Biological Soil Crusts Status Report

2003 National Cooperative Soil Survey Conference
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National Soil Survey Conference
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Biological Soil Crust Subcommittee
Status Report

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The subcommittee on Biological Soil Crusts initially formed as a task force in response to a proposal from the West Regional Cooperative Soil Survey Conference, Coeur d'Alene, ID, 1998 and the rangeland health/soil quality indicator needs on rangelands:

> "Soil scientists need to include information about biological soil crusts (microbiotic soil crusts) when describing pedons on rangeland. The percent cover of biological soil crusts and relative amount of lichens, mosses and cyanobacteria need to be recorded for each pedon description. It would take a squirt bottle and five minutes to train employees and to have them perform this task in field, according to Jayne Belnap (Research Ecologist, USGS, Moab, UT). In turn, this pedon description information should be accessible to researchers so they can incorporate it into their studies. Include information about soil biological crusts in range site descriptions." –Bill Ypsilantis, BLM. Excerpted from West Regional Cooperative Soil Survey Conference Proceedings.

The task force, under the coordination of Arlene Tugel, currently comprises representatives from NPS, USGS, BLM, USFS, Utah State University, NRCS SQI and GLTI, the Phoenix and Denver MOs, and NRCS Utah and Colorado field soil scientists. The force met for the first time in May, 2002, in Moab, Utah, considered by experts to be biological soil crust Mecca. The purpose for the get together was to 1) receive training from Dr. Jayne Belnap, renowned research ecologist on biological soil crusts, USGS, 2) test methods for recording the composition of biological soil crusts and other surface features, 3) record the needs of each of the partners in attendance, and 4) present a report of recommendations to the Standards Committee at the 2002 West Regional Cooperative Soil Survey Conference, held in Telluride.

For your convenience, the CD version of these proceedings contains the Task Force Report to the West Regional Cooperative Soil Survey Conference. The CD contains a first draft of material intended for incorporation into the Soil Survey Manual, guidelines for recording soil surface features, a review of methods used to describe surface roughness, and examples of how a soil pedon with a biological soil crust could be described. We introduce the idea of recording soil surface features at two scales, that is at the pedon scale and at the component scale, and we present the notion of a hierarchical framework that differentiates features <u>at</u> the surface from the actual <u>shape</u> of the surface. So I encourage you to pour over the CD version of these proceedings to get an in-depth appreciation for the work this subcommittee has accomplished.

What are biological soil crusts and what are they good for?

I want to take a few minutes to introduce biological soil crusts, their ecosystem function, explain why they are important to our NCSS partners, and what this subcommittee has accomplished. Then I'll give Bill Ypsilantis and Pete Biggam an opportunity to chat about steps they are taking to get biological soil crusts integrated into their soil surveys.

Biological soil crusts are also known as cryptogams or microbiotic crusts. They formed by non-vascular living organisms and their by-products, creating a crust of soil particles bound together by organic material. They occur in all climates, but are a prominent feature in arid and semi-arid regions such as the Columbia Basin, Great Basin, Colorado Plateau, and Sonoran Desert. Prevalent in the surface few centimeters of soil, biological soil crusts are comprised of cyanobacteria, mosses, lichens, and microfungi. They function within ecosystems to 1) stabilize soil and protect it from erosion, 2) fix carbon and nitrogen for plant growth, and 3) provide sites for seed entrapment. The effect of biological crusts on infiltration varies with soil texture. Biological crusts are indicators of rangeland health and soil quality. Their presence and spatial distribution relative to higher plants are management-dependent, and can be used to infer disturbance effects on soil stability and erosion resistance. Presently, the National Cooperative Soil Survey (NCSS) does not record this soil-biotic component in soil surveys nor does it provide interpretations related to its functions. Thus, resource managers are unable to use soil surveys to spatially extend information about the likely occurrence and dynamic nature of biological crusts.

Needs identified by NCSS regarding biological soil crusts:
1. All public lands agencies must address biological soil crusts in National Environmental Policy Act (NEPA).
2. BLM needs a simplified field guide of factors related to biological crusts that should be included in NEPA documentation.
3. Where are biological soil crusts a management consideration and where not?
4. NPS must shift from managing visitors to managing resources. Need to identify biological soil crusts in the soil survey program.
5. NPS would use biological crusts in information and education programs on ecological significance of crusts across landscapes.
6. NPS would use crust information in biological inventory, possibly as vital signs or indicators for ecosystem processes.
7. USGS needs a database that links biological crust information to soil properties, site characteristics, and location.
8. USGS needs multi-agency support (money) for training and mapping. Because of limited resources and knowledgeable personnel, need to “train the trainers.”
9. USFS Region 3 is currently making ocular estimates to document biological soil crusts composition in their Terrestrial Ecological Unit Inventories, and therefore recognize a need for a protocol to describe and record crusts in soil survey.
10. NRCS - Which regions or soils are crusts an important part of the system in terms of overall function? Do they function differently in different ecosystems?
11. NRCS - Must add biological soil crust information to site descriptions.
12. NRCS - What role do crusts play in each “state” (State and Transition Model).
13. NRCS - Consider biological crust as a possible threshold indicator: Where and when does it work?
14. NRCS - Biological crusts are used in Ecological Site Descriptions and the National Resources Inventory (NRI).

Findings of the West Regional Cooperative Soil Survey Standards Committee:
As to whether collecting information on biological soil crusts was a soil survey function, there was not unanimous agreement among the West Regional Standards Committee. The committee did make the following recommendations:

1. A standard protocol for identification and description of biological crusts should be proposed as a change to the Soil Survey Manual.
2. For the sake of efficiency in collecting data for compositional and functional analysis, those kinds of surface features commonly recorded during routine soil survey activities should be recorded at the same time. This common-sense idea evolved during the testing phase of various methods for transecting biological soil crusts and other surface cover features.

   In general, the NCSS appears to be collecting limited data related to soil properties at the soil–air interface. Except for percentage of various shapes and sizes of rock fragments, NASIS doesn't provide much in the way of options for recording other features at the soil surface, e.g. nothing for bare mineral soil material, organic soil material, plant litter, bedrock, pararock fragments, woody debris, fractions > 2mm, such as 2-5mm, 5-20. The biological soil crust subcommittee has developed a fairly complete table of kinds of surface features. After some additional refinements, we plan to distribute the surface feature table for a broader technical review.

3. The Soil Biological Crust Task Force should work closely with Soil Survey Classification and Standards staff to clarify terms and to incorporate soil crust methodology in the SSM.

Work in progress for 2003

The subcommittee is working on two high priority items in 2003 that were identified during the 2002 Moab meeting, that is 1) explore ways to describe surface roughness and 2) develop a protocol for describing biological soil crusts in pedon descriptions.

Surface roughness

The Soil Survey Manual offers little in the way of guidelines for determining surface roughness. This subcommittee conducted a literature review of some of the current methods. The cost and time constraints associated with high-end methods, such as laser microrelief and acoustical technology, preclude their application in standard soil surveys.

There is promise in exploring fractals to describe surface roughness. The Task Force has not pursued this. There is potential also in applying modern photogrammetric digital techniques to spatially analyze the shape of the surface at close-range. The subcommittee strongly recommends that the NCSS take the lead in developing these technologies.

The subcommittee was impressed with a method developed by Saleh. The theory is that a chain of given length (L1) will traverse a shorter horizontal length (L2) when it follows a rough surface compared to a smooth surface. The difference between L1 and L2 is related to the degree of roughness:

$$\mathbf{Cr = (1 - L2/L1) \bullet 100,}$$ where Cr is roughness in any direction.

The drawback to Saleh's method is that the ratio does not necessarily interpret variations in height (e.g. did the chain fall across one large bolder or two stones and a cobble?). Perhaps if Saleh's ratio is combined with a narrative description of surface morphology, then we will come a little closer to describing surface roughness.

An expedient technique for rapid field assessment and relative class placement of roughness would be to photograph areas of selected roughness conditions. A standardized set of photographs could be used to illustrate class limits of roughness; placement in the appropriate class (e.g. none, slight, moderate, and high) may be made directly from the photographs. Until better techniques become available, photos of the soil surface (both plan view and cross-section, with scale) could be archived.

Pedon descriptions

Biological soil crusts are in fact soil horizons, albeit in many cases less than 1 cm in thickness, the result of soil forming factors and processes acting upon and within the soil surface (figure 1). The following example separates the percent composition of features at the surface, such as biological soil crusts, rock fragments and surface roughness, from the A horizon description.

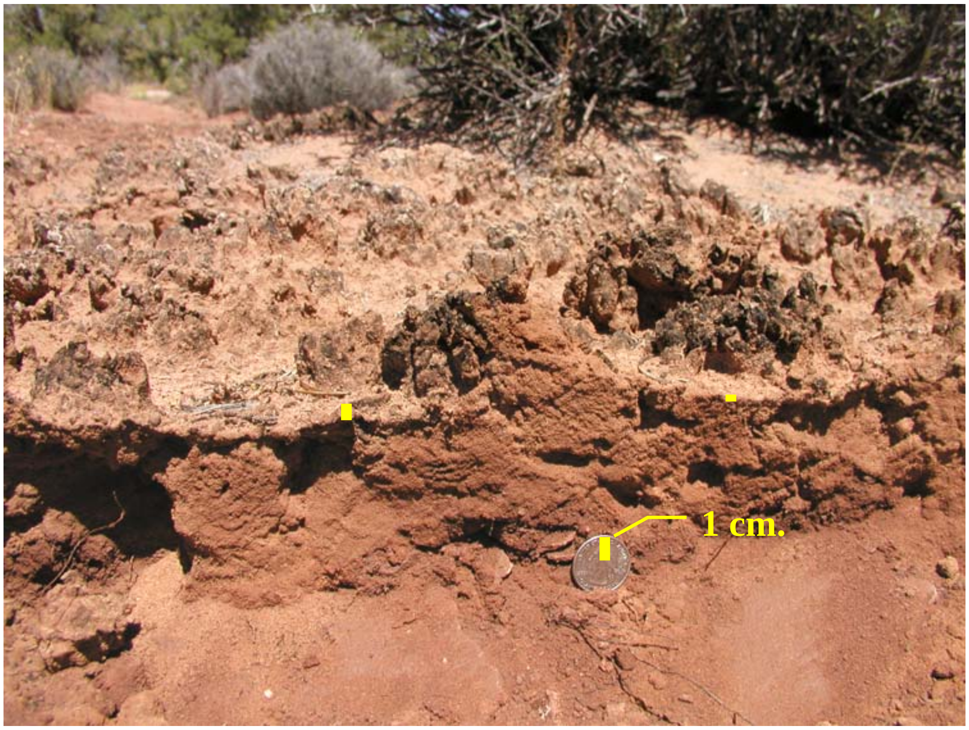

Figure 1 - Thickness of this biological soil crust horizon is about .3 to .8 cm. (Colorado Plateau, Moab, UT. May, 2002)

Pedon-scale surface features: Soil surface morphology is about 60 percent pinnacles, each pinnacle approximately 2 to 4 cm wide, 6 to 9 cm long, and 1 to 5 cm in height, spaced about 4 to 12 cm apart. Surface roughness index is 35 (1 - ratio of ground chain length to actual chain length). Surface features are 30 percent bare mineral soil (5YR 6/6 dry), 30 percent light cyanobacteria (5YR 6/6 dry), 10 percent dark cyanobacteria (color optional), 10 percent lichen (color optional), 5 percent moss (color optional), 10 percent plant bases, and 5 percent pebbles.

A--0 to .8 cm; light red (5YR 5/4) fine sandy loam, reddish brown (5YR 4/4) moist; weak medium platy structure parting to single grain; soft, very friable; very fine roots and root-like structures; many medium interstitial pores; strongly effervescent; carbonates are disseminated; moderately alkaline (pH 8.2); very abrupt broken boundary (70 percent continuous) . (.3 to .8 cm thick).

Activities planned for 2004

The Task Force will continue to evaluate and refine the methods, procedures and examples discussed in this status report. Of primary interest is the applicability of methods in areas of the Sonoran, Mohave, and Chihuahuan Deserts. A field tour is being planned for the fall, 2003.

