters, 15 km to the south at 1000 m, register snowfall during all months, except 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 four soil survey, as per USDA (1980) guidelines, was conducted and soil at this 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 the Intermittent Riparian Shrub Community Type (Romme et al., 1993). 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).

Landuse History

Cattle and sheep have grazed CARE since the late 1800s. Since 1954, the Hartnet Draw and surrounding area has served as winter pasture for cattle but was used year-round before that time. 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. Animal unit months (AUM) range from 1,008 to 1,500 with stocking at approximately 0.06 AUM•ha^{-1} (0.02 AUM•acre^{-1}). Rabbits and rodents are the only native mammalian herbivores at the research site.

A 6-ha exclosure was fenced in 1987 and 1988 to protect the experimental sites from humans and livestock. Small, bounded ephemeral drainage channels served as paths for human foot traffic while experiments were conducted.

Treatments

Three treatments were used for infiltration-erosion tests conducted in June and July of 1990 and 1991. 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 l•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 was 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 simulated rainfall 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.

Plot Descriptions

Vegetation Sampling. Visually determinable soil surface characteristics for each plot were recorded before treatment assignment and application. Percentage surface area occupied by microphytes (by life form), vascular plants (by species), litter, pebble, cracks, and bare soil were determined from 90 points with a point frame (500 mm × 1000 mm) suspended on legs that were placed outside the plots (Floyd and Anderson, 1982). One half of the plot was sampled, then the point frame was repositioned over the second half. After rainfall simulation, the plots were clipped, and all vascular vegetation except for a few low frequency forbs was separated by species. All plant materials were stored in paper bags, returned to the laboratory in Logan, and dried for 24 h at 105° C.

Soil Sampling. Soil cores were collected at depths of 0 to 50 mm and 50 to 100 mm immediately outside all plots before tests, and were used to determine pH and EC (McLean, 1982), gravimetric soil moisture, porosity, and bulk density (Gardner, 1986). Soil samples were not collected from within the plots before rainfall simulations in order to avoid disturbance of the soil surface. After rainfall simulation, bulk soil samples were collected from the upper 50 mm of soil within each plot, which were used to obtain an integrated measure of aggregate stability (Kemper and Rosenau, 1986), particle size distribution (Gee and Bauder, 1986), organic matter (Jackson, 1955), and extractable cation concentrations—Na, K, Ca, and Mg (Rhoades, 1982: adapted for arid land soils by R. D. Gavlak, D. A. Horneck, and R. O. Miller, Utah State University Soils Laboratory, Logan). Particle size distribution was also determined for soil within the microphytic crusts removed in the scalped treatment.

Surface slope and roughness were measured by placing a rill meter (McCool et al., 1976) at three positions parallel to the slope and at three positions perpendicular to the slope. Slope was the average change in elevation down the plot. The mean square errors of the roughness measurements in both directions were used as a relative index for comparisons among treatments (Sanchez and Wood, 1987; Roundy et al., 1990).

Volumetric soil moisture was measured in the upper 200 mm of the soil surface before each rainfall simulation. Nondestructive measurements inside the plot were made using time domain reflectometry (TDR) with a Tectronics 5402c wave sampler and 250-mm stainless steel wave guides (Topp and Davis, 1985; Reeves and Smith, 1992).

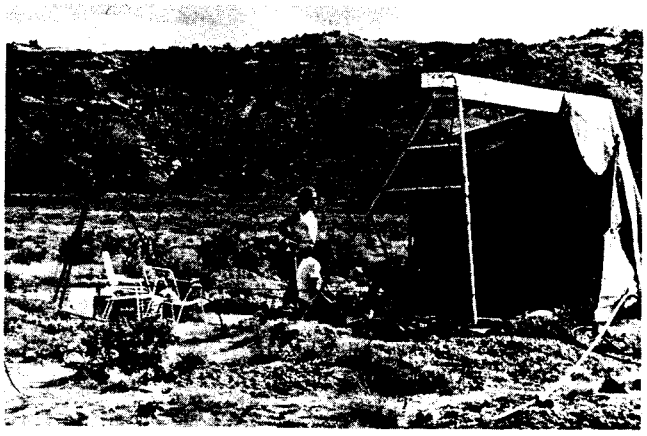

Figure 1–Rainfall simulator with wind guard.

