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# Proceedings—Ecology and Management of Annual Rangelands

**Stephen B. Monsen**
**Stanley G. Ketchum**

## Preface

Introduced weeds, both annuals and perennials, have become a problem in sustaining native plant communities. Within the Intermountain Region, no other weedy species has attained the widespread distribution and dominance of cheatgrass (*Bromus tectorum*). Other weeds possess undesirable features and may be difficult to eradicate or control, but few have occupied and disrupted the ecology of such vast areas as cheatgrass. Early workers and land stewards recognized the explosive nature of this annual grass as it caught fire and its ability to compete with native vegetation. Initially, some land managers were concerned about the loss or gain in seasonal forage as cheatgrass and other annual weeds appeared, but the ecological impact of this species was soon realized.

Although various efforts have been directed toward containing and restoring infested sites, cheatgrass and other related annual weeds continue to expand, presenting ever more serious management problems. The loss of native plant communities to less desirable introduced annuals damages various resources—including watershed and wildlife. The value of these resources has become increasingly important as weeds have continued to expand.

Cheatgrass presents an increasingly acute problem—fire. The conversion of diverse native communities to annual grasses has resulted in a dramatic increase in the frequency of fires. The cost of containing and restoring sites that frequently burn has become a major problem throughout the West. Site degradation results not only from the displacement of native vegetation by cheatgrass, but also from repeated burning.

Although considerable information has been developed concerning the ecology, competitive traits, management, and revegetation potential of cheatgrass communities, measures are needed to contain and restore weed-infested sites. Continued expansion of annual weeds must be corrected. This symposium was developed to better identify weed problems on range and wildland sites, and to address management and restoration measures that can be employed.

Papers in the proceedings are grouped in nine principal topics that range from introductory material to information on ecology and resources, various restoration subjects, and management.

## Acknowledgments

The symposium was cooperatively developed by the U.S. Department of the Interior, Idaho Bureau of Land Management, the U.S. Department of Agriculture, Forest Service, Intermountain Research Station, and the University of Idaho. Appreciation is extended to Mike Pellant, Idaho Bureau of Land Management, Boise, who assumed a major role in developing the program. Other individuals contributed to the symposium, field tours, and publication of the proceedings. Their efforts are certainly appreciated, and they have provided considerable information and insight to the management of sites infested with weeds.

In addition, we appreciate the efforts of the following individuals who coordinated and hosted their symposium sections:

| | |
|---|---|
| Ecology | J. Ross Wight, Agricultural Research Service, U.S. Department of Agriculture, Boise, ID |
| Weed Control | Richard Stevens, Utah Division of Wildlife Resources, Ephraim, UT |
| Fire Ecology and Management | G. Allen Rasmussen, Utah State University, Logan, Melanie Miller, Bureau of Land Management, U.S. Department of the Interior, Boise, ID |
| Seed Germination | Terry Booth, Agricultural Research Service, U.S. Department of Agriculture, Cheyenne, WY |
| Seedbed Preparation | Dale Turnipseed, Idaho Fish and Game Department, Nampa, ID |
| Resource Impacts | Alan Sands and Mike Pellant, Bureau of Land Management, U.S. Department of the Interior, Boise, ID |
| Management | Val Jo Anderson, Brigham Young University |
| Species Utility | Christine Whittaker, Montgomery Watson, Boise, ID |

