Soil Properties in Relation to Cryptogamic Groundcover in Canyonlands National Park

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Highlight: A comparative study was made of the soils of a virgin grassland and an adjacent grazed area in Canyonlands National Park. Soils from the virgin site were finer textured than those of the grazed area, and the surface 5 cm contains a significantly lower amount of calcium. In addition, the surface 5 cm of the virgin site contains significantly greater amounts of phosphorus, potassium, and organic matter. Subsurface soils in the two parks are less dissimilar. Cryptogams on the virgin grassland appear to have an important influence on chemical characteristics of the surface 5 cm of soil. The difference in surface soils between the parks may be related to the presence of these species. Data point strongly to light winter grazing as a disturbing influence that has contributed to the differences in the surface soil and in vegetational characteristics between the sites.

A comparative study of soil characteristics of a virgin grassland (Virginia Park) and an adjacent grazed area (Chesler Park) within Canyonlands National Park, Utah, has been made. Until all grazing was terminated in 1962, Chesler Park had been relatively lightly grazed by cattle and horses for 3 or 4 months each winter for several decades. Virginia Park has never been utilized by domestic grazers due to lack of access.

Canyonlands National Park, created in 1964 as the 32nd U.S. National Park, comprises 104,308 ha. The sites under investigation are part of the Needles section of Canyonlands, immediately south of the junction of the Green and Colorado rivers. Alternating red and cream-colored beds of the Cedar Mesa Sandstone were deposited during Permian times through the process of alternating exposure and inundation (Kunkel 1960).

Climate is semiarid to arid with a temperature range of 60°C. Annual precipitation is about 25 cm. Warm season rainfall constitutes from 55–75% of the total annual precipitation.

The two study areas (parks) are separated by a narrow rock wall 0.4 km wide, hence climatic variations between them are minimized. Soils of both are believed to be derived from the same parent materials, and topographic differences between the park are slight. Both parks may be characterized as small valleys surrounded by high rock walls, and containing slightly dissected alluvial fans sloping from the walls (Fig. 1). The high park walls provide source material for continuous physical weathering. Virginia Park is 97 ha in area compared to 389 ha in Chesler.

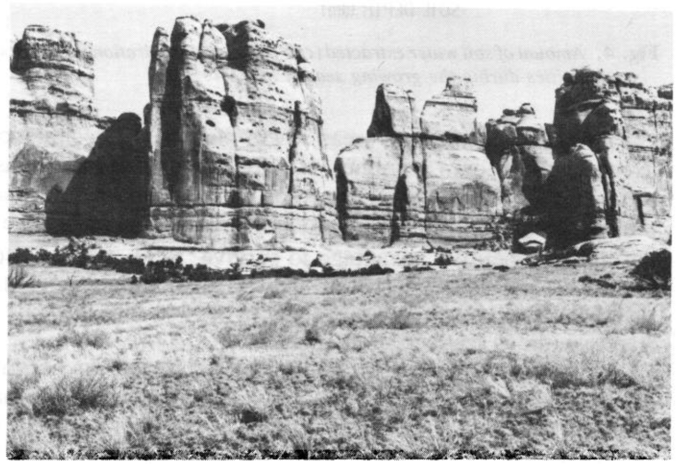

Fig. 1. *Interior view of Virginia Park.*

The most prevalent plant species in both parks is black lichen (*Collema tenax*). The 15 most prevalent plant species in Virginia Park, selected on the basis of constancy-times-frequency index (Curtis 1959), include seven cryptogams and eight herbaceous species. By contrast, seven species prevalent in Virginia Park are either absent or relatively insignificat in Chesler Park.