Simulated Rainfall

Equipment. Rainfall was simulated with a portable Purdue-type rainfall simulator capable of producing (fig. 1; Meyer and Harmon, 1979; Neibling et al., 1981). The rainfall simulator produced raindrop size distribution, distributed evenly across the plots, at raindrop velocity and impact very closely approximating that of a 25 to 50 $mm \cdot h^{-1}$ convectional storm (Meyer and Harmon, 1979). Experimental units were 1-m^2 plots positioned in shrub interspaces and bordered by steel plot frames.

Rainfall Simulation and Sample Collection. We conducted a preliminary study ($n = 8$) in September 1989 to determine the sample size needed to detect a true difference in δ at $\alpha \leq 0.05$ and $P \geq 0.80$ for infiltration capacity. A sample size of $n = 8$ was determined to be adequate (Sokal and Rohlf, 1981). Forty-eight plots were randomly assigned one of the three treatments to be applied in either 1990 or 1991 in a balanced design.

Circular areas (1.1 m^2) that included the plots were pre-wetted with a mist nozzle to apparent surface saturation (≈ 12 mm) 24 h before application of the simulated rainfall. The plots were covered with plastic and allowed to drain to field capacity. This procedure was intended to reduce variation in antecedent soil surface moisture and simulate the soil-moisture conditions the day after a light monsoonal shower.

Simulated rainfall was applied at an average rate of 87 $mm \cdot h^{-1}$, requiring the machine to operate at full capacity. Applying water at a slower rate would not produce runoff in less than an hour. The simulated rainfall exceeded the calculated 100-year return period intensities for 1-h periods at CARE headquarters (28.2 $mm \cdot h^{-1}$) or Hanksville (37.9 $mm \cdot h^{-1}$) (Richardson, 1971) and was nearly twice the largest intensity at the site during the previous three years (48 $mm \cdot h^{-1}$).

Rainfall was applied for 90 min after water began flowing through the trough into the catchment. After 45 min of runoff we stopped the simulation for 5 min to refuel the pump and generator. Water for rainfall simulation had mean concentrations ($Mg \cdot l^{-1}$) of Na^+, K^+, Ca^{++}, and Mg^{++} in the water were 2.4, 0.7, 3.7, and 2.4, respectively.

Table 1. Plot characteristics initially considered for covariates

Soil	
Antecedent moisture (50 and 100 mm) (% mass and % volume) (GSM5CM, VSM5CM, TDRSM)	
Bulk density (50 and 100 mm)($Mg \cdot m^{-3}$) (BD5CM and BD10CM)	
Extractable cations (Na, K, Ca, Mg)($mmol \cdot kg^{-1}$) (NA, K, CA, MG)	
Electrical conductivity from extract (EC)	
Organic matter (% mass) (SOM)	
Porosity (50 and 100 mm) (% volume) (f50mm, f100mm)	
pH from extract ($-\log[H^+]$) (PH)	
Temperature (100 and 200 mm) (C°) (T100mm and T200mm)	
Texture (sand, silt, and clay) (% mass) (Sand, Silt Clay)	
Surface	
Slope (%) (down plot - SLOPED, across plot SLOPEA)	
Roughness (residual mean square error)	
— With slope (RSMED)	
— Across slope (FSMEA)	
Cover and composition (% area)	
Cyanobacterial crust (CC)	Litter (LTTR)
Amsinckia sp. (AMSP)	*Opuntia polyacantha* (OPPO)
Atriplex confertifolia (ATCO)	*Oryzopsis hymenoides* (ORHY)
Bare soil (BARE)	Pebble (PBBL)
Collema sp. (lichen) (COSP)	*Salsola kali* (SAKA)
Cracks (CRKS)	*Sporobolus cryptandrus* (SPCR)
Gilia sp.(GISP)	*Tetradymia* sp. (TESP)
Gutierrezia sarothrae (GUSA)	*Tortula* sp. (moss) (TOSP)
Hilaria jamesii (HIJA)	Miscellaneous forbs (MISC)
Lepidium sp. (LESP)	Total (TOTCV)
Vegetation biomass ($g \cdot m^2$)	
Atriplex confertifolia (ATCOB)	*Sphaeralcea* sp. (SPSPB)
Bouteloua gracilis (BOGRB)	*Opuntia polyacantha* (OPPOB)
Gilia sp. (GISPB)	*Oryzopsis hymenoides* (ORHYB)
Gutierrezia sarothrae (GUSAB)	*Salsola kali* (SAKAB)
Halogeton glomeratus (HAGLB)	*Sporobolus cryptandrus* (SPCRB)
Hilaria jamesii (HIJAB)	*Tetradymia* sp.
Lepidium sp. (LESP)	Miscellaneous forbs (MISCB)
Litter (LTTRB)	Total (TOTBIO)