Section divider illustrations by L. E. Spence, 1936



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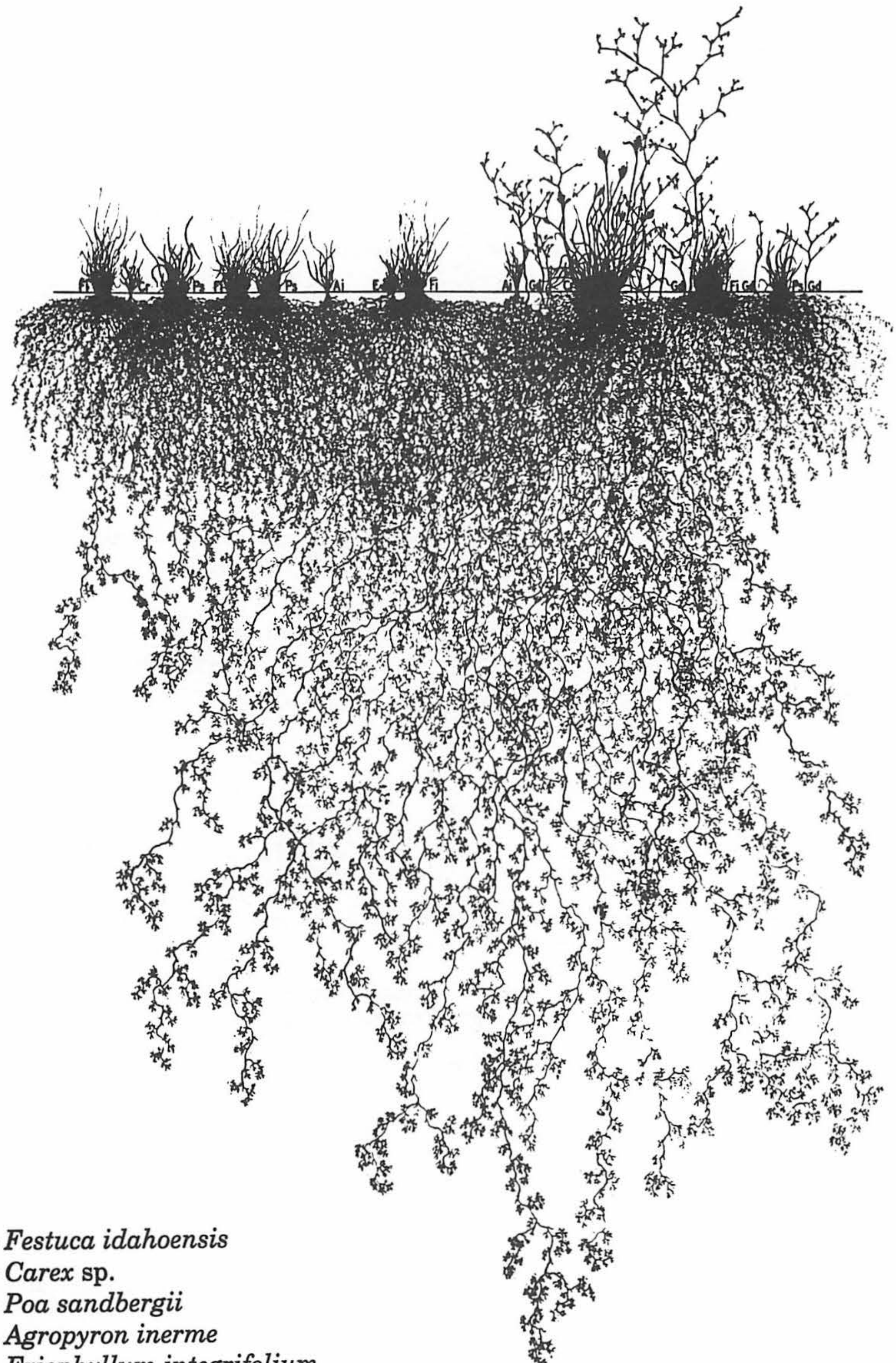
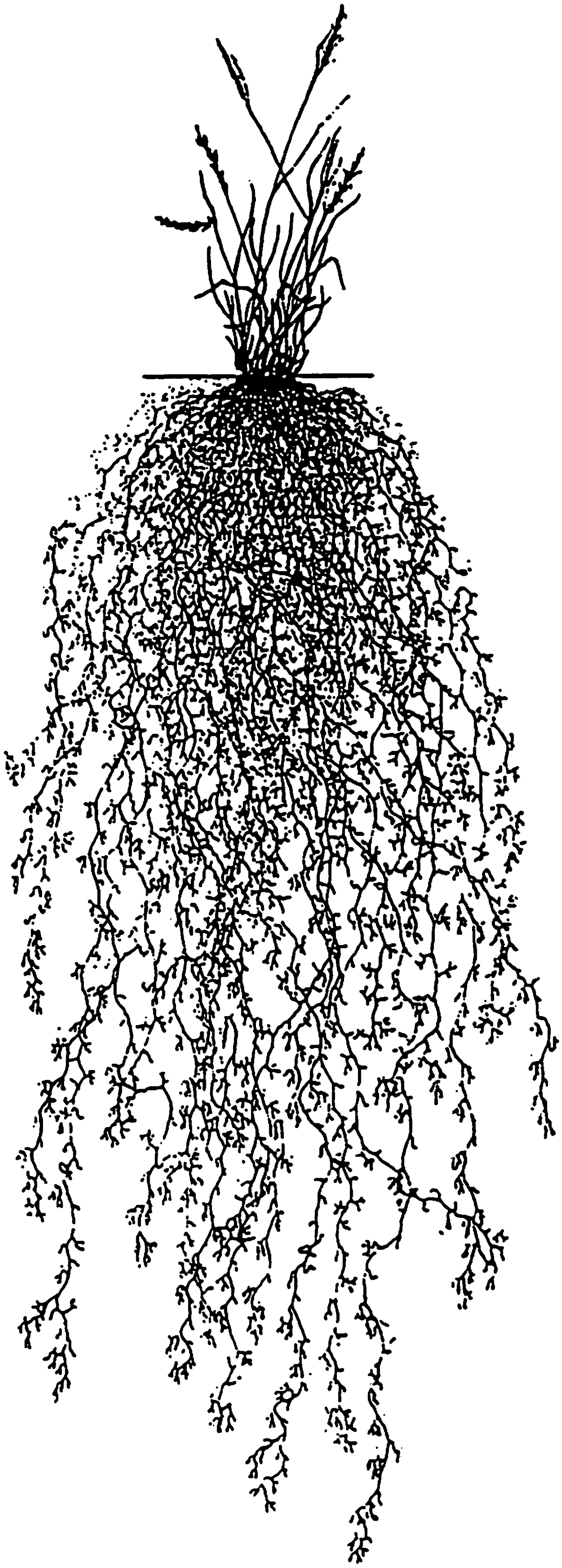