Four major perennial grasses, galleta (*Hilaria jamesii*), needleandthread (*Stipa comata*), Indian ricegrass (*Oryzopsis hymenoides*), and sand dropseed (*Sporobolus cryptandrus*),

Fig. 2. *Example of vegetational boundary between needleandthread and galleta sites.*

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Fig. 3. *Typical view of ground surface in Chesler Park.*

occupy high prevalence positions in both parks (Kleiner and Harper 1972). Relative abundance of galleta is considerably greater (47%) in Virginia than in Chesler Park; the other three perennial grasses are more abundat in Chesler (35, 18, and 131%, respectively). Although shrubs such as joint fir (*Ephedra viridis*), winterfat (*Eurotia lanata*), big sagebrush (*Artemisia tridentata*), and pinyon-juniper (Colorado pinyon *Pinus edulis* and Utah juniper *Juniperus osteosperma*) do occur in the parks, they occupy an insignificant part of the total vegetative cover. Floristically, Virginia Park is much richer than Chesler, in both vascular and cryptogamic species. Vegetational boundaries are relatively sharp and distinct (Fig. 2), particularly in Virginia Park.

Erosionally pedicelled grass bunches (Fig. 3) are characteristic of Chesler Park. By contrast, cryptogam-covered pedestals characterize the surface in Virginia Park (Fig. 4), occurring only occasionally in Chesler Park. Soils of both parks are classified as nonskeletal argids (U.S. Dep. Agr. 1975). Chesler Park soils, particularly near the surface, average about 10% more sand than those in Virginia Park.

Methods

A total of 60 sites (circular plots, each 50 m^2) were sampled in the two parks, 40 in Virginia and 20 in Chesler. Sites were selected subjectively, using homogeneity of environment (aspect and slope) and vegetation as the criteria for each location. Homogeneity of vegetation and environment within each stand was requisite in order to maximize comparative vegetational information, as well as associated soils and other environmental factors. An attempt was made to distribute sites uniformly throughout the two parks. This compensates, at least in part, for the lack of randomization of site selection. In addition, six paired samples of the surface soil were taken in Virginia Park to test the effect of cryptogamic (i.e. lichens and mosses) crusts on surface soil characteristics.

All sampling, except for soil temperature, was completed during June and July, 1967. Soil-temperature readings were taken at the 38-cm depth at three locations in each site on September 20, 1967. Distance and inaccessibility of the study areas precluded additional soil-temperature readings or continuous monitoring for an extended period. Temperatures were taken with a dial-type thermometer having a 61-cm steel stem, which was thrust into the soil to the desired depth and allowed to come to equilibrium.

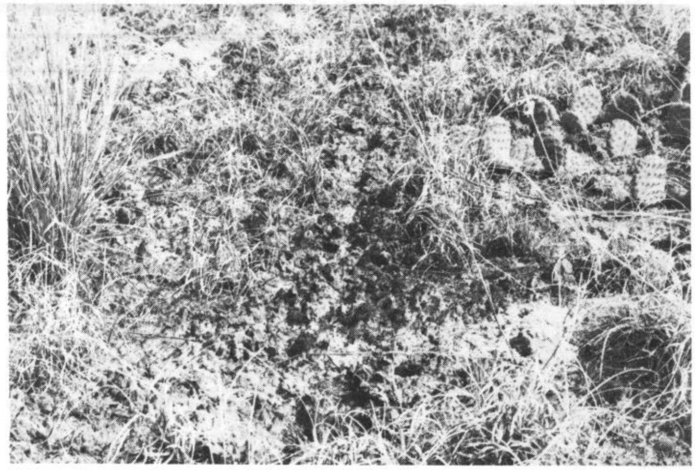

Fig. 4. *Typical view of cryptogamic cover in Virginia Park.*

Significant environmental variables, including aspect, elevation, and percent slope, were recorded at each site. Soil samples were taken at the center of each site at each of the following depths: 15–30, 46–61, and 76–91 cm (6–12, 18–24, and 30–36 inches, respectively). In addition, samples of the surface 5 cm (2 inches) of the soil profile were collected at five different points within each sampling site and combined. All samples were transported to the laboratory in sealed plastic bags. Soil structure, color, amount of rock, intensity of rooting, and depth to a consolidated layer were noted as the auger samples were removed from the profile.