The surface features table will be further developed, tested, and distributed for review in 2004.

And now if Bill and Pete will share some of their thoughts of how they see biological crust being "institutionalized" with their program areas, I'll gladly step down and let them have the floor.

Current Developments among NCSS Cooperators

Pete Biggam, National Park Service: We are using the protocols initiated by the NCSS Biological Soil Crust taskforce on our ongoing soil resource inventory at Big Bend NP, and will continue to evaluate these on any future inventories.

There is a potential for their evaluation on our soil resource inventory which is currently in progress out at Channel Islands National Park, off the California coast.

Numerous units within the Colorado Plateau are currently "managing for crusts" as part of their "Visitor Experience, Resource Protection" (VERP) program. Arches NP has a well established program.

Here are a few Websites for your review;

http://data2.itc.nps.gov/nature/subnaturalfeatures.cfm?alphacode=arch&topic=11&loc=4

Zion NP General Management Plan addresses microbiotic soil;

http://www.nps.gov/zion/pr/zion_gmp.pdf

Site from Bryce Canyon NP;

http://www.nps.gov/brca/nacryptosoil.htm

Channel Islands NP Resource Management Plan addresses crusts;

http://www.nps.gov/chis/rm/PDF/NR%20STATUS.pdf

Bill Ypsilantis, Bureau of Land Management: The Bureau of Land Management (BLM) is very interested in having biological soil crusts described in conjunction with soil survey activities. Biological soil crusts play a vital ecological role on public rangeland and are an important indicator of rangeland health. Most soil surveys on public land are conducted through Interagency agreements with the Natural Resources Conservation Service (NRCS), though we do have one BLM Ecological Site Investigation team in eastern Oregon inventorying soils. BLM is actively working with the National Cooperative Soil Crust Task Group to develop standard inventory protocols for biological soil crusts. Until those protocols are approved, the Bureau is strongly encouraging so

Soil Crust Task Force Report

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Telluride, CO

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1. Identify agencies' needs and potential uses for biological soil crust information.
2. Locate areas to test soil crust identification and definition criteria in the field.
3. Develop and test the process to describe soil crusts.
4. Prepare recommendations and report to be presented to the West Region Cooperative Soil Survey Standards committee.

The Soil Crust Task Force was established in response to a proposal from the West Regional Cooperative Soil Survey Conference, Coeur d'Alene, ID, 1998 and the rangeland health/soil quality indicator needs on rangelands. The Task Force conducted the initial field test of methods to be used to describe biological soil crusts for soil survey activities in Moab, Utah, May 6-9, 2002. Cover methods were developed by biological soil crust expert, Dr. Jayne Belnap, Research Ecologist, USGS, Moab, UT, Arlene Tugel, NRCS Soil Quality Institute, Las Cruces, NM and Dr. Jeff Herrick, ARS Jornada Experimental Range, Las Cruces, NM. Dr. Belnap provided training and technical guidance during the week and led a tour of the variety of soil crust types and associated soil parent materials typical of the Colorado Plateau. Arlene Tugel led the field test of four methods for measuring soil surface cover of biological crusts. Task Force members developed examples of soil profile descriptions that characterize biological crusts. Pat Shaver, Grazing Lands Technology Institute, NRCS made a presentation on State and Transition Models, a decision aid for land managers that explains vegetation dynamics and recognizes that disturbances can affect dynamic soil properties as well as the plant community. The Bureau of Land Management, National Park Service, Forest Service, US Geological Survey, and Natural Resources Conservation Service representatives described agency needs for soil crust information.

There was 100% agreement among the Task Force Members that biological soil crusts are important and their identification and description should be included in soil survey. Crusts perform valuable functions in soil stability, nutrient cycling and the hydrologic cycle and information is needed in agency programs. The Task Force suggested and agreed that information on all surface features important for soil surface resistance to erosion, raindrop interception and runoff, not just biological crusts, should be gathered in soil survey work.

Recommendations made by the Task Force are listed below. Part II fully discusses the Task Force response to each charge. Part III summarizes research needs, action items and additional charges that need to be addressed. Part IV lists resources for additional information. Part V, Appendices, includes the list of agency needs, a Soil Survey Manual draft, the surface cover methods, soil descriptions and photos.

Recommendations

1. **Biological crusts are important and their identification and description should be included in soil survey.**
   The attributes of crusts that the task force identified as important to measure are, at minimum: percent cover by morphological group (moss, lichen, cyanobacteria – light vs. dark) and surface roughness/surface relief (organism neutral). Other important features are the location of crusts in relation to canopy cover and color of crust organisms.
2. **Alternative approaches to incorporating crust morphology (vertical and horizontal) into a soil description must be developed and evaluated.**
   Suggested alternatives are 1) an A horizon with biological crust or 2) a surface feature that is a part of the profile description. See Appendix 4 for example profile descriptions.
3. **All surface features (e.g., biological, physical and chemical crusts, bare ground, rock fragments, litter and plant bases) should be included in soil surface cover methods. Protocols are needed for soil survey.**
   By including all surface features that relate to soil surface stability, runoff and infiltration in one transect, the surface feature method: 1) collects data valuable for functional interpretation, 2) increases efficiency of data collection, and 3) facilitates the development of a nationally applicable transect spreadsheet in which statistical analyses can be performed. "Guidelines for describing soil surface features" (ver. 2.0) were modified after the test in Moab and incorporate this recommendation (Appendix 3). Additional criteria for physical and chemical crusts must be included.
4. **Appropriate surface cover methods should be identified in the standards and specifications for each soil survey based on considerations of workloads and interpretation needs. The methods (Appendix 3) and their suggested uses are:**
   a) **Ocular estimates (Method 5) of total biological crust cover (0, 1-5, 6-25, >25%) and presence or absence of dark cyanobacteria, lichen, or moss will be recorded in field notes;**
   b) **Line-point transects (Method 4) will be used to measure surface features at typical pedons and for map unit component documentation. Transects will be georeferenced.**
   c) **Photographic documentation of surface features will be taken at pedons and georeferenced.**
   d) **Quadrats (Methods 2 and 3) have value for training and calibration and can be ideal methods in ecosystems other than those tested in Moab.**
5. **New crust data elements developed must be added to soil survey databases (National Soil Survey Information System, NASIS).**

6. **Soil surface cover and soil description methods must be tested on other types of biological crusts in other physiographic/ecological regions, including the Chihuahuan Desert, Sonoran Desert, Mojave Desert, Great Basin and short grass prairie.**
7. **Biological crust training for agency personnel is needed. Multi-agency support for this training is encouraged.**

CHARGE 1. Identify agencies' needs and potential uses for biological soil crust information.

1. Needs and uses. A full list of needs and potential uses presented by agency representatives is in Appendix 1. Agencies either currently use or plan to use biological soil crust information in a variety of activities including NEPA documentation, soil survey, ecological site descriptions, state and transition models, information and education programs, inventory and monitoring (National Resources Inventory, biological inventories), rangeland health and soil quality assessments of ecosystem processes, and possibly as vital signs or threshold indicators for ecosystem processes.

Task Force Participants also identified needs for information and research. Information about where and when crusts are a management consideration is needed. We know that biological crusts help stabilize soil and protect it from both wind and water erosion. Crust organisms fix carbon and some crust organisms fix nitrogen for plant growth. They also provide sites for trapping seeds and can effect infiltration in a variety of ways, depending on soil texture and surface roughness. Crusts may not be as important in some ecosystems as in others. Inventory data showing where different types of crusts occur is needed. Research conducted in a variety of ecosystems will add valuable information to our current knowledge of the importance of biological crusts in different ecosystems. Research topics include 1) the role of biological crusts in soil surface stability, mineral cycling, and water cycling, 2) the use biological crusts as a threshold indicator, and 3) the effects of management on biological crusts and the functions they perform.

Specific needs include protocols to describe crusts, a simplified photographic field guide of crusts, a simplified guide for NEPA documentation such as a checklist or flow chart and training available to field personnel of all agencies. Multi-agency support ($$$) is needed for training. A database that links biological crust information to soil properties, site characteristics and location is needed.

2. How can soil survey address biological soil crusts (BSCs)? All task force participants agreed that BSCs were important for understanding soil function in an ecological context, and agreed that a minimum set of data on BSCs should be included in standard soil survey methods. In the next phase of the National Resources Inventory (NRI), NRCS intends to gather line-point intercept data to monitor a variety of properties, including biological soil crusts, that reflect ecosystem functions. This data will be tied to soil map units. If BSC occurrence and characteristics can be linked to soils data, we have the potential to develop and test predictive models.

However, many participants were concerned with the increasing amount and diversity of data required for soil and site descriptions. Depending on the difficulty of excavation and soil depth and complexity, one whole day could be spent on pedon morphology without addressing BSCs. Therefore, we must 1) identify which BSC attributes are most important for understanding ecological function, and 2) determine the most efficient methods for collecting a standard data set characterizing these attributes. The most important BSC attributes and their priority are listed in Table 1. Brief explanations of why the attribute is important are provided for each.

- **Surface roughness.** Surface roughness has implications for infiltration and surface runoff. For example, a high degree of surface roughness can slow runoff and increase infiltration.

- **Cover by morphological groups of organisms.** Moss, lichen and cyanobacteria (light and dark) are three different morphological groups. Morphological group cover has implications for soil stability and nutrient cycling. Crusts containing mosses and lichens are more stable than crusts dominated by cyanobacteria. Cyanobacteria crusts stabilize soil better than bare soil. Mosses and lichens fix more carbon than cyanobacterial crusts. Some lichens and cyanobacteria fix nitrogen. The terms morphological and functional are often used interchangeably. Morphological group is preferred for our purposes. The term functional, if applied to crust organism groups, can be confusing in relation to N fixation. Some species of cyanobacteria and some types of lichen (gelatinous) fix N, but not all species. So, not all lichens function the same way in regards to N-fixation, but both cyanobacteria and gelatinous lichen do.

- **Spatial distribution in relationship to plants.** Spatial distribution provides information about soil-plant relationships and can be used to infer disturbance effects on soil stability and resistance to erosion (e.g., BSC concentrated under shrubs indicates that soil under plants is more resistant to surface erosion than soil in the interspace between plants). Although spatial distribution can be very site-specific and related to land management practices or intensity of use (e.g. heavy use by wildlife, livestock or humans), it is a dynamic soil property that is important for state and transition models, assessments and monitoring programs. Spatial distribution of total crust cover can be documented qualitatively with photo-documentation, and provides a good historical record, but photo resolution may not be high enough to distinguish morphological groups. Quantifiable methods such as transects provide information for each morphological group in relation to canopy.

Table 1. Biological Crust Attributes and Their Importance.

Priority	Attribute	Function or Importance
1 – high	Surface roughness	Runoff and infiltration
2 – high	Cover by kind (CYN, LIC, MOS) and total cover	Soil stability, nutrient cycling, infiltration
3 – medium	Location of crust in relation to canopy cover	Disturbance impacts, soil stability
low	Color of biological crust organisms	Genus or species present, N-fixation potential

3. Properties related to crust occurrence and function. We also discussed specific soil properties that research indicates are related to biological crust occurrence and function. Some of these are also important for interpreting the resistance and resilience of biological crusts to disturbance. Important properties are:

- **Texture:** It is unlikely that lichens and moss will occur in the interspace on extremely sandy soil because the shifting sands may not provide a stable enough substrate for organism colonization and growth. However, cyanobacteria will generally occurs on sandy soil. Biological crusts can also facilitate trapping of fine particles, evidenced by finer texture in the upper few mm of soil. Texture can determine whether a biological crust increases or decreases infiltration.
- **Major cations:** An abundance of cations (ie. Ca, K) in soil may facilitate BSC colonization and morphological composition. Because BSCs play an important role in nutrient cycling, the presence and morphological composition may also influence the vertical distribution of major cations in soil.
- **Carbonates and gypsum:** It is likely that soil chemical constituents influence BSC morphological composition. For example, we observed the most developed and morphologically diverse BSC community on gypsiferous soils.
- **pH:** Soil reaction likely influences BSC morphological composition. Dr. Belnap has observed cyanobacterial crusts occurring at pH 7.0 to 10.5. At pH less than 7, green alga crust occur. BSC can also influence the vertical distribution of soil pH; Dr. Belnap observed a pH of 10.5 in the upper 0.5 mm of soil with a biological crust.
- **Physical and biological crust relationships.** Biological crusts often form on physical crusts. The effect of biological crusts on infiltration can be confused with the effect of the underlying physical crust on infiltration. The role of biological crusts in the breakdown of physical crusts in not known.