In the field we recorded antecedent volumetric soil moisture, time to ponding, time to runoff, runoff after each 5-min period, and simulated-rainfall after 45 and 90 min. Runoff was weighed in a container suspended from a scale and the weight was recorded in 5-min intervals. The infiltration capacity ($mm \cdot h^{-1}$) was the difference between rainfall and overland flow divided by the period of measurement. Water was assumed to have infiltrated if evaporated, detained by vegetation, or ponded on the plot.

We agitated and collected subsamples from 15-min accumulations of runoff. One liter was treated with 5 mL of chlorine, which was then stored in the dark until it was vacuum filtered through a tared No. 2 Whatman qualitative filter. Filters were dried at 105° C for 24 h and weighed to measure suspended soil particles ($g \cdot l^{-1}$). One-half liter subsamples were collected in Whirl-Pak bags and frozen. These subsamples were analyzed for pH and EC in the laboratory using a glass-electrode meter (McLean, 1982).

Data Analysis

Analysis of Variance. A 3 × 2 (treatment × year) factorial experiment and analysis of variance (ANOVA) were used to test for differences in plot characteristics among treatments (Ott, 1988). Rejection of the null hypothesis was set at $\alpha \leq 0.05$. The Ryan-Einot-Gabriel-Welsch multiple range test was used for mean separation. Of the tests available, this test was recommended by the SAS User's Manual for the best control of α and β errors (SAS Institute, 1990). Linear correlation analysis ($\alpha \leq 0.5$) was used to determine relationships between plot variables and the dependent variables of infiltration capacity and interrill erosion (Neter et al., 1983).

Regression with Indicator Variables. Time to ponding and time to runoff, infiltration capacity, and interrill erosion were analyzed for differences among treatments using adjusted means obtained by regression with covariates and indicator variables. Covariates (table 1) were selected by iterative process and adjusted means tested for differences among treatments (Neter et al., 1983; Myers, 1990).

Results

Similarity of Plot Characteristics

A number of plot characteristics were significantly different between years (table 2). Because no comparisons were made with plots outside of the exclosure, we attribute these differences to temporal variability and not the result of protection from disturbance. A few plot characteristics were significantly different among treatments (table 3), but were not correlated with time to ponding and time to runoff, infiltration capacity, or interrill erosion.

Simulated Rainfall Results

Time to ponding and runoff was significantly greater in the scalped treatment. Control and chemically killed treatments were not significantly different in ponding time. All three treatments significantly differed in runoff time. The relative response order in both cases was chemically killed < control < and scalped (tables 4 and 5). Infiltration capacity was not significantly different among treatments for any 5-min time period after initiation of runoff (table 6). Infiltration capacity in our study was approached after approximately 80 minutes of runoff (fig. 2). Interrill

Table 2. Plot characteristics that differed significantly between years*

	Year	
Variable	1990	1991
Soil		
Antecedent moisture		
Gravimetric (% mass)		
50 mm	12.6±1.0	6.7±0.4
100 mm	11.9±0.6	6.5±0.6
Bulk density ($Mg \cdot m^{-3}$)		
50 mm	1.3±0.1	1.5±0.0
Extractable cations ($mmol \cdot kg^{-1}$)		
Ca	26.4±1.1	29.7±1.3
EC	251.7±26.9	161.7±7.7
Organic matter (%)	0.4±0.0	0.3±0.0
pH ($-\log[H^+]$)	8.3±0.1	8.5±0.1
Surface Cover and composition (% area)		
Litter	11.7±2.1	19.0±2.2
Sporobolus cryptandrus	0.8±0.5	0.0±0.0
Gutierrezia sarothrae	0.5±0.4	0.1±0.1
Amsinckia sp.	0.3±0.2	0.0±0.1

* Mean values (± standard error) significantly different between columns within rows at $\alpha = 0.05$.

