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An Introduction to Biological Soil Crusts

In more arid regions, vegetative cover is generally sparse. Open spaces are usually covered by biological soil crusts, a highly specialized community of cyanobacteria, mosses, and lichens (Figure 1).

Biological soil crusts are commonly found in semiarid and arid environments throughout the world. Areas in the United States where crusts are a prominent feature of the landscape include the Great Basin, Colorado Plateau, Sonoran Desert, and the inner Columbia Basin. Crusts are also found in agricultural areas, native prairies, and Alaska (Figure 2). Outside the United States, crusts have been studied in the Antarctic, Australia, and Israel, among other locations. In fact, microbiotic crusts have been found on all continents and in most habitats, leaving few areas crust-free.

What's the right name?

Biological soil crusts are also known as cryptogamic, microbiotic, cryptobiotic, and microphytic crusts, leading to some confusion. The names are all meant to indicate common features of the organisms that compose the crusts. The most inclusive term is probably biological soil crust, as this distinguishes them from physical crusts without limiting the crust components to plants. Whatever name used, there remains an important distinction between these formations and physical or chemical crusts.

Biological soil crusts are formed by living organisms and their by-products, creating a crust of soil particles bound together by organic materials.

Chemical and physical crusts are inorganic features such as a salt crust or platy surface crust, often formed by trampling.

Structure and Formation

Crusts are formed by living organisms and their by-products, creating a surface crust of soil particles bound together by organic materials. Aboveground crust thickness can reach up to 10 cm. The general appearance of the crusts in terms of color, surface topography, and surficial coverage varies. Mature crusts of the Great Basin and Colorado Plateau are usually darker than the surrounding soil (Figure 3, Figure 4). This color is due in part to the density of the organisms and to the often dark color of the cyanobacteria, lichens, and mosses. Crusts generally cover all soil spaces not occupied by vascular plants, and may be 70% or more of the living cover (Figure 5).

These crusts are characterized by their marked increase in surface topography, often referred to as pinnacles or pedicles. The process of creating surface topography, or pinnacling, is due largely to the presence of filamentous cyanobacteria and green algae. These organisms swell when wet, migrating out of their sheaths (Figure 6). After each migration new sheath material is exuded, thus extending sheath length. Repeated swelling leaves a complex network of empty sheath material that maintains soil structure after the organisms have dehydrated and decreased in size. Frost heaving, subsequent uneven erosion, and lack of surface plant roots results in high pedicles. In in warmer regions such as the the Sonoran, Mojave, and Chihuahuan deserts, lack of frost heaving has been used to explain the absence of pinnacles (Figure 7). In northern deserts, where most rain falls in the winter and surface plant roots are plentiful, crusts are generally rolling or smooth.

Species Composition

Crusts are predominantly composed of cyanobacteria (formerly called blue-green algae), green and brown algae, mosses, and lichens. Liverworts, fungi, and bacteria can also be important components (Figure 8, Figure 9).

In the Great Basin and the Colorado Plateau, *Microcolues vaginatus* (a cyanobacteria) composes the vast majority of the crust structure. Lichens of the genera *Collema* spp. and mosses from the genera *Tortula* spp. are common. In hot deserts, such as the Sonoran, other cyanobacteria are more common. Some more acidic soils are dominated by green algae. Shifts between green algal and cyanobacterial dominance have been attributed to changes in pH, with the decreasing alkalinity favoring green algae. More stable crusts are dominated by lichens and/or mosses. The organism that dominates the crust is partly determined by microclimate and may also represent different successional stages in crust development.

Ecological Functions

Crusts play an important role in the environment. Because they are concentrated in the top 1 to 4 mm of soil, they primarily effect processes that occur at the land surface or soil-air interface. These include soil stability and erosion, atmospheric nitrogen-fixation, nutrient contributions to plants, soil-plant-water relations, infiltration, seedling germination, and plant growth.

Soil Stability

Crust-forming cyanobacteria have filamentous growth forms that bind soil particles (Figure 10). These filaments exude sticky polysaccharide sheaths around their cells that aid in soil aggregation by cementing particles together (Figure 11, Figure 12). Fungi, both free-living and as a part of lichens, contribute to soil stability by binding soil particles with hyphae. Lichens and mosses assist in soil stability by binding particles with rhizines/rhizoids, increasing resistance to wind and water erosion. The increased surface topography of some crusts, along with increased aggregate stability, further improves resistance to wind and water erosion (Figure 13, Figure 14).

Water Infiltration

Crusts can alter water infiltration. Studies where crusts greatly increase surface roughness generally have increased infiltration (Figure 15). Where crusts do not significantly increase surface roughness, infiltration is generally reduced due to the presence of cyanobacterial filaments. Differences in findings are therefore site-specific and also related to soil texture and chemical properties of the soil.

Effects on Plant Germination and Growth

Studies investigating the role of crusts in plant germination have had varied results. Increased surface relief is believed to provide safe sites for seeds, while darker surface color increases soil temperatures to those required for germination earlier in the season, coinciding with spring water availability.