CHARGE 2. Locate areas to test soil crust identification and definition criteria in the field.

1. Locations. Six regions where biological crusts are dominant features on the landscape are the Colorado Plateau, Chihuahuan Desert, Sonoran Desert, Mojave Desert, Great Basin, and short grass prairie. Biocrust organisms (moss, liverworts) also occur in more humid environments but their ecological importance in these systems is unknown. The dominant morphological group varies among the six regions. This initial field test was conducted in the Colorado Plateau where pinnacled crusts (Appendix 5, photo) of cyanobacteria and lichen are prevalent. Additional tests are needed in other regions where crust composition and morphology are different.

2. Terminology and fundamental information. A draft Soil Survey Manual document “Biological Soil Crusts” (Belnap and Tugel) was prepared to provide fundamental information and terminology for biological crusts in soil survey (Appendix 2). The occurrence of crusts in arid regions and their composition are described. The importance and types of biological crusts, their relation to physical crusts and their distribution are also discussed.

CHARGE 3. Develop and test the process to describe soil crusts.

Methods for measuring soil surface coverage of biological crusts (total and by morphological group) and cover stratified by canopy were tested on the Colorado Plateau. Soil scientists also prepared descriptions of the pinnacled crusts at this site to illustrate the variety of ways that pinnacled crusts can be described. The results of these activities are discussed below.

1. Cover. The Task Force tested four methods (Appendix 3) in Moab, UT where pinnacled crusts of dark cyanobacteria and lichens are the dominant crust type. The step-point, ocular estimate with quadrats/transect, line-point quadrat methods were used to estimate or measure biological crust cover. The line-point intercept method from the Montioring Manual for Grassland, Shrubland and Savanna Ecosystems (Herrick et al., in press) will be a part of NRI and was slightly modified for this test for soil survey purposes. It can be used to measure biological crust cover stratified by canopy. Results of the test are reflected in the recommendations. The following are comments by task force members on the four test methods for evaluating cover:

Step-point (Method 1)
- Destroyed what you were trying to look at
- Repeatability limited because of destruction from steps
- Hard to maintain a straight line around vegetation. The tendency would be to walk around and avoid dense or thorny plants, thus biasing the results.
- Had to bend down and look at tiny crust features, didn't look as closely as for other methods
- Fast
- Easy to get randomness and lots of points in areas with low vegetation cover

Ocular estimate with quadrats (Method 2)
- Need to get calibrated each field season before using with confidence. FS uses a modification of this method now.
- Fast
- Has training and calibration value

Line-point quadrat (Method 3)
- Rapid
- Easy
- Seems fairly accurate
- Has value in teaching crust organisms and for calibration

Stratified line-point intercept (Method 4)
- Method is used in monitoring (part of NRI protocols)
- Seemed less appropriate for determining morphological composition of biological crusts than quadrat methods in this ecsosystem
- If one goes to trouble to set up line, take as much info as possible (i.e., rock fragment cover, etc.)
- Once line is set up, fairly rapid
- Need to emphasize that you have to get down and look closely at the organisms.
- Can obtain information on spatial patterns (i.e., crusts associated with canopy/no canopy or with plant species).
- May be most appropriate for determining soil surface cover for typical pedons, not day to day mapping

We then asked the question, which methods, if any, would you use in day-to-day soil mapping activities? Those task force members who work primarily in the field stated they would probably use an ocular estimate method, unless required to do otherwise by superiors. All recognized the importance of using a more reliable method. But, they admitted that time was limited and there was already an abundance of data to collect in pedon and site descriptions. In order to insure that inaccruate values of crust cover by morphological group were not made by ocular estimate, the group agreed to the need for a fifth method. Ocular estimates (Method 5) of total biological crust cover will use four cover classes (0, 1-5, 6-25, >25%) and simply indicate the presence or absence of dark cyanobacteria, lichen, or moss. The stratified line-point method was the preferred method for data collection at pedons and for ecological sites.

Because of workload considerations, some members of the Task Force suggested that ocular estimates of total biological crust cover be recorded in field notes and line-point transects be used to measure all surface cover features at typical pedons for initial surveys. For update soil survey operations, use line-point transects of all soil surface cover features for all map units and their components and georeference and photograph the profile and surface features.

Because of ease of use and the variable nature of the distribution of crusts, some methods are better suited than others to specific situations. Dr. Belnap suggested that the line-point method is best suited where there is >25% shrub or tall grass cover, OR where patches of biological crusts are widely scattered. The quadrat/transect method (frame-point) is best suited to the Colorado Front range, bunchgrasses, OR where shrub cover is < 25%.

2. Soil descriptions. A significant amount of our discussion focused on how best to accurately and efficiently describe biological crusts in the context of a pedon and site description. Some argued in favor of describing the BSC as a horizon feature. Others argued that BSC should be described solely as a surface feature. Most acknowledged that it may be possible to describe BSCs as both surface and horizon features.

The task force broke into groups and each was charged with describing a soil that had a well developed, pinnacled biological crust. The descriptions are in Appendix 4. The first group treated the biological soil crust primarily as a horizon feature. Because the BSC was very highly pinnacled, soil depth to hard bedrock was 8 cm measuring from the valleys between pinnacles and13 cm measuring from pinnacle tops. Therefore, they described the crust as an A horizon from 0 to 3 cm, ranging in thickness from 1 to 5 cm, and used the mid-point of the crust as the effective soil surface. They noted “pinnacled” in the “accessory property” column of the soil description form (R3-FS-2500-6). They noted the average width of and distance between pinnacles, and the morphological groups of organisms present.

The second group also focused on the biological crust as a horizon, describing “pinnacled” vs. “non-pinnacled” areas. Measuring up from the lithic contact, they described two A horizons separated by a broken boundary. The A1 was the pinnacle itself, which had a high concentration of biological crust material, and the A2 was the thin crust between pinnacle, with a high concentration on undifferentiated material (physical crust and light cyanobacteria crust). They suggested describing biological crusts similarly to ped and void surface features (page 2-24 of Field Book for Describing and Sampling Soils). Filaments and sheaths of crust organisms would be described similarly to roots in the soil matrix.

The third group focused on the biological soil crusts as a soil surface feature. They first identified the type as “pinnacled. The measured the vertical (height of pinnacles) and horizontal (length and width) dimensions. They suggested describing size classes, similar to classes of blocky or prismatic soil structure. Cover by morphological group, average color for pinnacle and inter-pinnacle space, location on the soil surface, thickness of the "rind" (crust), and surface roughness could be described. This group identified the soil surface (0 cm) at the valley (lowest part) between the pinnacles.

The last group acknowledged that there was merit in describing the biological crust as both a horizon and a soil surface feature. Because some important information may be lost if the crust is lumped with underlying soil, a 1-cm crust was split out and the pinnacle height was included in the range of horizon thickness. They suggested that the surface of the soil (0 cm) could possibly start at the base of the "rind" (crust), but most others did not agree. The crust could be identified with a special suffix in the horizon designation ("u" for cr<u>u</u>st, for example). Soil surface spatial features should also be described; a table for all types of soil crusts is probably needed in NASIS.

3. Conclusions on cover methods and profile descriptions. Following these independent group observations and the test of cover methods, the task force revisited the specifics of describing biological crusts in soil survey. Everyone agreed that BSCs should be described as soil surface features. There was general consensus that BSCs should be included in surface cover characterization and that we should develop protocols for describing all types of soil crusts as well as all surface features:

- Physical crusts
- Chemical crusts (e.g., salt crusts)
- Biological crusts
- Biologic components at the surface, e.g., periphyton
- Rock fragments
- Plant bases
- Bare soil and non-crusted soil
- Litter

Modifications to methods 1-4 and a new Method 5 based on the recommendations of this test are in "Guidelines for describing soil surface features (ver 2.0)." The methods were modified to include all surface features important for soil surface resistance to erosion, raindrop interception, and runoff.

The attributes of crusts that the task force identified as important to measure were, at minimum:

1. % cover by morphological group (moss, lichen, cyanobacteria – light vs. dark)
2. Surface roughness/Surface relief (organism neutral). Ideas on how to describe this included:
    - Shape, height, width, and length of units
        - Structural units? For example, establish three size classes for three structural unit shapes
    - Distance or area between units
    - total surface area/ total 2D area of observation

Color may also be an important property to describe, however Dr. Belnap considers it less important than cover, roughness and spatial distribution. Lichens occur in many colors including black, brown, white, pink, yellow and green. Old, stable lichen crusts commonly have a grater diversity of species and hence more colors than young crusts.

There was less agreement on whether to describe biological crusts as horizons and, if so, how. However, there was some consensus that we needed more information, and the following recommendations were made:

- Evaluate alternate approaches to describe crust morphology (vertical and horizontal) as a part of a soil description, e.g., A horizon or a surface feature;
- Examine crusts in other areas of the country;
- Explore options for sampling soil crusts for laboratory characterization.
- Consider use of "u" subscript to indicate the surface has some kind of crust.

1. Research Needs. Continued research is needed to answer questions about the role and occurrence of crusts in various ecosystems. This information will help with the interpretation of biological crust information and prediction of the effects of land use and disturbances on biological crusts. Priority needs are:

1) Document occurrence of biological soil crusts in different ecosystems (Research and Inventory):
   - Document location and current condition of crusts (Inventory and Assessment);
   - Develop predictive model of potential crust distribution (Research).
2) Determine relative importance of biological soil crust function in different ecosystems.
3) Develop models of resistance and resilience of biological soil crusts to disturbances at various levels:
   - Landscape (e.g., soil-landscape-vegetation transects);
   - Soil mapping unit – Soil surveys can provide info on resistance and resilience based on soil-biological crust relationships;
   - Ecological site.
4) Biological soil crusts as indicators of ecological thresholds.

2. Action items.

1. Develop issue paper on accurately, consistently, and efficiently capturing biological soil crust information in soil descriptions, addressing the options of treating biological crusts as horizon vs. surface features.

   Who: Park and Ramsey When: Dec 2002
   Status:

2. Summarize methods available for measuring surface roughness and evaluate their potential for documenting biological soil crust morphology.
   Who: Boettinger, Reedy, Parslow When: Dec 2002
   Status:

3. Develop written guidelines for the ocular method for estimating biological soil crust cover to be used for field notes.
   Who: A. Tugel, J. Belnap When: July 2002
   Status: Completed. See Appendix 3.

4. Make revisions to the surface cover methods based on the field test in the Colorado Plateau. Incorporate all surface features and guidelines for transect length and number of points per transect that are needed for soil components smaller than 50 meters across.
   Who: A. Tugel, J. Belnap When: July 2002
   Status: Completed. See Appendix 3.

3. Additional charges that need to be addressed.

1. Provide illustrations of how biological crust information can impact or improve resource assessment, land management and soil interpretations.
2. Review the draft manuscript “Biological Soil Crusts” for inclusion on the Soil Survey Manual.
3. Guidance on when and where to measure this dynamic soil property is needed. Alternatives include an area that represents the site potential, a plant community likely to shift to a different state or a plant community in a “stable” functional state. Selecting the site will require a well trained range conservationist and soil scientist working together.

The items below are readily available. They contain information about biological soil crusts and their importance.