Fi - *Festuca idahoensis*
Cr - *Carex* sp.
Ps - *Poa sandbergii*
Ai - *Agropyron inerme*
Ei - *Eriophyllum integrifolium*
Gd- *Gayophytum diffusum*

# Restoration: Weed Control



*Stipa lettermanii*

# POTENTIAL ROLE OF CRYPTOBIOTIC SOIL CRUSTS IN SEMIARID RANGELANDS

**Jayne Belnap**


## ABSTRACT

*The role of cryptobiotic soil crusts in the functioning of semiarid and arid ecosystems is discussed. These roles include microstructuring of soils in cold-desert ecosystems, influencing soil nutrient levels, and influencing the nutrient status, germination, and establishment of vascular plants in crusted areas when compared to uncrusted areas. For these reasons, re-establishment of these crusts should be an important part of reclamation efforts. Natural recovery rates and the effectiveness of inoculation efforts are discussed.*


## INTRODUCTION

It has long been reported in the literature that cryptobiotic soil crusts, consisting of cyanobacteria, mosses, and lichens, are an important component of ecosystems in semiarid areas. These crusts may represent up to 70 percent of the living cover in some of these systems. Many roles have been ascribed to these crusts, including effects on soil stability (Anantani and Marathe 1974; Anderson and Rushforth 1976; Anderson and others 1982a,b; Belnap and Gardner 1992; Campbell 1979; Fletcher and Martin 1948; Harper and Marble 1990; Kleiner and Harper 1972, 1977; Loope and Gifford 1972; Marathe 1972; Metting and Rayburn 1983; Shields and Durrell 1964), soil moisture and nutrient status of soils (Belnap and Harper 1992; Brotherson and Rushforth 1983; Campbell 1979; Harper and Belnap, unpublished data; Shields and Durrell 1964), contribution of fixed nitrogen (Belnap 1991; Evans and Ehlringer 1992; Skujins and Klubek 1978), and enhancement of seedling establishment (Harper, unpublished data). Data suggest that these crusts are slow to recover from severe disturbance, requiring 40 years or more to recolonize even small areas (Belnap 1992).

This paper discusses the ecological role of cryptobiotic soil crusts, including their structure, effects on the nutrient status of plants, and effects on seedling establishment and success, as well as ways to hasten their recovery from disturbance. Data are drawn from several different studies conducted over the past 5 years by Belnap (1991, 1992), Belnap and Gardner (1992), Belnap and Harper (1992), Harper and Belnap (1992) and Harper (unpublished).

Paper presented at the Symposium on Ecology, Management, and Restoration of Intermountain Annual Rangelands, Boise, ID, May 18-22, 1992.
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## METHODS

Cyanobacterial soil crusts from sandstone- and gypsum-derived soils were collected from Arches and Canyonlands National Parks located in southeastern Utah near Moab. For scanning electron microscopy (SEM) work, samples were either directly gold coated or were prepared by freeze substitution, and then examined with a JEOL 840A scanning electron microscope.

The presence of chlorophyll *a* was used to estimate the biomass of living cyanobacteria and green algae in the crusts found on the sandy and gypsiferous soils from Arches National Park. Chlorophyll *a* was extracted from collected samples with dimethyl sulfoxide (DMSO). The DMSO extraction samples were centrifuged and spectrally analyzed on a diode array spectrophotometer at 665 nm to obtain relative values for the amount chlorophyll *a* present (Belnap 1991).