Paired soil samples were taken to evaluate the effect of cryptogamic crusts in Virginia Park. Samples were obtained at points on which well-developed crusts occurred adjacent to spots that were almost devoid of cryptogamic life. At each of the six sites selected, the paired samples were taken as close together as possible and in no case more than 2 meters apart. All samples were taken from interspaces between vascular plants in order to minimize higher plant effects on characteristics of the soil. At each sampling point, the surface 2 cm of soil were removed from two dm^2 spots. At one of the dm^2 sampling spots of each pair, soil from the 2–5 cm depth was collected.

Soil texture was analyzed by the hydrometer method as described by Bouyoucos (1928). Bulk density was obtained by weighing a known volume of each soil sample. The pH was determined by preparation of a slurry consisting of a soil-water mixture in a ratio of 1:1 and measurement with a glass electrode pH meter. Free carbonates were estimated from the degree of effervescence when 10% hydrochloric acid was added to the soil. Degree of effervescence was evaluated subjectively and ranked on a five-part scale.

Calcium and potassium analyses were performed by flame photometry (Jackson 1958). Ions had been previously extracted with 0.2 N acetic acid. Organic matter was determined by the potassium chromate method (Jackson 1958). Soil phosphorus was analyzed according to a method developed by Goldenberg and Fernandez (1966). Total nitrogen was estimated by means of micro-Kjeldahl digestion and a modified nesslerization procedure (Jackson 1958) on all samples except those taken to evaluate the effect of cryptogamic crusts on soil nitrogen. These latter samples were digested in the same manner, but the ammonium was then distilled into boric acid and determined by back titration with sulfuric acid.

In reporting results of chemical analyses of soil, the average of the surface 0–5 cm of each profile is contrasted with the average of analyses from the 15- to 91-cm interval of the profile. Although calcrete is obviously involved in the lower depths, a comparison between the surface soil and lower depths as it relates to rooting characteristics of plants is necessary. Textural analyses are reported as the mean of the 0- to 30-cm and the 30- to 91-cm intervals. Chemical

Table 1. Comparison of coefficients of variation (CV) for 24 physical-chemical variables associated with the sites studied in Virginia and Chesler Park.

Variable	Depth (cm)	Virginia Park min.	Virginia Park max.	Virginia Park $\bar{X}$	Virginia Park CV	Chesler Park min.	Chesler Park max.	Chesler Park $\bar{X}$	Chesler Park CV
Altitude (m)		1722	1732	1729	1	1701	1737	1709	1
Slope (%)		3	22	7.8	48	2	13	7	45
Depth to prominent $CaCO_3$ zone		38	*	76	94	30	*	73	103
Consolidated material (% by wt)	46-61	0	19	5.1	147	0	24.4	6.1	126
" "	76-91	0	34.9	11.8	89	0	28.6	10.2	110
Bulk density (g/cc)	0-5	1.27	1.36	1.3	2	1.3	1.4	1.3	2
" "	15-91	1.13	1.3	1.2	3	1.2	1.35	1.3	3
Sand (%)	0-30	50.3	80.8	64	11	62.2	90.9	75	10
"	31-91	43.6	85	63	18	55.1	91.2	72	14
Silt (%)	0-30	10.6	38	25	25	4.8	22.8	16	27
"	31-91	7	51.2	23	40	4.1	28.6	16	44
Clay (%)	0-30	6.6	19.6	13	21	4.3	16	9	28
"	31-91	5.2	22.3	15	30	3.7	19.9	12	41
Organic matter (%)	0-5	.18	2.04	1.33	27	.68	1.15	.88	17
Soil temperature on 9/20/67 (°C)	38	18.67	20.67	19.83	1	19.5	21.17	20.28	1
pH	0-5	7.35	8.45	8.08	3	7.93	8.50	8.29	2
"	15-91	8.28	8.96	8.47	2	8.33	8.58	8.46	1
Calcium[1]	0-5	2.03	11.63	5.16	45	5.50	12.84	8.1	24
"	15-91	10.5	26.58	17.35	24	9.39	24.96	17.98	29
Potassium[1]	0-5	.047	.242	.11	46	.039	.133	.08	25
"	15-91	.021	.272	.07	100	.024	.158	.06	67
Phosphorus[1]	0-5	.027	.168	.09	44	.015	.067	.05	20
"	15-91	.006	.056	.02	50	.005	.021	.01	33
Nitrogen[1]	0-5	.263	.83	.43	33	.205	.913	.46	35
Average					38				34