Belnap, J., J.H. Kaltenecker, R. Rosentreter, J. Williams, S. Leonard and D. Eldridge. 2001. Biological soil crusts: ecology and management. TR-1730-2, USDI, BLM, Denver, CO. Web site http://www.blm.gov/nstc/library/techref.htm

Herrick, J.E., J.W. Van Zee, K.M. Havstad and W.G. Whitford. in prep. Monitoring manual for grassland, shrubland and savanna ecosystems. USDA-ARS Jornada Experimental Range. Island Press, Washington, D.C. contact jherrick@nmsu.edu

NRCS. 1997. Introduction to microbiotic crusts. USDA-NRCS, Soil Quality Institute and Grazing Lands Technology Institute, Ft Worth, TX. Web site http://www.statlab.iastate.edu/survey/SQI/

NRCS. 2001. Rangeland Soil Quality Information Sheets - 10 titles including Soil Biota; Soil Crusts-Physical and Biological. USDA-NRCS, Soil Quality Institute and Grazing Lands Technology Institute, USDA-ARS Jornada Experimental Range, USDI Bureau of Land Management. Web site http://www.statlab.iastate.edu/survey/SQI/

Pellant, M. et.al., 2000. Interpreting Indicators of Rangeland Health, ver 3. Technical Reference 1734-6. USDI-BLM, Denver, CO. Web site http://www.blm.gov/nstc/library/techref.htm

Stringham, T.K., W.C. Krueger, and P.L. Shaver. 2001. States, transitions, and thresholds: Further refinement for rangeland applications. Ag Exp. Sta. Special Report 1024, Oregon State University. (Order copies from: Dept. of Rangeland Resources, Oregon State University, 202 Strand Hall Corvallis, OR 97331-2218), or download pdf at http://www.ftw.nrcs.usda.gov/glti/pubs.html

Websites

BLM. Soil Biological Communities. http://www.blm.gov/nstc/soil/index.html

BLM, USGS, USPS. Biological Soil Crusts http://www.soilcrust.org/

NRCS-Soil Quality Institute Website. Soil Biology Information Resources http://www.statlab.iastate.edu/survey/SQI/SBinfo.htm

Appendix 1. Agency needs

Appendix 2. Soil Survey Manual manuscript, draft,

Belnap, Jayne and Arlene J. Tugel. 6-19-02 draft. Biological Soil Crusts.

Appendix 3. Methods
Appendix 3a. – Data sheets

Belnap, Jayne, Arlene J. Tugel and Jeffrey E. Herrick. 6-26-02 draft. Guidelines for describing soil surface features (ver 2.0) and data sheets used in the Moab test.

Appendix 4. Soil descriptions

Appendix 5. Photos

Appendix 1. Agency Needs

BLM

1. Where is crust a management consideration and where not?
2. Must address biological soil crusts in NEPA documentation.
3. Need a simplified field guide such as a check list or flow chart of factors related to biological crusts that should be included in NEPA documentation.
4. Need a simplified field guide (with photos) for assessing crusts related to inventory and monitoring protocol.
5. Need information on how to minimize impacts to biological crusts.
6. Need training for the field personnel in federal agencies.
7. Need a database clearing house (NASIS?) for collected data and photo records.
8. Need a module in soil data viewer related to crusts.
9. The Ecological Site Description is a good tool to pull together soil and ecological resource information.
10. We encourage other states to follow the BLM partnership model in New Mexico for Ecological Site development.

NPS

1. See BLM, ditto for Park Service.
2. NPS must shift from managing visitors to managing resources.
3. Need to identify crusts in the soil survey program.
4. Would use biological crusts in information and education programs on ecological significance of crusts across landscapes.
5. Would use crust information in Park Service to help identify concepts of impairment of the resource.
6. Need a monitoring network.
7. Would use crust information in biological inventory, possibly as vital signs or indicators for ecosystem processes.
8. Would look at the State and Transition Models as a tool.
9. We encourage the use of Ecological Site Descriptions in monitoring and inventory.
10. All federal agencies (e.g., BLM, NPS) should share model sites illustrating ecological condition.

FS, Reg. 3.

1. Region 3 is already documenting the occurrence of biological soil crusts using an ocular method in their Terrestrial Ecosystem Surveys.
2. Need to describe and record crusts in soil survey.
3. Need protocols to describe crusts.
4. Biological soil crusts must be included in NEPA documentation as more information is needed for appeals, etc.
5. The BLM Crust training course needs to be continued for all agencies.
6. Welcome distribution of USGS fact sheets on biological soil crusts to FS personnel.

USGS

1. Need multi-agency support (money) for training and mapping.
2. Because of limited resources and knowledgeable personnel, need to “train the trainers”.

3. Other agencies must state need for information on biological soil crusts.
4. Need a database that links biological crust information to soil properties, site characteristics, and location.

NRCS

1. Where are crusts an important part of the system in terms of water cycle and infiltration? What are the functions of biological soil crusts in different ecosystems? What roles do they play in mineral cycling? Water cycling (e.g., infiltration)? Soil stability?
2. Must add biological soil crust information to site descriptions – should not be too difficult a problem.
3. What role do crusts play in each "state" ("states" of a State and Transition Model).
4. Consider biological crust as a possible threshold indicator: Where and when does it work?
5. Biological crusts are used in Ecological Site Descriptions and the National Resources Inventory (NRI).

USFWS

Email from Larry England, USFWS, UT.
"Our office is responsible for reviewing federal projects or actions affecting federal lands for compliance with the Endangered Species Act and commenting on impacts described in associated NEPA document to satisfy our responsibilities under the Fish and Wildlife Coordination Act. We have a long term interest in projects effecting cryptogamic soil crusts. Many plant species listed under the provisions of the Endangered Species Act are endemic to geologic formations supporting cryptogamic soil crusts. In addition, erosion of these soils affects watersheds harboring federally listed endangered fish species."

Biological Soil Crusts
Appendix 2 - Draft material for incorporation into the Soil Survey Manual

Jayne Belnap, USGS, Moab, UT and Arlene J. Tugel, NRCS-SQI, Las Cruces, NM
3-26-02 (rev 6-28-02)

Biological soil crusts are a living community of cyanobacteria, mosses and lichens that occur in most arid and semi-arid regions. They are a part of, and can heavily influence, the morphology of the near-surface zone of soils in these regions. They affect local hydrologic patterns by either increasing or decreasing infiltration (depending on their morphology and site characteristics) and by retarding evaporation of soil moisture. The polysaccharide material extruded by these organisms binds soil particles together, providing protection from raindrop-induced erosion and physical crusting and creating soil aggregates. These soil aggregates provide sequestration sites for nutrients and carbon and activity sites for decomposition. They also increase the water-holding capacity of the upper few millimeters to centimeters of the soil. Biological soil crusts fix both carbon and nitrogen, making them an important source of soil nutrients.

Biological soil crusts occur in all regions where plant cover is sparse, especially semi-arid and arid regions. Biological soil crusts also occur in temperate zones where soils are infertile (e.g., pine barrens) or where vegetation removal (e.g., treefall or agricultural activities such as herbicide treatment of orchard rows) has left soil exposed and available for crust colonization. In our definition, biological soil crusts do not include thick vegetative moss mats where most of the biomass is above-ground (e.g., spike moss; club moss mats in northern latitudes).

Relationship to Mineral Crusts

Non-biotic soil surface crusts, or physical crusts, are also a major structural feature in many arid regions. Chemical crusts are dominated by macro- or microcrystalline evaporites. Physical crusts are soil-surface layers generally formed by raindrop impact, disruption of soil aggregates followed by in-filling of pore spaces, deposition of sediments from short-range runoff, or puddling resulting from freeze-thaw processes on bare ground (no biological soil crust present). They range in thickness from less than one millimeter to a few centimeters. The presence of a physical crust often aids biological soil crust establishment, as the physical crust provides a stable surface for colonization. Like biotic crusts, physical crusts reduce soil loss via wind erosion. However, because physical crusts often disperse when wet and biotic crusts do not, biotic crusts are more effective at reducing soil loss from water erosion. Well-developed biological crusts resist both wind and water erosion. Biotic crusts also create stable soil aggregates, unlike physical crusts.

Types of Biological Soil Crusts

There are 4 main types of biological soil crusts (Belnap 2001), distinguished by the soil surface microtopography that they create (Figure 1). The microtopography is reflected in the height of the “peaks” and the width of the spaces between the “peaks”.

Smooth crusts and *rugose* crusts occur in hyper-arid and arid hot deserts where high air temperatures and low rainfall result in very high potential evaporation (PET) and soils never freeze. In contrast, *pinnacled crusts* and *rolling crusts* occur in semi-arid cool and cold deserts, where soils freeze during cold winters and PET is lower than hot deserts. These crust classifications are based on late successional stages of crusts; in frequently disturbed areas, smooth or rugose crusts can be seen in any geographic region.

Smooth crusts: Smooth crusts are dominated by cyanobacteria, and lack lichens and mosses. Soil surfaces are mostly mineral particles. They are extremely flat, as the binding action of cyanobacteria create an even smoother soil surface than bare ground. Smooth crusts occur in hyperarid and arid regions, where precipitation is very low, temperatures are very high, and soils never freeze (e.g., central Sahara desert, Negev desert in Israel). There are few crusts of this type in the western US, except in areas where soils are frequently disturbed.

Rugose crusts**:** Rugose crusts occur in arid and semi-arid regions where soils never or seldom freeze, but that have lower PET than areas with smooth crust. Like smooth crusts, rugose crusts are dominated by cyanobacteria, but they also contain sparse patches of lichens and mosses growing on the more-or-less even soil surface. This type of crust occurs in the Sonoran, Chihuahuan, and Mojave deserts. Rugose crusts can also occur as a successional stage in areas where soils are recovering from disturbance.

Pinnacled crusts: Pinnacled crusts occur in areas where soils freeze during winter. They are dominated by cyanobacteria, but support up to 40% lichen and moss cover. These crusts are characterized by strikingly pedicelled mounds that are formed as the frost-heaved soils are differentially eroded by downward-cutting water. These castle-like mounds can be up to 10 cm high and have delicate tips that are less than 4 mm across. Lichens, mosses, small rocks, or concentrations of cyanobacteria often act as a cap for these tips, offering greater resistance to erosion than adjacent soil. Pinnacled crusts occur in mid-latitude cool deserts such as the Colorado Plateau and the southern Great Basin. This crust type is the most vulnerable to soil surface disturbance, as the frost-heaved surface is easily broken and churned, often burying crustal organisms.

Rolling crusts: Rolling crusts occur in colder regions where soils freeze in winter and where PET is low (e.g., northern Great Basin, Columbia Plateau and the Arctic tundra). Rolling crusts are heavily dominated by lichens, mosses, and/or thick dark mats of cyanobacteria. The upward frost-heaving of the soil is counteracted by the cohesive, thickly-encrusted mats of lichens, mosses, and surface roots of vascular plants; thus, rather than pinnacled surfaces, this combination creates a rough, rolling surface. When disturbed, these types of crusts are sometimes easily detached from the soil surface, as they can adhere more to themselves than the soil. This makes them vulnerable to soil surface disturbances.

Major Components of Soil Crusts: Cyanobacteria, Lichens, and Mosses

Biological soil crusts include bacteria, microfungi, cyanobacteria, green algae, mosses, liverworts and lichens (Belnap et al. 2001). Various characteristics that do not require identification to the species level can be used to differentiate the three major components (broad morphological groups) of soil crusts in the field.

Cyanobacteria ("blue-green algae") are primitive filamentous or single-celled bacteria that come in a variety of sizes and shapes. These organisms fix both carbon and nitrogen. Only the filamentous species can be seen without a microscope. They look like fine threads that dangle and twirl when chunks of the soil surface are held aloft (unlike roots, which are often too stiff to blow as freely). These threads often have small soil particles attached. Cyanobacterial crusts with low biomass and diversity are generally the color of the substrate (most often light). Cyanobacterial crusts with high biomass and diversity are dark (brown-black), due both to increased biomass and the production of UV-protective pigments by the organisms. *Lichens* are fungi that capture and cultivate photosynthetic algae or cyanobacteria as partners. There are two main types of lichens, gelatinous and non-gelatinous. Gelatinous lichens are black, swell when moistened, and are capable of nitrogen fixation. Non-gelatinous (crustose, squamulose, foliose, and fructicose) lichens come in all colors, do not swell when moistened, and generally do not fix nitrogen. In deserts of the western US, soil lichens are generally a mixture of gelatinous, crustose and squamulose lichens.