Plant tissue of the native annual grass, *Festuca octoflora*, and the native perennial dicotyledonous herb, *Mentzelia multiflora*, was chosen to compare nutrient status of plants on and off crusted surfaces. *Festuca octoflora* was collected from a site approximately 20 miles (33 km) southwest of Moab, UT. *Mentzelia multiflora* was collected from Arches National Park, 10 miles (17 km) northeast of Moab. Both areas have been protected from domestic livestock grazing for over 10 years. Plants were collected from two immediately adjacent sandy sites; one area had well-developed cyanobacterial-*Collema* lichen crusts, while the other lacked such a crust. At Arches, windblown sand accounted for the lack of crust; at the *F. octoflora* site, the lack of crust was due to repeated trampling by people over a period of years. Composite samples of at least five individuals (or 2.0 g tissue for the tiny *Festuca* plants) were collected at each of five locations for each soil surface condition class at each site. Two composite samples of the surface 3.0 cm of the soil profile were collected from each soil surface class at each site.

Soils were analyzed for percent sand using a hydrometer procedure (Bouyoucous 1936). Soil reaction was determined with a glass electrode on a saturated soil/distilled water slurry. Organic matter was determined by wet digestion in 1.0N potassium dichromate (Moodie and others 1963). Total nitrogen in soils was estimated using a micro-kjeldahl procedure (Association of Official Analytical Chemists 1980). "Available" phosphorus was extracted in 0.2N acetic acid, and determined using the iron-TCA-molybdate method (Goldenberg and Fernandez 1966). Exchangeable bases were displaced from the soil with 1.0N ammonium chloride and concentrations in the extractable solution were determined using an atomic absorption unit (David 1960). Air-dried plant samples (whole plants including major roots remaining when individual plants were pulled up) were cleaned of adherent sand and ground through a 40-mesh sieve using a rotating mill. Samples were stored until analyzed in capped plastic vials. Nitrogen was determined by micro-kjeldahl procedures. A single 1.0-g sample of each specimen was fully digested using a sulfuric acid-nitric acid procedure (1:5 parts respectively of the concentrated acids). Elemental content of essential minerals was determined on aliquots of the digestate using an atomic absorption unit and appropriate analytical procedures (Association of Official Analytical Chemists 1980). Results of tissue analyses for individual elements were compared using an unpaired *t*-test model.

Seedling germination and establishment were measured over a period of 4 years. Seeds were planted through a template into permanent plots. Seedling establishment and success were measured after germination and after 4 years using a 0.25-$m^2$ quadrat frame and Daubenmire cover classes.

## RESULTS AND DISCUSSION

The structure of soil crusts from the Colorado Plateau region of Utah was studied by Belnap (1992) using a scanning electron microscope. The crusts in this region are dominated by the cyanobacterium *Microcoleus vaginatus* (Anderson and Rushforth 1976; Campbell and others 1989; Johansen and Rushforth 1985), which often represents up to 95 percent of the biomass in the soil (Belnap, personal observation). Figures 1-3 show *M. vaginatus* and *M. vaginatus*-dominated crusts in sandstone-derived soils. *M. vaginatus* has a large, distinct, sticky extracellular sheath that surrounds groups of living filaments (fig. 1). When wetted, this sheath material swells, and filaments within are mechanically extruded through the soil. As the substrate dries, the exposed filaments secrete additional sheath material. Rewetting repeats this cycle, resulting in sheath material that winds among the sand particles much like fibers in fiberglass (fig. 2). Even when dry, the sheath material can be seen firmly adhering to soil particles (fig. 3). These connections appear to reduce wind and water erosion, as well as holding the otherwise loose material on slopes well beyond the angle of repose. When wetted, the sheath material swells and covers the soil surface even more extensively than when dry. Sheath material can absorb up to eight times its weight in water, thus absorbing precipitation quickly and increasing the water-holding capacity of sandy soils (Brock 1975; Campbell 1979; Campbell and others 1989). Even when swollen, there is space for rainwater and vascular plant roots to penetrate into the soil between sheaths (fig. 4).