Large-seeded plants often require burial for germination. Native seeds have self-drilling mechanisms or are cached by rodents. However, soil crusts reduce soil movement, and this may limit passive burial and germination of large-seeded exotic plants like *Bromus tectorum* (cheatgrass).

Studies of how crusts effect plant health are clear-cut. Many studies have shown increases in survival and/or nutrient content in crust-covered environments as opposed to bare soil. Nutrients shown to increase in plant tissues grown in the presence of crusts are nitrogen, phosphorus, potassium, iron, calcium, magnesium, and manganese. Some of the plants benefited by crust presence include *Festuca octoflora* (sixweeks fescue), *Mentzelia multiflora* (desert blazing star), *Arabis fecunda* (rock-cress), *Kochia prostrata* (prostrate summercypress), *Linum perenne* (blue flax), *Lepidium montanum* (mountain peppergrass), and *Sphaeralcea* *coccinea* (scarlet globemallow).

Response to disturbance

Crusts are well adapted to severe growing conditions, but poorly adapted to compressional disturbances. Domestic livestock grazing, and more recently, recreational activities (hiking, biking, and off-road driving) and military activities place a heavy toll on the integrity of the crusts. Disruption of the crusts brings decreased organism diversity, soil nutrients, stability, and organic matter.

Direct damage to crusts usually comes in the form of trampling by humans and livestock or vehicles driving off of roads (Figure 16). Compressional disturbances break sheaths and filaments and drastically reduces the ability of the soil organisms to function, particularly in providing nitrogen and soil stability. Changes in plant composition are often used as indicators of range health. This indicator may not be sensitive enough to warn of damage to microbiotic crusts. Studies of trampling disturbance have noted that losses of moss cover, lichen cover, and cyanobacterial presence can be severe (1/10, 1/3, and 1/2 respectively), runoff can increase by half, and the rate of soil loss can increase six times without apparent damage to vegetation. Disturbance to soil surfaces in arid regions can lead to large soil losses (Figure 17, Figure 18)

Other disturbance impacts are indirect. Several native rangeland shrubs (*Artemisia tridentata*, *Atriplex confertifolia*, and *Ceratoides lanata*) may have allelopathic effects on the nitrogen-fixing capabilities of crusts, potentially lowering nitrogen fixation by 80 percent. Actions that increase the shrub component, such as excessive grazing, can have an unexpected impact on crust functioning.

Another indirect disturbance occurs through crust burial. When the integrity of the crust is broken through trampling or other means, the soil is more susceptible to wind and water erosion. This soil can be moved long distances, covering intact crusts. Crusts tolerate shallow burial by extending sheaths to the surface to begin photosynthesis again. Deeper burial by eroded sediment will kill crusts (Figure 19).

Fire is a common occurrence in many regions where microbiotic crusts grow. Investigations show that fires can cause severe damage, but that recovery is possible. The degree to which crusts are damaged by fires apparently depends on the intensity of the fire. Low-intensity fires do not remove all of the crust structure, which allows for regrowth without significant soil loss. Shrub presence (particularly sagebrush) increases the intensity of the fire, decreasing the likelihood of early vegetative or crust recovery.

Full recovery of crust from disturbance is a slow process, particularly for mosses and lichens. There are means to facilitate recovery. Allowing the cyanobacterial and green algae component to recover will give the appearance of a healthy crust. This visual recovery can be complete in as little as 1 to 5 years, given average climate conditions. However, recovering crust thickness can take up to 50 years, and mosses and lichens can take up to 250 years to recover (Figure 20). Limiting the size of the disturbed area also increases the rate of recovery, provided that there is a nearby source of inoculum.

Future Research

The land where crusts occur is used for a wide range of purposes--from grazing and recreation to military uses, and in some places, crops. Ultimately, land managers need to know how the functions of crusts change under different practices. Where the functions of crusts are impaired or eliminated because of land use practices, land managers need guidelines to adapt their practices to protect or restore the functions of crusts.

Glossary

Algae: nonvascular photosynthetic plant-like organisms, they are informally divided into groups by their dominant pigments (i.e., green, brown, red, etc.).

Bacteria: microscopic, single-celled organisms.

Cyanobacteria: photosynthetic bacteria formerly called blue-green algae, their growth forms tend to be filamentous.

Fungi: nonphotosynthetic multicellular organisms that are either saprophytic or parasitic.

Hyphae: single strands of a fungus.

Lichen: a composite plant consisting of fungi living symbiotically with algae or cyanobacteria.

Liverworts and mosses: nonvascular plants of small stature, the two are similar with the exception of reproductive methods.

Rhizines/rhizoids: root-like structures of lichens and mosses respectively, they are used for attachment.

Sheaths: external coating formed by some filamentous cyanobacteria, those discussed in the article are formed from polysaccharides.

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