Mosses are photosynthetic plants with small leaves that unfurl when moistened (thus the moss appears to swell). When dry, mosses are dark and dull-colored; when moistened, the color changes markedly to a bright, light green to brown. This makes them easy to distinguish from lichens.

Morphological groups (Table 1) group organisms that are similar in shape, appearance, and function. Minor and difficult-to-observe components can be included with the three major biological crust groups (cyanobacteria, lichen, moss). Green algae, single-celled photosynthetic organisms, are included with cyanobacteria because they are difficult to observe in the field without high magnification but sometimes give the moist soil surface a green tint. Liverworts are minor in arid environments and can be included with lichen. For special studies, such as monitoring the abundance of N-fixing lichens, specific morphological groups, or even species, can be measured.

Table 1. Morphological groups for biological crust components and their N-fixing characteristics. (Belnap et al. 2001)

Broad morphological group	Morphological group	Representative taxa	N-fixing
Cyanobacteria	Green algal crusts	Coccoids	No
	Cyanobacterial crusts	*Microcoleus vaginatus, Nostoc spp*	Most species
Lichen	Crustose lichen	*Fulgensia desertorum*	No
	Gelatinous lichen	*Collema coccophorum*	Yes
	Squamulose lichen	*Psora decipiens*	A few species
	Foliose lichen	*Peltigera occidentalis*	No
	Fruiticose lichen	*Aspicilia hispida*	No
	Liverworts	*Riccia spp*	No
Moss	Short moss (< 10mm)	*Bryum* spp.	No
	Tall moss (> 10mm)	*Tortula* ruralis	No

Soil Surface Roughness/Crust Age

The roughness of the soil surface is important in runoff, the retention of water and litter, and can provide an indication of crust age. For example, in Colorado Plateau and southern Great Basin pinnacled crusts, the height of the pinnacles relates to the number of frost-heaving events that have occurred once disturbance has ceased Thus, the age of pinnacled crusts can be estimated via soil surface roughness. In an undisturbed crust, pinnacles "grow" about 1 cm a year for about 5 years, and so surface roughness is estimated in 1 cm increments up to 5 cm. After reaching 5 cm, the height of the pinnacle is determined by soil texture and the species composition of the biological crust. The exception is areas where water pools; here, the crust micro-topography is often limited to 1 cm or less.

Lichens and moss generally take at least 10 years to colonize; thus soils with lichen/moss cover have generally been undisturbed for at least this long. For smooth, rugose, and rolling crusts, height cannot be used to age the soil crust. The only visible indicator of development is lichen and moss cover. These components recover more quickly on fine-textured soils and with increasing effective precipitation. Therefore, before using lichen and moss cover as an indicator of soil crust age, these site-specific factors must be taken into account.

Distribution of Crusts

The percent cover and the components of the crust can vary across short distances. For example, the percent cover and abundance of morphological groups in interspaces can be quite different than those under shrub canopies. Closed plant canopies or thick litter layers limit the development of crust organisms. Where soil-disturbing activities are present, soil crusts are likely to be most developed in areas protected from trampling such as under shrubs, or adjacent to obstacles such as fallen trees and rocks (Rosentreter et al. 2001). Recording information about the distribution of crusts in relation to the plant canopy species or type (herbaceous, shrub, tree, none) will aid in the interpretation of the function of biological crusts on the site.

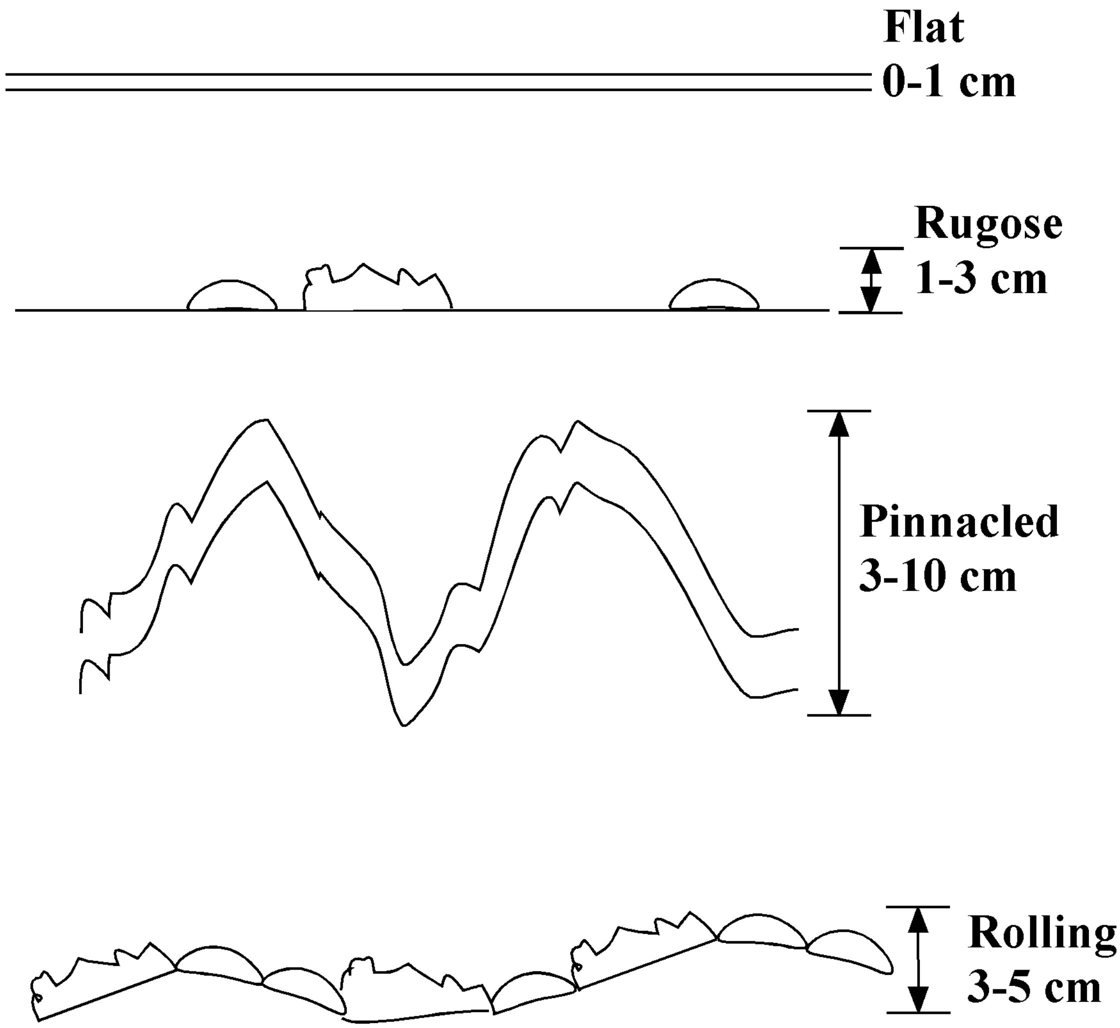
References

Belnap, J. 2001. Comparative structure of physical and biological soil crusts. *In:* J. Belnap and O.L. Lange, eds . Biological soil crusts: structure, function, and management. Ecological studies, v. 150. Springer-Verlag, Berlin.

Belnap, J., J.H. Kaltenecker, R. Rosentreter, J. Williams, S. Leonard and D. Eldridge. 2001. Biological soil crusts: ecology and management. TR-1730-2, USDI, BLM Denver, CO.

Rosentreter, R. D.J. Eldridge, and J.H. Kaltencker. 2001. Monitoring and management of biological crusts. *In:* J. Belnap and O.L. Lange, eds . Biological soil crusts: structure, function, and management. Ecological studies, v. 150. Springer-Verlag, Berlin.

Figure 1. Biological soil crust types. Flat crusts contain only cyanobacteria, and are not frost-heaved. Rugose crusts are similar to flat crusts, except they contain occasional lichen/moss patches. Pinnacled crusts are cyanobacterially-dominated, and can have up to 40 percent cover of lichen/moss. Their distinctive characteristic is great surface roughness due to frost-heaving. Rolling crusts are also frost-heaved, but their high lichen/moss cover prevents the heightened surface roughness of pinnacled crusts; instead, they exhibit a rolling surface.



Additional information: Not for inclusion in the Soil Survey Manual

Rationale for measuring cover for morphological groups as well as total cover.

Measures of cover and abundance of morphological groups can be obtained more rapidly and simply than measuring individual species. Rosentreter et al. 2001 p 460

"Given the variable responses of species, the presence and abundance of individual species or morphological groups of species may be better indicators of range condition and soil stability than total crust cover." Warren and Eldridge, 2001" p 407 in Belnap and Lange, 2001

The edits and additions in Version 2.0 are based on the initial field test of Version 1.0 methods in Moab, UT, May 6-9, 2002. This document is a part of the report of the Biological Crust Task Force, West Regional Soil Survey Conference, Telluride, CO, July 8-12, 2002.

Guidelines for describing soil surface features

Version 2.0

6-26-02

J. Belnap, A. J. Tugel, J. E Herrick

(Replaces "Proposed guidelines for describing biological soil crusts" Ver 1.0 4-25-02)

Soil surface features include 1) physical, biological and chemical crusts and structural aggregates that affect the resistance of the soil surface to erosion and 2) rocks, woody debris, litter, and plant bases that intercept raindrops or slow runoff.

Record total coverage of each surface feature (Surface Features table), surface roughness (needs to be developed), and (optional) distribution of surface features in relation to plant canopy.

1. **Surface features**

   a. **Biological Crust** *(also called microbiotic, microphytic or cryptogamic crust): a thin, biologically dominated surface layer comprised most commonly of cyanobacteria (blue-green algae), green and brown algae, mosses, liverworts and/or lichens (NRCS, 1997, Belnap, 2001).* **–** identify biological crust components based on broad morphological groups (cyanobacteria, lichen and moss). Groups consist of organisms that are similar in shape and appearance. *Note: Biological crusts often establish on top of a physical crust. Guidelines for describing such combination crusts have not been proposed, but need to be discussed.*

   b. **Physical and chemical crusts** – identify type of crust (not yet developed for rangelands)

   c. **Plant bases –** identify plant bases by species or plant functional group (perennial grass, shrub, tree, etc.)

   d. **Rock and litter** – identify bedrock inclusions, rock fragments by size class, woody debris and litter on the soil surface.

   e. **Structural aggregates** – identify other surface features including structural aggregates or bare soil

Table 1. Surface features

Surface feature	Code	Include:	General Description (see footnotes below)
Cyanobactera (dark)	CYN	Cyanobacteria	Darker than soil color to black and has small fibers in the soil. Can be green when moist.
Lichen	LIC	Lichen (crustose, gelatinous, squamulose, foliose, and fruticose), liverworts	All colors. Do not change color when wetted. Black gelatinous species swell when wetted.
Moss	MOS	Moss	Dark and dull colored. Turn bright green or brown when wetted.
Undifferentiated	U	Cyanobacteria, algae, incipient physical crust	Presence of small fibers in soil. Soil-colored, can be green when moist. [1]
Physical crust		*Not yet developed*	
Chemical crust		*Not yet developed*	
Structural aggregates	SA	Soil structural aggregates or massive at the surface.	A soil surface that does not have a biological, physical or chemical crust; no fibers; but does have surface stability.[2]
Rock	G, CB, ST, BY, BR	Rock fragments on the surface or inclusions of bedrock (BR)	Rock fragments are either on the surface or partially embedded in the soil. Use standard size classes.
Woody debris	W	Woody fragments	Dead twigs, branches and logs >5mm diameter (1/4")
Litter mat	LM	O horizon material in a continuous or discontinuous mat	O horizon with no clear boundary between litter and soil or a mat of litter that is not displaced by rain or wind storms of annual frequency.
Plant base	PLT, species code, or canopy code	PLT for plant base; or species or plant functional group of each plant base	See Canopy Type table for plant functional group codes.
Bare soil	BAR	Soil surface that is not stabilized or covered by any of the above.	Loose or weakly aggregated soil; soil with no crust and no fibers.
Litter	L	Herbaceous litter, scattered conifer needles, dung	Dead stems and leaves < 5 mm in diameter. Record this type of litter as a lower canopy layer resting on one of the surface features defined above.