Cyanobacteria and cyanobacterial components of soil lichens fix atmospheric nitrogen most of the year (Belnap 1992; Fuller and others 1960; Skujins and Klubek 1978; Terry and Burns 1987; West and Skujins 1977). Studies

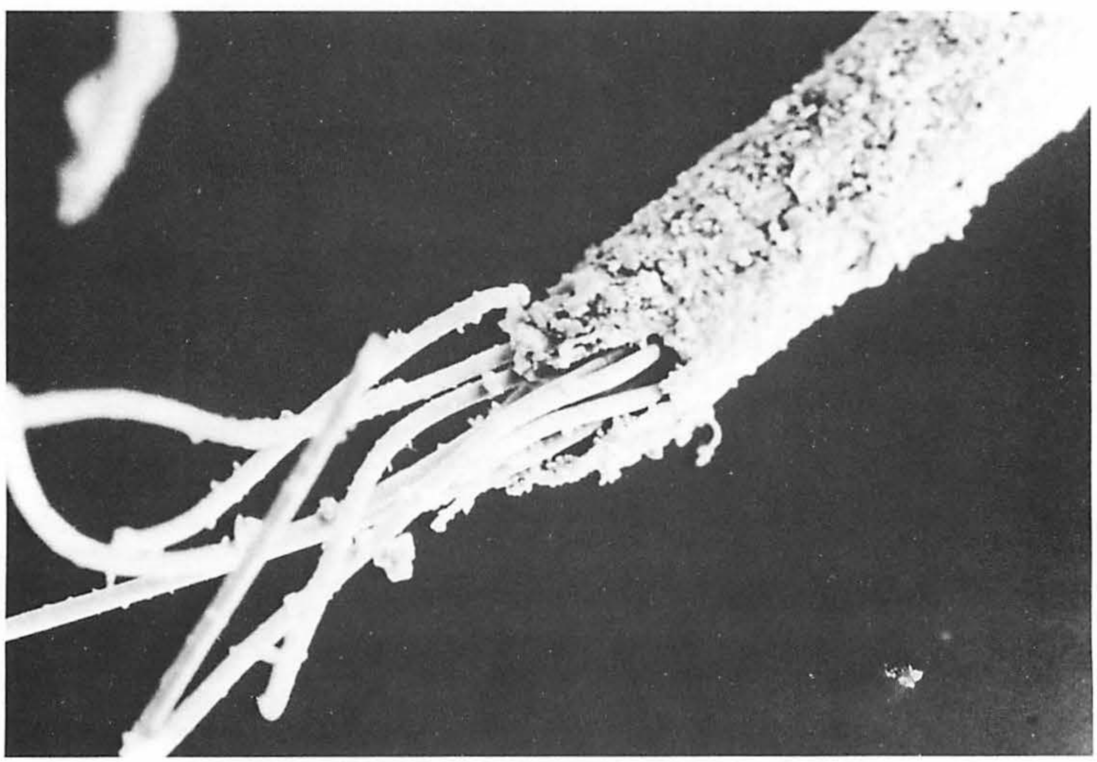

**Figure 1**—Scanning electron micrograph of *Microcoleus vaginatus*, the dominant cyanobacterium in soil crusts of the Colorado Plateau. Note the living filaments extruded from the sticky extracellular sheath (magnification x 700), as occurs when the organism is wetted.