*Compact layer not reached in some stands.
[1] mg/g soil

and textural soil characteristics are compared by means of the *t* statistical test (Steel and Torrie 1966).

All data concerning environmental and soil factors were subjected to the desired statistical tests with $P < .05$ for the limit of significance.

Results

Gross environmental characteristics vary little between Virginia and Chesler Parks (Table 1), although the textural characteristics and the surface nutrient characteristics of the soils differ somewhat. In both parks the soils appear to have weathered from sand and siltstone beds of the same general strata of the Cedar Mesa Sandstone. Color is relatively uniform and ranges from light red to reddish brown to pink or dark cream in some deeper samples. Structure throughout is single grain. Profiles are rock-free except to the extent that a somewhat consolidated sandstone layer was reached in a few of the deeper samples. We were able, however, to obtain a soil sample at the 76- to 91-cm depth in all stands except one. Rooting was generally good in the surface 30 cm and poor below. Differences in percentages of sand and silt are highly significant between the parks ($P < 0.001$ at 0–30 cm and $P < 0.01$ at 31–91 cm). Bulk density and surface pH are also distinguishing physical characteristics ($P < 0.001$), and temperature is significantly different as well ($P < 0.01$). Although soils in both parks are sandy loams on the basis of the proportion of sand, silt, and clay (U.S. Dep. Agr. 1951), Chesler Park soils include significantly more sand (about 10%) and less silt than the soils of Virginia Park. Among chemical variables, calcium, phosphorus, and organic matter are very significantly different ($P < 0.001$) in the surface soil of the two parks (Table 1). Potassium is different, but less significantly so ($P < 0.01$). The abundance of free carbonates in the surface soil was also found to differ significantly between the parks.

There was no significant difference in total nitrogen between the surface soils of the two parks. This was unexpected, since organic matter in the surface soils did differ significantly. As we have shown elsewhere (Kleiner and Harper 1972), the difference in surface organic matter appears to be related to loss of

Table 2. Average values of soil characteristics for sites with and without well-developed cryptogamic crusts in Virginia Park.

Characteristics	0–2 Crust	0–2 No crust	0–2 Significance of difference	2–5 Crust	2–5 No crust	2–5 Significance of difference[1]
Texture						
Sand (%)	54.8	59.2	NS	63.7	60.4	NS
Silt (%)	33.3	25.5	*	25.6	23.3	NS
Clay (%)	12.0	15.4	NS	10.7	16.3	**
Organic matter (%)	1.06	.96	NS	.81	.69	NS
pH	8.4	8.6	*	8.4	8.7	*
Avail. phosphorus[2]	.060	.058	NS	.061	.054	NS
Total nitrogen[2]	.193	.438	*	.278	.240	NS

Depth (cm) spans both column groups.

[1] ** = significant at the .01 level of probability; * = significant at the .05 level of probability; NS = not significant.
[2] mg/g soil.

cryptogamic crusts in the grazed park. Higher plant cover is almost identical in the two parks, but cryptogamic cover is over 7 times as abundant in the virgin as compared to the formerly grazed park (38% and 5%, respectively). Since significant differences were detected in the case of potassium and phosphorus, it seemed likely that the nesslerization procedure employed in the nitrogen analyses was too insensitive to detect the small differences that might exist between parks.

Data on Table 2 suggest that the nesslerization procedure was indeed insensitive. The distillation and back titration method for determination of nitrogen in microkjeldahl-digested samples demonstrates a significant difference in total nitrogen in surface soils (0–2 cm depth) with and without cryptogamic crusts.