[1] Weakly developed cyanobacteria crusts may not have enough biomass to produce a dark or black color, so the presence of fibers and a slake test must be used to distinguish these crusts from bare soil and structural aggregates. For cyanobacteria that is light- or soil- colored

and has fibers place a fragment of dry soil 2-3mm (<1/8") thick and 6-8mm (1/4") diameter in a cap of water. If less than 50% of the fragment slakes in 300 seconds, and is not a lichen, moss, or rock, record as undifferentiated (U). If greater than 50 percent slakes in 300 seconds, record as bare. *Note: need to test whether 30 sec or 300 sec is most meaningful for surface stability.*

[2] Distinguish "structural aggregates" from "bare soil" as follows: place a fragment of dry soil 2-3mm (<1/8") thick and 6-8mm (1/4") diameter in a cap of water. If less than 50% of the fragment slakes in 300 seconds, it is a "structural aggregate." Neither structural aggregates or bare soil have cyanobacterial fibers.
Note: need to test whether 30 sec or 300 sec is most meaningful for surface stability.

2. Percent Cover – determine total percent cover (surficial extent) for each surface feature.

a. Equipment
- Measuring tape (50 meters)
- 2 steel pins for anchoring tape
- "pointer": a straight piece of wire or rod at least 75 cm long (e.g. a long pin flag) and less than 2.5 mm in diameter
- Water mister bottle
- Hand lens (10-20 power)
- Quadrat frame, 25cm^2 with 4 wires or strings wrapped across each side to form a grid
- Clipboard, data forms and pencils
- Soil Stability Kit or empty bottle cap

Strength and weaknesses of Methods 1, 2 and 3 were discussed during testing in the Colorado Plateau, 5-9-02 (See Task Force Report). These methods are valuable for training and personal skills calibration for ocular estimates (Method 5) but are not the preferred method for the cyanobacterial dominated crusts observed during this field test. However, quadrat frames (20-point) are often more useful in physiographic/ecological regions that have small amounts of biological crust cover.

b. Method 1. Step-point (Method code) Sampling unit = transect. Estimate percent cover of each surface feature using a step-point method on a traverse of up to 100 meters with a minimum 50 stops. Length depends on the diameter or width of the component. Record the surface feature encountered at each stop (use a pointed stick, pin flag, etc.). Calculate percent by dividing the total of the number of hits in each category by the total number of stops.

In NASIS:

- Specify Step-point method.
- Record percent cover for each surface feature..

c. Method 2. Ocular estimate with quadrats (Method code) Sampling unit = transect. Estimate percent cover of each surface feature with 0.25 m2 quadrat frame, either randomly-placed or at pre-determined stops along a transect line, using ocular estimates of cover classes. Choose a representative location. Set up 2 transect lines, each at least 45 m long and 10 m apart. Measure at least 15 quadrats on each line, spaced every 3 to 5 meters apart (e.g., 3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33, 36, 39, 42, 45; or, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75 m). A minimum of 15 quadrats per line x 2 lines = minimum 30 quadrats per site. If the soil component is less than 40 m in diameter or width, shorten the transect line and increase the number of lines. Quadrat spacing can be decreased to 0.5 m. Include a minimum of 30 quadrats per site.

For each quadrat, estimate cover class for each surface feature. Use cover classes 0, 1-5, 6-25, 26-50, 51-75, 76-95, 96-100.

To calculate percent cover for each category of surface feature for each line: add the number of times a cover class is recorded for each category, multiply by the mid-point of each cover class (e.g., for class 1 – 5 %, multiply by 2.5), total these values and then divide by the number of quadrats sampled. Do this for each line separately. Average the values of all lines to obtain a mean percent cover for each category at the site.

In NASIS:

- Specify Ocular estimate method.

- Record transect identification number and numbers of stops (quadrats) per transect.
- Record calculated percent cover for each surface feature.

Cover % Class	Cover % Class Code	Mid-point
0	0	0
1-5	1	2.5
6-25	2	15.0
26-50	3	37.5
51-75	4	62.5
76-95	5	85.0
96-100	6	97.5

d. Method 3. Line-point quadrat (Code   ) Sampling unit = transect. Measure percent cover of each surface feature using a line-point quadrat method and point hits (0.25m^2, 20-hit frame). Determine percent cover of each surface feature for each quadrat. Choose a representative location. Set up 2 transect lines, each at least 45 m long and 10 m apart. Do a minimum of 15 quadrats spaced every 3 to 5 meters apart (e.g., 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75 m). A minimum 15 quadrats per line x 2 lines = minimum 30 quadrats per site. If the soil component is less than 40 m in diameter or width, shorten the transect line and increase the number of lines. Quadrat spacing can be decreased to 0.5 m. Include a minimum of 30 quadrats per site. Record what surface feature is “hit” with pins.

To calculate the percent cover for each category (e.g., moss, plant base, etc): total the number of hits within each category for all quadrats along a line (e.g., number of hits on moss within the 15 quadrats) and divide by the total number of hits possible (e.g., 20 points per quadrat x 15 quadrats per line = 300 hits; this would be the maximum total hits possible).

To calculate the mean percent cover value for each category at a site, average the values obtained within a category for each line, and then average the category values for all lines.

In NASIS:

- Specify Line-point quadrat method.
- Record transect identification numbers and numbers of stops (quadrats) per transect.
- Record calculated percent cover for each surface feature.

NOTE: Methods 1, 2 and 3 do not stratify soil surface features under canopy or interspaces. Method 4 gives quantitative distribution of surface features under the canopy and for interspaces.

Method 4 was preferred during testing in the Colorado Plateau, 5-9-02 because of the efficiency gained by gathering all surface feature information in the same method. Method 5, a rapid method for field notes, was proposed by the Task Force, but not tested in Moab.

e. Method 4. Stratified line-point intercept (Method code) Sampling unit = transect. Set up 2 transect lines, each at least 50 m long and 10 meters apart. Record observations every 0.5 m (100 points) on each line. If the soil component is less than 40 m in diameter or width, shorten the transect line and increase the number of lines. Observation spacing can be decreased to 0.25 m. Include a minimum of 200 points per site.

Note: See pages 7 – 9 for method instructions. Method 4, from the Monitoring Manual for Grassland Shrubland and Savanna Ecosystems, Herrick et al, in press), is designed to monitor changes in ecosystem functions and can be modified to meet soil survey needs. Most of the Method 4 codes were not changed for this test. Dual codes are listed on the data sheet (e.g. LC (LIC) to show the relationship between Methods 1,2 and 3, and Method 4. This method can be modified to attain consistency. One suggested change is the replacement of greater than 5mm rock fragment size with size classes from the soil survey manual.

"Stratified" Line-Point Intercept **(Herrick, et al, in press) See updated versions for revisions.**

Line-point intercept is a rapid, accurate method for quantifying ground cover including vegetation, litter, rocks and biotic crusts. These measurements are related to wind and water erosion, water infiltration and the ability of the site to resist and recover from degradation.

Materials

- **Measuring tape (length of transect) - (if foot tape, use one marked in tenths of feet)**
- **2 steel pins for anchoring tape**
- **"pointer": a straight piece of wire or rod at least 75 cm (2.5') long (e.g. a long pin flag) and less than 2.5 mm (1/10") in diameter**
- **clipboard, dataforms and pencils**

Standard Methods (rule set)

1. Pull out the tape and anchor each end with steel stake (Fig. 2).

Rules

1.1 Line should be taut.

1.2 Line should be as close to the ground as possible (thread under shrubs using a steel stake as a needle).

2. Begin at the "0" end of the line.

3. Move to the first point on the line and work from left to right. Always stand on the same side of the line.

4. Drop a pin flag to the ground from a height of __ cm next to the tape (Fig. 3).

Rules

4.1 The pin should be vertical.

4.2 The pin should be dropped from the same height each time. A low drop height minimizes "bounces" off of vegetation, but increases the possibility for bias.

4.3 Do not guide the pin all the way to the ground. It is more important for the pin to fall freely to the ground than to fall precisely on the mark.

5. Once the pin flag is flush with the ground, record every plant species it intercepts.

Rules

5.1 Record the species of the first stem or leaf intercepted in the "Top Canopy" column using its common name or a 4-letter code based on the first two letters of the genus and species.

5.2 If no leaf or stem is intercepted, record "NONE" in the "Top Canopy"

5.3 Record all additional species intercepted by the pin.

5.4 Record herbaceous litter as "L" if present, where litter is defined as: dead stems and leaves that are part of a layer that is in contact with the ground.

5.5 Record each canopy species only once, even if it is intercepted several times.
5.6 If you can identify the genus, but not the species, record XX for the species code (e.g. Artemisia species = ARXX).
5.7 If you cannot identify the genus, use the following codes:
AF = Annual forb (also includes biennials)
PF = Perennial forb
AG = Annual grass
PG = Perennial grass
SH = Shrub
TR = Tree
5.8 Canopy can be live or dead, but only record each species once. Make sure to record all species intercepted.

6. Enter a species code (for a plant base) or one of the following in the "Soil Surface" column:
RF = Rock fragment (> 5mm or ¼" in diameter)
BR = Bedrock
W = Woody debris (>5mm (1/4" diam.)
LM = Litter Mat (or EL, embedded litter)
M = Moss
LC = Lichen Crust on soil (lichen on rock is recorded as "R")
S = Soil which is unprotected by any of the above

Rules

6.1 For unidentified plant bases, use the codes listed under 5.7.
6.2 Record litter mat as LM where there is no clear boundary between litter and soil or where the litter is not removed during typical storms (i.e., those occurring annually).
6.3 Additional categories may be added (e.g., CYN = dark cyanobacterial crust).

The figures on the next page show the first two points on a line. In Point 1. the pin flag is touching dead Fescue, live Bluegrass, Clover, live Fescue, litter and a rock. We record Fescue only once, even though it intercepts the pin twice. In Point 2, the flag touches Fescue, then touches litter and then the Fescue plant base. The data form below shows how to record these two points.

Point	Top Canopy Species Code	Lower Canopy Layers				Soil Surface Code
		Code	Code	Code	Code	
1	Fescue	Blue-grass	Clover	L		R
2	Fescue	L				Fescue
3	Fescue	L				S
etc						

"Stratified" Line-point Intercept (Herrick et al, in press) Figures.

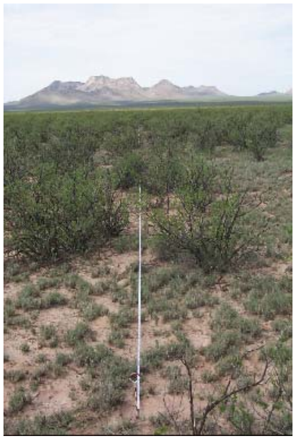
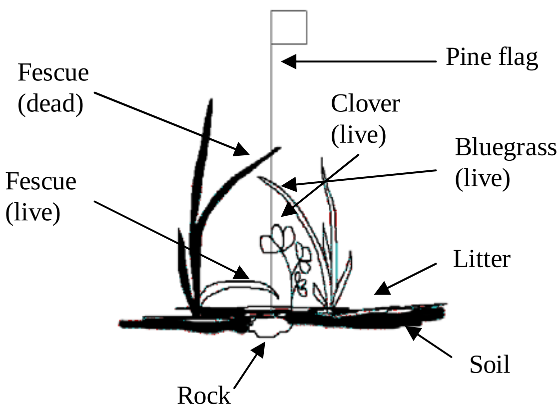


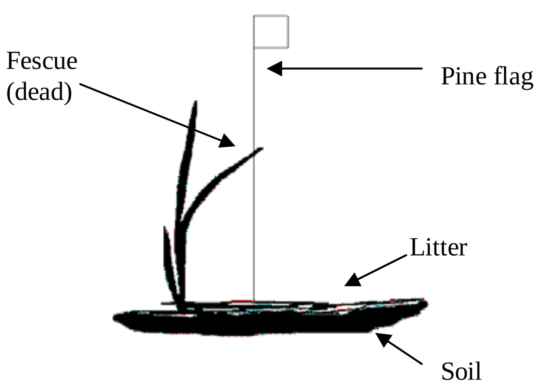
Figure 2

Figure 3

POINT 1



POINT 2



In NASIS:

- Specify Stratified line-point method.
- Record transect identification numbers and numbers of stops per transect.