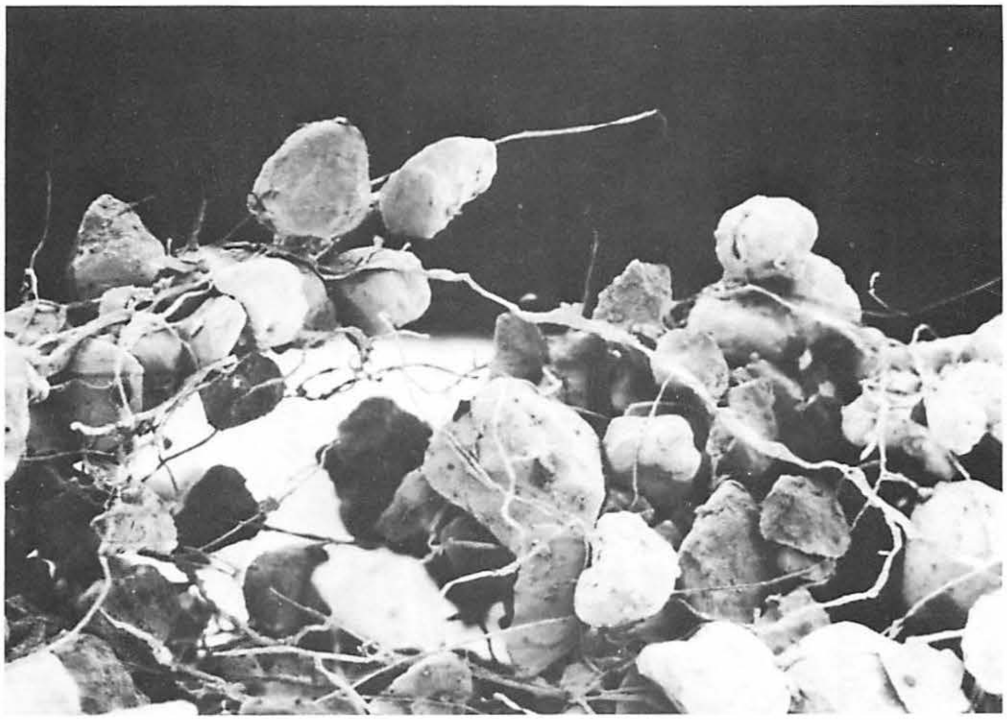

**Figure 2**—Scanning electron micrograph of dry cyanobacterial sheaths winding through sandy soils from Moab, UT. Note firm attachment of sheath material to the individual sand grains, even though sheath material is dry (magnification x 90).

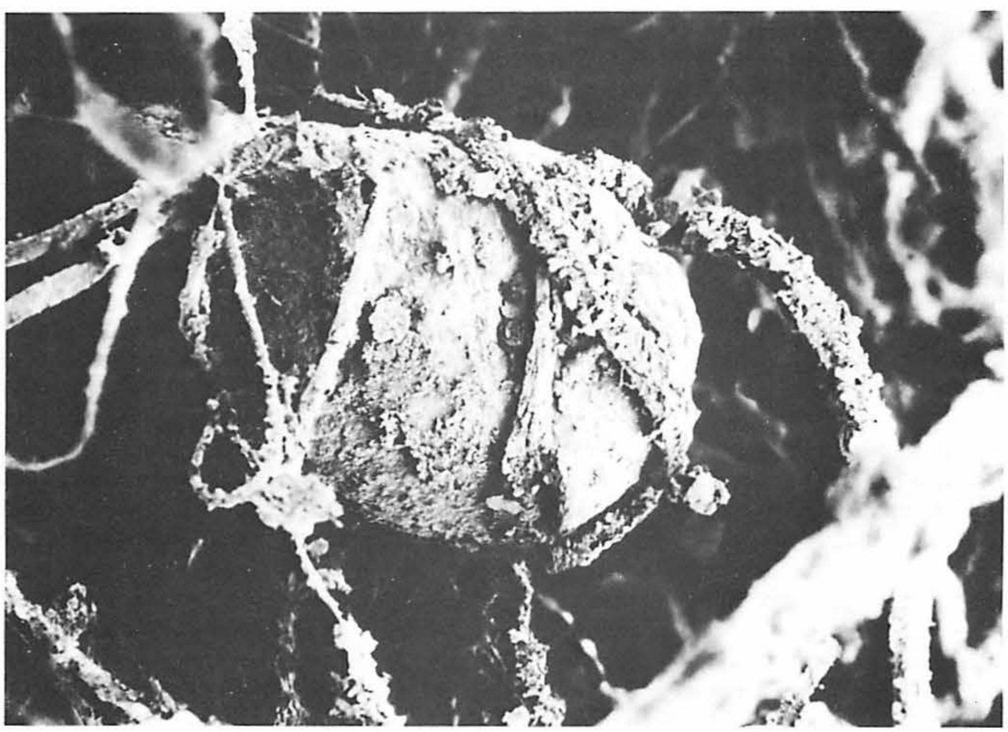

**Figure 3**—Scanning electron micrograph of a sand grain wrapped by cyanobacterial sheaths (magnification x 400).

**Figure 4**—Scanning electron micrograph of wet cyanobacteria on the surface of a moistened sandy soil from Moab, UT. Note the swollen, rounded sheaths "net" the surface, keeping fine soil particles in place (magnification x100).

utilizing radioactive isotopes of nitrogen have demonstrated that nitrogen fixed by cyanobacteria in the crusts is available to neighboring vascular plants (Mayland and McIntosh 1966; Mayland and others 1966). In some desert systems, these crusts have been demonstrated to be the dominant source of this often-limiting element for associated seed plants (Evans and Ehlringer 1992).