The results of Table 2 indicate that cryptogamic crusts do have significant impact on nitrogen and pH of the surface soil. The impact on organic matter is less marked but nevertheless detectable.

Discussion and Conclusions

Major differences between Virginia and Chesler Parks are exhibited among the surface soil characteristics. These characteristics may be related in part to the differences in cryptogamic cover between the two parks. It is known that cryptogamic crusts in the area in question are composed, in part, of blue-green algae and the lichen *Collema*, which consists of a blue-green alga living symbiotically with a fungus (Kleiner and Harper 1972; Snyder and Wullstein 1973). The evidence suggests that such crusts may play a more important role in the stability of desert grassland soils than has been generally recognized. Certainly the cryptogamic cover would tend to increase the stability of the highly erodable sandy soils of these grasslands during torrential summer rains and heavy wind storms. Many differences between the two parks seem attributable to the protection against erosion that the cryptogamic cover of Virginia affords. For example, the widespread pedicelling of perennial bunchgrasses has been noted in Chesler, in contrast to very little pedicelling in Virginia Park. In the same vein, rapidly eroding secondary drainage channels cut far into the head of watersheds of Chesler while such channels are stable in Virginia. Lower organic matter, less available phosphorus, and higher calcium content of surface soils in Chesler may be explained in terms of slow sheet erosion and loss of the weathered and organically enriched few centimeters of surface soil.

Soil texture is known to influence development of cryptogamic crusts. The number of cryptogamic species and cryptogamic cover is significantly higher on the finer texture sites even within Virginia Park (Kleiner and Harper 1972). Differential cryptogamic crust development in Virginia and Chesler Park may thus be partially related to inherent, small textural differences between the parks. Those differences have unquestionably been exaggerated by grazing, however. The combined impacts of coarser texture and grazing may account for many of the soil differences observed between Chesler and Virginia parks.

Parent (source) material of variable sand-silt content may account for some of the textural differences observed between these two adjacent parks. Two sites within an alluvial collection basin could have received depositions of variable texture due to different patterns of current within the water body. Greater sheet erosion in Chesler could account for some textural differences also. Likewise, less available phosphorus, and higher calcium content of surface soils in Chesler may be explained in terms of slow sheet erosion and loss of the weathered and organically enriched few centimeters of surface soil.

Shields (1957) and Shields et al. (1957) consider the role of algae and lichens in surface soil stabilization and nutrient cycling. Cryptogams are instrumental in the buildup of organic matter and soil nutrients. The differential between nutrient content, particularly nitrogen, of surface and subsurface soils and between alga- and lichen-stabilized surface crusts and those not so stabilized, is recognized. The contribution of these organisms to total nitrogen is believed to be especially significant in arid soils because of their persistence during even extreme drought. Looman (1964) points out that even though lichens and bryophytes do not root, they are indicators of edaphic factors. Many species reveal affinities for certain soils. The exact reasons are not known, but the correlations are very high and universal. Traditionally, the cryptogams have occupied an insignificant role in the management of western grasslands, but, as Looman suggests and as this study demonstrates, cryptogam analysis can be useful in evaluating the quality of grassland management.

Since Virginia differs from Chesler in respect to both cryptogamic cover and soil texture as well as in respect to various mineral elements, there was some question as to whether cryptogams or soil texture was responsible for the mineral differences. To clarify this question, a multiple regression analysis was run using cryptogamic cover and percent silt and clay as independent variables and soil phosphorus as the dependent variable. The results of that analysis suggest that the cryptogamic cover in Virginia is of considerably less importance than soil fines as an influencer of soil phosphorus.

Results of soil and vegetational analyses have revealed significant differences between the two areas with regard to surface soil characteristics and cryptogamic components. Data point strongly to light winter grazing as a disturbing influence that has contributed to the surface soil and vegetational differences observed between the two parks.

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