Record calculated percent cover for each soil surface feature as a total for the site or stratified by canopy and interspaces. Identify canopy by species code or other canopy term. See table for possible canopy types. If a category such as shrub or tree includes both litter-producing and non-litter producing species, record them separately by species.

Alternative A		**Alternative B**		**Alternative C**	
Canopy type (strata)	**Code**	**Canopy type (strata)**	**Code**	**Canopy type (strata)**	**Code**
None (interspace)	NONE	None (interspace)	NONE	None (interspace)	NONE
Canopy	CAN	Herbaceous	HERB	Annual forb	AF
		Shrub	SH	Perennial forb	PR
		Tree	TR	Annual grass	AG
				Perennial grass	PG
				Shrub	SH
				Tree	TR

f. Method 5. Ocular estimate (percent cover of biological crusts for field notes only) Estimate total biological crust cover and specify presence or absence of CYN, LIC, MOS, and Undifferentiated.

Estmated %	**Estimated % Class Code**
0	0
1-5	1
6-25	2
>25	3

Making an ocular estimate of biological crust distribution according to the table below was determined to be too difficult during testing in the Colorado Plateau, 5-9-02. Surface feature distribution in relation to canopy should be calculated from data collected in Method 4.

3. Distribution - for methods 1, 2, 3 only.

Distribution	Code[1]	General Description
Even	1B 1C 1L 1M	Biological crusts somewhat evenly to evenly distributed in relation to plant canopy; no apparent distribution pattern in relation to plant canopy.
Canopy higher	2B 2C 2L 2M	Biological crust cover higher under canopy (herbaceous, shrubs or trees) and lower or absent in interspaces. (test 1.5 x higher? 2 x higher?)
Interspace higher	3B 3C 3L 3M	Biological crust cover higher in interspaces and lower or absent under canopy (herbaceous, shrubs or trees). (test 1.5 x higher? 2 x higher?)

[1] B, biological crust; C, cyanobacteria; L, lichen; or M, moss.

4. Surface roughness - *Not yet developed. See Task Force Report.*

References

Belnap, J. 2001. Comparative structure of physical and biological soil crusts. *In:* J. Belnap and O.L. Lange, eds . Biological soil crusts: structure, function, and management. Ecological studies, v. 150. Springer-Verlag, Berlin.

Belnap, J., J.H. Kaltenecker, R. Rosentreter, J. Williams, S. Leonard and D. Eldridge. 2001. Biological soil crusts: ecology and management. TR-1730-2, USDI, BLM, Denver, CO.

Elzinga, C.L., D.W. Salzer and J.W. Willoughby. 1998. Measuring and monitoring plant populations. TR-1730-1. USDI, BLM, Denver, CO.

Herrick, J.E., J.W. Van Zee, K.M. Havstad and W.G. Whitford. in prep. Monitoring manual for grassland, shrubland and savanna ecosystems. USDA-ARS Jornada Experimental Range. Island Press, Washington, D.C. contact jherrick@nmsu.edu

NRCS. 1997. Introduction to microbiotic crusts. USDA-NRCS, Soil Quality Institute and Grazing Lands Technology Institute, Ft Worth, TX.

Rosentreter, R. D.J. Eldridge, and J.H. Kaltencker. 2001. Monitoring and management of biological crusts. *In:* J. Belnap and O.L. Lange, eds . Biological soil crusts: structure, function, and management. Ecological studies, v. 150. Springer-Verlag, Berlin.

Ver 1.0 tested in Moab, Utah, May 6 -9, 2002

Proposed guidelines for describing biological crusts

(Need to be field tested)

Draft Draft Draft Draft 4-25-02

J. Belnap, A. J. Tugel,

Biological Crust (also called *microbiotic, microphytic* or *cryptogamic* crust): a thin, biologically dominated surface layer comprised most commonly of cyanobacteria (blue-green algae), green and brown algae, mosses,

M rphololo63

2. Cover – determine total biological crust cover and cover by morphological group.

a. Method 1. Step-point (Method code) Sampling unit = transect) Estimate soil cover using a step-point method along a 100m transect (minimum 50 stops). Record whether CYN, MOS, LIC, rock, plant base, or bare soil is encountered at each stop (using a pointed stick, pin flag, etc.). Calculate cover by dividing the total of the number of hits in each category by the total number of stops.

   In NASIS:
   - Specify Step-point method.
   - Record percent cover for each cover category (CYN, MOS, LIC, rock, plant base, or bare soil).

b. Method 2. Ocular estimate with quadrats (Method code) Sampling unit = transect) Estimate soil cover with 0.25 m2 quadrat frame, either randomly-placed or at pre-determined stops along a transect line, using ocular estimates of cover clarl Tci2hooseongof

c. Method 3. Line-point quadrat (Code ___) Measure soil cover using a line-point quadrat method and point hits (0.25m^2, 20-hit frame). Determine percent cover of each morphological group for each quadrat. Choose a representative location. Set up 2 transect lines, each at least 45 m long and 10 m apart. Do a minimum of 15 quadrats spaced every 3 to 5 meters apart (e.g., 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75 m). A minimum 15 quadrats per line x 2 lines = minimum 30 quadrats per site. Record what soil cover component (CYN, MOS, LIC, rock, plant base, bare soil) is "hit" with pins.

To calculate the percent cover for each category (e.g., moss, rock, etc): total the number of hits within each category for all quadrats along a line (e.g., number of hits on moss within the 15 quadrats) and divide by the total number of hits possible (e.g., 20 points per quadrat x 15 quadrats per line = 300 hits; this would be the maximum total hits possible).

To calculate the mean cover value for each category at a site, average the values obtained within a category for each line, and then average the category values for the 2 lines.

In NASIS:

- Specify Line-point quadrat method.
- Record transect identification numbers and numbers of stops (quadrats) per transect.
- Record calculated percent cover for CYN, MOS, LIC, rock, plant base and bare soil.

NOTE: Methods 1, 2 and 3 do not stratify soil cover under canopy/canopy type or interspaces. Method 4 gives quantitative distribution of crust morphological groups, litter and rock fragments under the canopy and for interspaces.

d. Method 4. Stratified line-point intercept (Method code ___) (sampling unit = transect) See Monitoring Manual for Grassland, Shrubland and Savanna Ecosystems for method.

"Stratified" Line-Point Intercept **(Herrick, et al, in press) See updated versions for revisions.**

Line-point intercept is a rapid, accurate method for quantifying ground cover including vegetation, litter, rocks and biotic crusts. These measurements are related to wind and water erosion, water infiltration and the ability of the site to resist and recover from degradation.

Materials

- **Measuring tape (length of transect) - (if foot tape, use one marked in tenths of feet)**
- **2 steel pins for anchoring tape**
- **"pointer": a straight piece of wire or rod at least 75 cm (2.5') long (e.g. a long pin flag) and less than 2.5 mm (1/10") in diameter**
- **clipboard, dataforms and pencils**

Standard Methods (rule set)

1. Pull out the tape and anchor each end with steel stake (Fig. 2).

Rules

1.1 Line should be taut.
1.2 Line should be as close to the ground as possible (thread under shrubs using a steel stake as a needle).

2. Begin at the "0" end of the line.

3. Move to the first point on the line and work from left to right. Always stand on the same side of the line.

4. Drop a pin flag to the ground from a height of __ cm next to the tape (Fig. 3).

Rules

4.1 The pin should be vertical.
4.2 The pin should be dropped from the same height each time. A low drop height minimizes "bounces" off of vegetation, but increases the possibility for bias.
4.3 Do not guide the pin all the way to the ground. It is more important for the pin to fall freely to the ground than to fall precisely on the mark.

5. Once the pin flag is flush with the ground, record every plant species it intercepts.

Rules

5.1 Record the species of the first stem or leaf intercepted in the "Top Canopy" column using its common name or a 4-letter code based on the first two letters of the genus and species.
5.2 If no leaf or stem is intercepted, record "NONE" in the "Top Canopy"
5.3 Record all additional species intercepted by the pin.
5.4 Record herbaceous litter as "L" if present, where litter is defined as: dead stems and leaves that are part of a layer that is in contact with the ground.

5.5 Record each canopy species only once, even if it is intercepted several times.
5.6 If you can identify the genus, but not the species, record XX for the species code (e.g. Artemisia species = ARXX).
5.7 If you cannot identify the genus, use the following codes:
AF = Annual forb (also includes biennials)
PF = Perennial forb
AG = Annual grass
PG = Perennial grass
SH = Shrub
TR = Tree
5.8 Canopy can be live or dead, but only record each species once. Make sure to record all species intercepted.

6. Enter a species code (for a plant base) or one of the following in the "Soil Surface" column:
RF = Rock fragment (> 5mm or ¼" in diameter)
BR = Bedrock
W = Woody debris (>5mm (1/4" diam.)
LM = Litter Mat (or EL, embedded litter)
M = Moss
LC = Lichen Crust on soil (lichen on rock is recorded as "R")
S = Soil which is unprotected by any of the above

Rules

6.1 For unidentified plant bases, use the codes listed under 5.7.
6.2 Record litter mat as LM where there is no clear boundary between litter and soil or where the litter is not removed during typical storms (i.e., those occurring annually).
6.3 Additional categories may be added (e.g., CYN = dark cyanobacterial crust).

The figures on the next page show the first two points on a line. In Point 1. the pin flag is touching dead Fescue, live Bluegrass, Clover, live Fescue, litter and a rock. We record Fescue only once, even though it intercepts the pin twice. In Point 2, the flag touches Fescue, then touches litter and then the Fescue plant base. The data form below shows how to record these two points.

Point	**Top Canopy Species Code**	**Lower Canopy Layers**				**Soil Surface Code**
		Code	**Code**	**Code**	**Code**	
1	Fescue	Blue-grass	Clover	L		R
2	Fescue	L				Fescue
3	Fescue	L				S
etc						

"Stratified" Line-point Intercept (Herrick et al, in press) Figures.

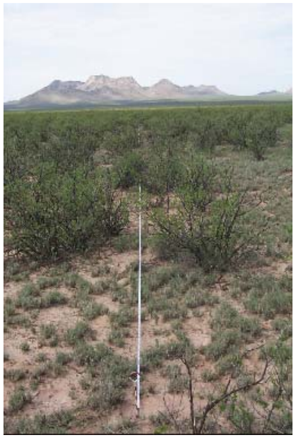
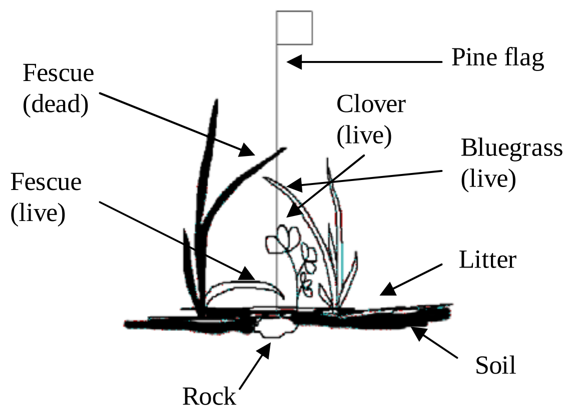


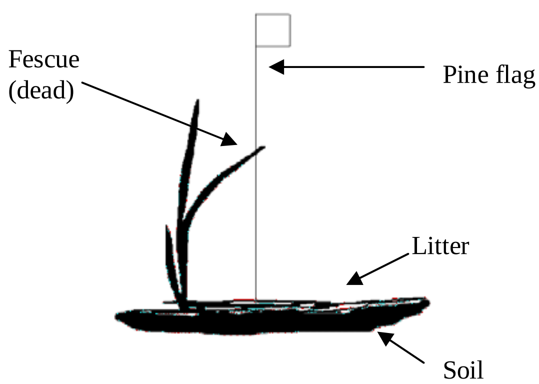
Figure 2

Figure 3

POINT 1



POINT 2



In NASIS:

- Specify Stratified line-point method.
- Record transect identification numbers and numbers of stops per transect.
- Record calculated percent cover for CYN, MOS, LIC, rock fragment, bare soil, plant base, and litter under canopy and interspaces. See table for possible canopy codes. Group to discuss this and determine needed categories of canopy.