Table 3. Plot characteristics significantly different between treatments – post-treatment

Characteristic	Treatments CO*	CK*	SC*
Soil			
Extractable cations (mmol•kg^{-1})			
Mg	1.1±0.0^a	1.1±0.0^a	0.9±0.0^b
Texture (% mass)			
clay	7.7±0.6^a	6.2±0.2^b	6.9±0.2^{ab}
Surface Roughness (RSME)			
Across slope	10.0±0.5^a	9.4±0.3^b	9.5±0.4^b
Cover and composition (% area)			
Cyanobacterial crust	56.8±2.5^a	61.5±2.3^a	0.0±0.0^b
Bare soil	2.8±1.0^a	4.2±1.1^b	67.3±2.1^b
Total cover	96.5±1.0^a	95.1±1.2^a	32.7±2.1^b

* Treatments are: CO = control, CK = microphytes killed, SC = microphytes removed (scalped). Mean values with same letter not significantly different within rows at $\alpha = 0.05$.

erosion differed significantly among treatments and changed through time (table 7). Interrill erosion in the control treatment was significantly less than the chemically killed treatment for all but the 45-min collection period, but only significantly less than the scalped treatment at 45 and 90 min. Scalped treatment means were significantly less than chemically killed means at 30 and 75 min. Interrill erosion was not correlated with infiltration or runoff. Accumulated interrill erosion was greatest in the chemically killed treatment and least in the control treatment.

Discussion

Time to Ponding and Time to Runoff. Several mechanisms might explain the rapid ponding in the control and chemically killed treatments. In the control treatment, rapid ponding potentially resulted from initial hydrophobic conditions created by microphytes. Although we did not directly test this hydrophobicity hypothesis, it is consistent with the fact that time to runoff was significantly slower in the control treatment than in the chemically killed treatment (table 5).

Alternatively, Eldridge (1993a) suggested that a similar result in a sandy soil (Greene et al., 1990) occurred because macropores were exposed by scraping. We believe that the differences in time to ponding and time to runoff were due to differences in soil texture within the crust and in the structure of the soil surface caused by the cyanobacteria. The microphytic crust contained more silt (5.5%; P = 0.04) than the subtending soil, similar to that reported elsewhere (Danin, 1978; Schulten, 1985; Tsoar and Möller, 1986). Cyanobacteria bind and contribute to the microstructure of fine soil particles in the Colorado Plateau near CARE (Belnap and Gardner, 1993). Desiccated hyphae and cyanobacterial filaments lose their ability to imbibe water (Fletcher, 1960), which is analogous to killing the microphytes with chemicals, potentially making the microphytes susceptible to hydrolysis (Lehninger, 1982).

Table 4. Time to ponding; covariates, indicator variables, and adjusted means

Variable	Parameter Estimate	Standard Error	T for H_0: Parameter = 0	Prob > |T|
Intercept	5.04	3.11	1.62	0.1131
Soil moisture (θ)	–0.24	0.15	–1.63	0.1116
Microtopography (s)	0.27	0.23	1.17	0.2509
Aggregate stability	0.24	0.12	1.91	0.0636
Porosity (50 mm)	39.20	20.98	1.87	0.0706
Organic matter (%)	–13.55	5.04	–2.69	0.0104
D_1 (CO vs. SC)	6.46	1.05	6.13	0.0001
D_2 (CO vs. CK)	–0.08	1.02	–0.08	0.0467
D_1,D_2 (SC vs. CK)	6.53	1.01	6.47	0.0001

Model P = 0.0001, adjusted R^2 = 0.53

Treatment*	Adjusted Mean (min)†
CO	1.4^a
CK	1.3^a
SC	7.9^b

* Treatments: CO = control, CK = chemically killed, and SC = scalped.
† Adjusted mean values with same letter not significantly different.

Table 5. Time to runoff; covariates, indicator variables, and adjusted means

Variable	Parameter Estimate	Standard Error	T for H_0: Parameter = 0	Prob > |T|
Intercept	39.02	5.06	7.72	0.0001
Soil moisture (θ)	–1.55	0.36	–4.30	0.0001
Hilaria jamesii (g)	–0.12	0.03	–3.70	0.0006
Slope (across, S)	–168.15	124.02	–1.36	0.1824
D_1 (CO vs. SC)	8.31	2.96	2.80	0.0077
D_2 (CO vs. CK)	–10.14	3.07	–3.30	0.0020
D_1,D_2 (SC vs. CK)	18.45	3.18	5.80	0.0001

Model P = 0.0001, adjusted R^2 = 0.4554

Treatment*	Adjusted Mean (min)†
CO	15.48^a
CK	5.34^b
SC	23.78^c

* Treatments: CO = control, CK = chemically killed, and SC = scalped.
† Adjusted mean values with same letter not significantly different.