Elemental levels of vascular plants are affected by the presence of these crusts. Levels of N, P, K, Fe, Ca, and Mg were higher in the annual grass *Festuca octoflora* growing on crusted soils than in plants growing on comparable noncrusted soils. Levels of N, Fe, Ca, Mg, and Mn were higher in the native perennial forb *Mentzelia multiflora* (Belnap and Harper 1992). Essential nutrient concentrations were also shown to be higher in the tissue of the biennial plant *Lepidium montanum* growing on soils covered by cyanobacterial-rich crusts than on paired plots where the surface 1.0 cm of crust had been stripped from around the plants 3 months prior to tissue nutrient analyses (Harper and Marble, in preparation). Experiments in the greenhouse show levels of nitrogen in sorghum and rape higher in pots with cyanobacteria when compared to pots without cyanobacteria. Dry weight of plants in pots with cyanobacteria were up to four times greater than in pots without cyanobacteria (Harper and Belnap, unpublished).

Several mechanisms have been postulated to explain this effect. Fletcher and Martin (1948) reported that crusts trapped soil fine particles, which are more nutrient-rich than sand (Black 1968). Lange (1974) demonstrated that compounds in the gelatinous sheath material of half the cyanobacteria species studied were able to chelate elements essential for their growth (for example, iron, copper, molybdenum, zinc, cobalt, and manganese). Four of the five genera shown to possess this ability (*Anabaena, Anacystis, Lyngbya*, and *Nostoc*) are represented by common species in the cryptobiotic crusts of western North American deserts (Shields and Durrell 1964). Belnap (1992) showed that cyanobacterial sheath material was often coated with negatively charged clay particles, providing a mechanism for holding positively charged macronutrients against leaching from the soil profile. It is also possible that nutrient differences are a result of a thermal effect, as dark crusts would be warmer that lighter uncrusted soils, and uptake of nutrients would occur at a higher rate.

The presence of soil crusts can also affect seedling establishment and survival. Experiments done by K. Harper (unpublished) at sites with both fine and coarsely textured soils demonstrate that seedling establishment was much higher for both forbs and grasses in crusted areas when compared to areas where the crust had been removed (table 1). Survival over a 3-year period was enhanced in the four species (grasses and forbs) measured at these sites as well (table 2). Other studies have reported similar enhancement of seedling germination and establishment in crusted areas when compared to noncrusted surfaces (Harper and St. Clair 1985; St. Clair and others 1984).

Trampling negatively affects the cohesion and coverage of cyanobacterial crusts, since the filaments are brittle when dry and easily crushed (Campbell 1989; Harper and Marble 1990). Visual examination of undisturbed soil crusts on

**Table 1**—Effects of cryptobiotic soil crust on vascular plant seedling establishment. Seedlings were measured 10 months after early winter planting of four species (*Linum perenne, Oryzopsis hymenoides, Sphaeralcea coccinea*, and *Elymus junceus*) at three different locations in central Utah. Thirty-two seeds of each species were planted through a template at five randomly chosen spots in each of at least 22 plots representing crusted or not crusted soils at each site. For this table, seedlings of all four species were pooled. The "no crust" treatment consisted of scalping the top 1.0 cm of the soil profile

| Site | No crust | Crust | *p* |
|---|---|---|---|
| Tintic Junction | 105 | 165 | <0.1 |
| Buckthorn Reservoir | 140 | 389 | <.1 |
| BLM-USU pasture | 59 | 198 | <.1 |
| All sites pooled | 304 | 753 | <.1 |

sandy soils of the Colorado Plateau shows cyanobacterial sheath material to occur as deep as 10 cm below the surface of the soil. In contrast, heavily trampled areas support only a thin veneer of cyanobacteria and cyanobacterial sheaths (Belnap 1992). Since no chlorophyll *a* is found below 1 cm (Belnap, unpublished), sheath material below that depth must represent remnants of cyanobacterial crusts once found near or at the soil surface and later buried by sediments. Thus as aeolian and water-borne materials are trapped in the polysaccharide sheaths of *M. vaginatus* and other cyanobacteria growing on the surface of desert soils, these sheaths are gradually buried, but their ameliorating influences on water-holding capacity, cation exchange capacity, and soil stability may extend far below the depth to which light can penetrate. Any damage to such abandoned sheath material is nonrepairable, since living cyanobacteria are apparently no longer present at these depths to regenerate filament and sheath materials. As a consequence, trampling may not only reduce soil stability, but soil fertility and soil moisture retention as well.

Restoration of these crusts has been studied by several investigators. These studies have examined both natural recovery and the use of inoculants. Recovery rates depend on the type and extent of disturbance and the availability of nearby inoculation material, as well as on the temperature and moisture regimes that follow disturbance events.