Table 6. Probabilities of infiltration capacity treatment differences by 5-min periods

Time Minutes	Prob > |T| D_1	D_2	Time Minutes	Prob > |T| D_1	D_2
5	0.3372	0.6842	50	0.4637	0.4767
10	0.4460	0.6228	55	0.4116	0.3282
15	0.0960	0.4708	60	0.4473	0.6702
20	0.3409	0.4708	65	0.5179	0.7595
25	0.4756	0.4972	70	0.5081	0.8230
30	0.5307	0.5512	75	0.5264	0.9880
35	0.6603	0.9168	80	0.2641	0.5438
40	0.7906	0.6700	85	0.3343	0.4695
45	0.5862	0.5626	90	0.1594	0.4551

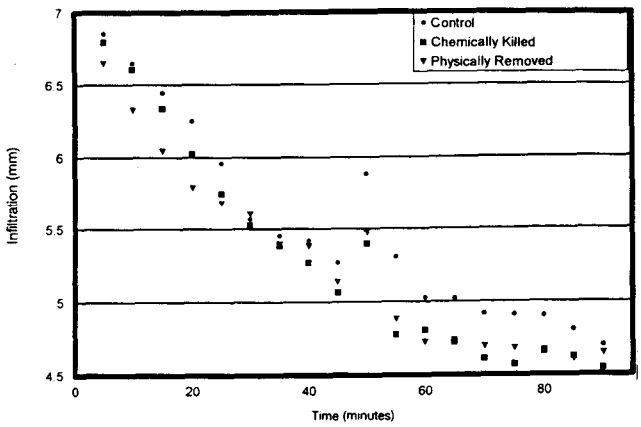

Figure 2–Mean infiltration capacity beginning at runoff and measured every 5 min.

Our contention is that the microphytes disintegrated and the resulting collapse, slaking, and a temporary sealing of the soil surface promoted rapid ponding and runoff from plots in the chemically killed treatment.

The short time to ponding and runoff suggests that microphytic crusts might have an influence of soil moisture regimes. However, this response was not investigated and comment would be purely speculative.

Table 7. Interrill erosion by 15-min period

Minutes	Parameter Estimate	Standard Error	T for H_0: Parameter = 0	Prob > |T|
15 D_1	2.03	1.18	1.73	0.0960
D_2	3.47	1.19	2.92	0.0071
D_1, D_2	–1.43	1.20	–1.19	0.2514
30 D_1	–0.11	0.69	–0.15	0.8776
D_2	1.77	0.75	2.40	0.0211
D_1, D_2	–1.89	0.74	–2.55	0.0146
45 D_1	2.04	0.74	2.77	0.0087
D_2	1.71	0.74	2.33	0.0254
D_1, D_2	0.33	0.73	0.45	0.6554
60 D_1	2.80	1.68	1.67	0.1038
D_2	3.00	1.75	1.70	0.0984
D_1, D_2	–0.17	1.55	–0.11	0.9146
75 D_1	2.57	1.64	1.57	0.1282
D_2	5.30	1.67	3.16	0.0038
D_1, D_2	–2.72	1.70	–4.61	0.0001
90 D_1	6.45	2.05	3.15	0.0038
D_2	6.06	2.02	3.00	0.0055
D_1, D_2	0.39	1.98	0.20	0.8428

Adjusted Means (g)*	CO†	CK†	SC†
15 min	3.55[a]	7.01[b]	5.58[ab]
30 min	1.46[a]	3.25[b]	1.36[a]
45 min	2.12[a]	3.83[b]	4.16[b]
60 min	7.09[a]	10.05[a]	9.89[a]
75 min	3.84[a]	9.13[b]	6.41[a]
90 min	5.17[a]	11.23[b]	11.62[b]

*Adjusted means not significantly different with same letters within rows.
†Treatments: CO = control, CK = chemically killed, and SC = scalped.

Infiltration Capacity and Interrill Erosion. The lack of significant differences in infiltration among treatments confirms conclusions from cyanobacterial crust studies conducted in the midwestern and southwestern United States (Booth, 1941; Faust, 1971). The importance in this confirmation is twofold—Booth (1941) drew conclusions from a severely limited sample size and Faust (1971) reported on results obtained from constructed plots in green-house conditions. The apparent discrepancy between time to ponding and runoff and infiltration likely results from loss of fine soil particles that otherwise could sort and plug soil pores.

Microphytic crusts in the control treatment, which were dominated by cyanobacteria (*Microcoleus vaginatus*), apparently increased soil stability and improved resistance to raindrop impact and flow detachment. Interrill erosion in the control and scalped treatments was consistently less than in the chemically killed treatment (fig. 3). The primary erosive force appeared to be raindrop impact resulting in soil splash. Rapid disintegration of the microphytic structure in the chemically killed treatment would mean that fine soil particles in the crust were easily dislodged, which is consistent with the greater interrill erosion relative to the control and scalped treatments. Apparently, the microphytic crusts retained fine soil particles in the control treatment and the structure of the sandy-loam soil initially resisted raindrop impact in the scalped treatment. Even though one would expect erosion to increase with runoff, poor correlation (r –0.03 to –0.20) was found between these variables during any period, being consistent with the results of Eldridge (1993b) in Australia.

Our purpose was to determine if cyanobacterial-dominated microphytic crusts influenced infiltration capacity or soil stability using a designed experiment (Eberhardt and Thomas, 1991). As noted above, the intensity of simulated rainfall greatly exceeded natural events expected in the near future. Interrill erosion in the scalped treatment was consistently greater than in the control treatment, although significantly so only at 45 and 90 min. Simulated rainfall (88 mm•h^{-1}) was double the maximum at CARE (44 mm•h^{-1}), or a third greater than the amount at Hanksville, Utah (60 mm•h^{-1}) calculated to occur once in 100 years (Richardson, 1971). A natural event of equal magnitude is highly improbable. Thus, at

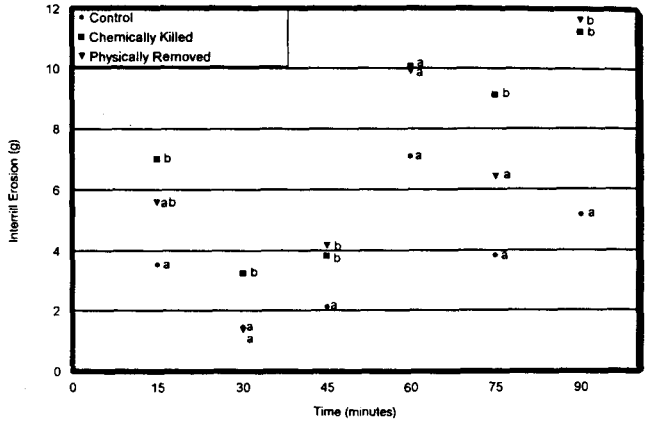

Figure 3–Mean treatment values for interrill erosion measured at 15-minute periods after start of runoff.

this successional stage the microphytic crusts' contribution to raindrop impact resistance by this sandy loam soil is marginal. The most important contribution is made by living microphytic crusts to stabilizing the fine soil particles accumulated at the surface. The accumulation of fine soil particles and associated microphytes have been implicated in the establishment and vigor of vascular plants and plant community structure (Eckert et al., 1989; Lesica and Shelly, 1992).

CONCLUSION

Our results show that microphytic crusts influenced time to ponding and runoff and contributed to soil stability against the erosivity of raindrop impact. These findings are consistent with extrapolated conclusions drawn from microscale studies concerning soil binding mechanisms of microphytes. Further research is required to determine if ponding or runoff time ultimately influence soil moisture regimes. The most important contribution by microphytic crusts is the stabilization of fine particles at the soil surface. These results support contentions that microphytic crusts are important to rangeland hydrology and soil stability. However, issues are not addressed that might be of direct importance to land managers, i.e., whether microphytic crusts actually reduce detachment and transport of soil by raindrops under common management plans. Additional designed experiments are necessary to determine how the stabilizing influence of microphytic crusts are affected by seasonality, type, degree, and frequency of disturbance over larger spatial and longer temporal scales.

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