**Table 2**—Effects of cryptobiotic soil crust on vascular plant survival over 3 years (1981-84) at three different sites with 3 different soil textures. The "no crust" treatment consisted of scalping the top 1.0 cm of the soil profile

| Site | Species | No crust | Crust |
|---|---|---|---|
| | | *- Percent survival -* | |
| Tintic Junction | *Linum perenne* | 79 | 88 |
| Tintic pastures | *Oryzopsis hymenoides* | 75 | 100 |
| | *Elymus junceus* | 0 | 100 |
| Buckthorn Reservoir | *Sphaeralcea coccinea* | 17 | 27 |
| | *Elymus junceus* | 14 | 100 |

Estimates of time for natural recovery from disturbance of cryptobiotic crusts have varied widely, ranging from a few years to 100 years for full recovery of all components (Anderson and others 1982b; Callison and others 1985; Cole 1991; Jeffries and Klopatek 1987). Belnap (1992) reported that if only visual estimates of cyanobacterial cover are considered, recovery appears quite rapid. In several experiments where the top 2 cm of the soil surface was removed, all plot surfaces, whether inoculated with nearby material or not, appeared completely covered by cyanobacteria, and most showed rudimentary pedicelling after only 1 year. This gave the impression that the cyanobacterial/green algal components of the crusts were mostly or fully recovered. Chlorophyll *a* measurements, however, told a different story: dramatic differences in chlorophyll *a* levels demonstrated that the amount of photosynthetic cryptobiotic tissue present differed greatly among treatments. Uninoculated plots sometimes supported only 2 percent as much chlorophyll *a* as was found in nearby undisturbed crusts. Estimates for full recovery of the cyanobacterial biomass, using chlorophyll *a* concentration as the indicator, ranged from 35 to 65 years. Other aspects of crust recovery, including the depth of accumulated cyanobacterial sheath material and lichen and moss species number and cover, were much slower.

Lichens showed some recovery at three of the four sites tested. At observed rates, full recovery at these three sites would take 45 to 85 years. At one site, no recovery was seen, even after 5 years; consequently, time to full recovery is impossible to predict. Moss recovery was even slower than that of the lichens. At two of the three sites where mosses were found in the undisturbed areas, no mosses were found in the disturbed areas. This makes prediction of recovery rates for mosses at these sites impossible, but clearly they are extremely slow. At the third site, where some recovery was seen, full recovery of moss cover would take over 250 years at the observed rate.

Several studies have demonstrated that inoculation can hasten the biological recovery of disturbed crusts (Ashley and Rushforth 1984; Belnap 1992; Lewin 1977; St. Clair and others 1986; Tiedemann and others 1980). In Belnap's 1992 study, inoculated plots had far greater chlorophyll *a* concentrations than uninoculated plots, indicating a larger biomass of cyanobacteria and green algae in inoculated sites. Inoculated plots also had significantly greater lichen species richness and greater lichen and moss cover than uninoculated plots. However, although lichen and moss cover was significantly greater on inoculated than uninoculated plots, recovery for both lichens and mosses was still extremely slow for both treatments.

Inoculation also hastened some aspects of visual recovery of the cyanobacterial/green algal component. Areas that had been inoculated had greater pedicellation sooner than areas that were not inoculated. Apparent coverage of the soil surface by this crustal component, however, was not hastened by inoculation, since all soil surfaces appeared completely covered within 1 year. Inoculation somewhat hastened the visual recovery of the lichens and mosses; however, absolute differences were so small it was difficult to tell treatments apart, even with close examination.

## CONCLUSIONS

Cyanobacterial-lichen soil crusts can contribute in many ways to the ecosystems in which they occur. Such crusts can enhance soil stability, reduce water runoff by producing more microcatchments on soil surfaces and adding absorptive organic matter, improve nutrient (nitrogen and some essential mineral elements) relations for at least some vascular plants, and enhance germination and establishment of some vascular plants. These black crusts may also stimulate vascular plant growth and nutrient uptake by producing warmer soil temperatures during cool seasons when free water is most likely to be available in the cold deserts of the western United States.

Until we have a greater understanding of the short- and long-term effects of impacts on the ecology and functioning of these crusts, and how to reestablish them on disturbed arid lands, land managers should minimize activities that may disturb them.

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Annual weeds continue to expand throughout the West eliminating many desirable species and plant communities. Wildfires are now common on lands infested with annual weeds, causing a loss of wildlife habitat and other natural resources. Measures can be used to reduce burning and restore native plant communities, but restoration is difficult and costly.

Keywords: cheatgrass, weed control, fire ecology, restoration, species utility, seed germination, seedbed ecology

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This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

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The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

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