Alternative A		**Alternative B**		**Alternative C**	
Canopy type (strata)	**Code**	**Canopy type (strata)**	**Code**	**Canopy type (strata)**	**Code**
None (interspace)	NONE	None (interspace)	NONE	None (interspace)	NONE
Canopy	CAN	Canopy	CAN	Canopy	CAN
		Herbaceous	HERB	Annual forb	AF
		Shrub	SH	Perennial forb	PR
		Tree	TR	Annual grass	AG
				Perennial grass	PG
				Shrub	SH
				Tree	TR

3. **Distribution -** for methods 1, 2, 3 only.

Distribution	**Code**[1]	**General Description**
Even	1B 1C 1L 1M	Biological crusts somewhat evenly to evenly distributed in relation to plant canopy; no apparent distribution pattern in relation to plant canopy.
Canopy higher	2B 2C 2L 2M	Biological crust cover higher under canopy (herbaceous, shrubs or trees) and lower or absent in interspaces. (test 1.5 x higher? 2 x higher?)
Interspace higher	3B 3C 3L 3M	Biological crust cover higher in interspaces and lower or absent under canopy (herbaceous, shrubs or trees). (test 1.5 x higher? 2 x higher?)

[1] B, biological crust; C, cyanobacteria; L, lichen; or M, moss.

References

Belnap, J. 2001. Comparative structure of physical and biological soil crusts. *In:* J. Belnap and O.L. Lange, eds . Biological soil crusts: structure, function, and management. Ecological studies, v. 150. Springer-Verlag, Berlin.

Belnap, J., J.H. Kaltenecker, R. Rosentreter, J. Williams, S. Leonard and D. Eldridge. 2001. Biological soil crusts: ecology and management. TR-1730-2, USDI, BLM, Denver, CO.

Elzinga, C.L., D.W. Salzer and J.W. Willoughby. 1998. Measuring and monitoring plant populations. TR-1730-1. USDI, BLM, Denver, CO.

Herrick, J.E., J.W. Van Zee, K.M. Havstad and W.G. Whitford. in prep. Monitoring manual for grassland, shrubland and savanna ecosystems. USDA-ARS Jornada Experimental Range. Island Press, Washington, D.C. contact jherrick@nmsu.edu

NRCS. 1997. Introduction to microbiotic crusts. USDA-NRCS, Soil Quality Institute and Grazing Lands Technology Institute, Ft Worth, TX.

Rosentreter, R. D.J. Eldridge, and J.H. Kaltencker. 2001. Monitoring and management of biological crusts. *In:* J. Belnap and O.L. Lange, eds . Biological soil crusts: structure, function, and management. Ecological studies, v. 150. Springer-Verlag, Berlin.

ReadMe

These datasheets were used in May, 2002 at the field test in Moab, Utah. They are a work in progress and are updated periodically. Please contact Arlene Tugel atugel@nmsu.edu for the most current version.

Method 1. Step-point **Biological Crust Cover** *Shaded cells for calculations* 5/2/2002

Soil name: ________________________________ **Ecological site:**_________________________
MUSYM:_____________ **Observer:**________________ **Recorder:**__________________
Direction:________________ **Date:**______________ **Page** ___**of**___
Location: ____

Transect no. **Direction:**

Point	Soil cover	Point	Soil cover	Point	Soil cover	Point	Soil cover	Point	Soil cover
1		11		21		31		41	
2		12		22		32		42	
3		13		23		33		43	
4		14		24		34		44	
5		15		25		35		45	
6		16		26		36		46	
7		17		27		37		47	
8		18		28		38		48	
9		19		29		39		49	
10		20		30		40		50	

Sub-totals					# points	%Cover (pts/50) x 100
CYN	CYN	CYN	CYN	CYN	CYN	
LIC	LIC	LIC	LIC	LIC	LIC	
MOS	MOS	MOS	MOS	MOS	MOS	
PLT	PLT	PLT	PLT	PLT	PLT	
BAR	BAR	BAR	BAR	BAR	BAR	
R	R	R	R	R	R	
				Total % CYN+LIC+MOS =		

Transect no. **Direction:**

Point	Soil cover	Point	Soil cover	Point	Soil cover	Point	Soil cover	Point	Soil cover
1		11		21		31		41	
2		12		22		32		42	
3		13		23		33		43	
4		14		24		34		44	
5		15		25		35		45	
6		16		26		36		46	
7		17		27		37		47	
8		18		28		38		48	
9		19		29		39		49	
10		20		30		40		50	

Sub-totals					# points	%Cover (pts/50) x 100
CYN	CYN	CYN	CYN	CYN	CYN	
LIC	LIC	LIC	LIC	LIC	LIC	
MOS	MOS	MOS	MOS	MOS	MOS	
PLT	PLT	PLT	PLT	PLT	PLT	
BAR	BAR	BAR	BAR	BAR	BAR	
R	R	R	R	R	R	
				Total % CYN+LIC+MOS =		

Soil cover category **CYN** = cyanobacteria **MOS** = moss **LIC** = lichen
PLT = plant base **BAR** = bare soil **R** = rock

Method 1. Step-point **Biological Crust Cover** *Shaded cells for calculations* 5/2/2002

Soil name: ______________________________ **Ecological site:**________________________

MUSYM:____________ **Observer:**______________ **Recorder:**_________________

Direction:______________ **Date:**_____________ **Page** ___**of**___

Location: ____

Transect no. **Direction:**

Point	Soil cover	Point	Soil cover	Point	Soil cover	Point	Soil cover	Point	Soil cover
1		11		21		31		41	
2		12		22		32		42	
3		13		23		33		43	
4		14		24		34		44	
5		15		25		35		45	
6		16		26		36		46	
7		17		27		37		47	
8		18		28		38		48	
9		19		29		39		49	
10		20		30		40		50	

Sub-totals

					# points	%Cover (pts/50) x 100
CYN	CYN	CYN	CYN	CYN	CYN 0	0
LIC	LIC	LIC	LIC	LIC	LIC 0	0
MOS	MOS	MOS	MOS	MOS	MOS 0	0
PLT	PLT	PLT	PLT	PLT	PLT 0	0
BAR	BAR	BAR	BAR	BAR	BAR 0	0
R	R	R	R	R	R 0	0
				Total % CYN+LIC+MOS =	0	

Transect no. **Direction:**

Point	Soil cover	Point	Soil cover	Point	Soil cover	Point	Soil cover	Point	Soil cover
1		11		21		31		41	
2		12		22		32		42	
3		13		23		33		43	
4		14		24		34		44	
5		15		25		35		45	
6		16		26		36		46	
7		17		27		37		47	
8		18		28		38		48	
9		19		29		39		49	
10		20		30		40		50	

Sub-totals

					# points	%Cover (pts/50) x 100
CYN	CYN	CYN	CYN	CYN	CYN 0	0
LIC	LIC	LIC	LIC	LIC	LIC 0	0
MOS	MOS	MOS	MOS	MOS	MOS 0	0
PLT	PLT	PLT	PLT	PLT	PLT 0	0
BAR	BAR	BAR	BAR	BAR	BAR 0	0
R	R	R	R	R	R 0	0
				Total % CYN+LIC+MOS =		0

Soil cover category **CYN** = cyanobacteria **MOS** = moss **LIC** = lichen
PLT = plant base **BAR** = bare soil **R** = rock

Method 1. Step-point **Biological Crust Cover** *Shaded cells for calculations* 5/2/2002

Soil name: ______________________________ **Ecological site:**________________________

MUSYM:____________ **Observer:**______________ **Recorder:**_________________

Direction:______________ **Date:**____________ **Page** ___**of**___

Location: ____

Transect no. **Direction:**

Point	Soil cover	Point	Soil cover	Point	Soil cover	Point	Soil cover	Point	Soil cover
1	BAR	**11**	LIC	**21**	CYN	**31**	CYN	**41**	CYN
2	LIC	**12**	CYN	**22**	CYN	**32**	LIC	**42**	CYN
3	LIC	**13**	LIC	**23**	PLT	**33**	CYN	**43**	CYN
4	CYN	**14**	LIC	**24**	CYN	**34**	LIC	**44**	CYN
5	CYN	**15**	CYN	**25**	CYN	**35**	LIC	**45**	CYN
6	LIC	**16**	LIC	**26**	CYN	**36**	CYN	**46**	CYN
7	LIC	**17**	CYN	**27**	CYN	**37**	LIC	**47**	CYN
8	CYN	**18**	LIC	**28**	CYN	**38**	CYN	**48**	LIC
9	LIC	**19**	BAR	**29**	LIC	**39**	LIC	**49**	LIC
10	CYN	**20**	CYN	**30**	CYN	**40**	LIC	**50**	LIC

Sub-totals

										# points		**%Cover** (pts/50) x 100
CYN	4	**CYN**	4	**CYN**	8	**CYN**	4	**CYN**	7	**CYN**	27	54
LIC	5	**LIC**	5	**LIC**	1	**LIC**	6	**LIC**	3	**LIC**	20	40
MOS		**MOS**		**MOS**		**MOS**		**MOS**		**MOS**	0	0
PLT		**PLT**		**PLT**	1	**PLT**		**PLT**		**PLT**	1	2
BAR	1	**BAR**	1	**BAR**		**BAR**		**BAR**		**BAR**	2	4
R		**R**		**R**		**R**		**R**		**R**	0	0
								Total % CYN+LIC+MOS =				94

Soil cover category **CYN** = cyanobacteria **MOS** = moss **LIC** = lichen
PLT = plant base **BAR** = bare soil **R** = rock

Method 2. Ocular estimate with quadrats **Biological Crust Cover** 5/2/02

Soil name: ________________________________ **Ecological site:**________________________

MUSYM:_____________ **Observer:**________________ **Recorder:**__________________

Direction:________________ **Date:**______________ **Page** ___**of**___

Location: ____

Transect no. **Direction:**

Point meter		CYN	LIC	MOS	PLT	BAR	R
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							

Class	Code	factor x # =			factor x # =			factor x # =			factor x # =			factor x # =			factor x # =		
0%	0	0			0			0			0			0			0		
1-5%	1	2.5			2.5			2.5			2.5			2.5			2.5		
6-25%	2	15			15			15			15			15			15		
25-50%	3	37.5			37.5			37.5			37.5			37.5			37.5		
51-75%	4	62.5			62.5			62.5			62.5			62.5			62.5		
76-95%	5	85			85			85			85			85			85		
96-100%	6	97.5			97.5			97.5			97.5			97.5			97.5		
			Sum:			Sum:			Sum:			Sum:			Sum:			Sum:	
Total # quadrats:																			
Sum/ # quadrats = %cover =					%cover =			%cover =			%cover =			%cover =			%cover =		

Method 3. Line-point quadrat 20 points per quadrat x ____ # quadrats = total hits = ____

Point meter		CYN	LIC	MOS	PLT	BAR	R
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
		# hits =	# hits =	# hits =	# hits =	# hits =	# hits =
# hits/total hits =		% cover =	% cover =	% cover =	% cover =	% cover =	% cover =

Total percent crust cover = % CYN + LIC + MOS =

Method 2. Ocular estimate with quadrats **Biological Crust Cover** 5/2/02

Soil name: ______________________________ **Ecological site:**________________________

MUSYM:____________ **Observer:**_______________ **Recorder:**__________________

Direction:_______________ **Date:**_____________ **Page** ___**of**___

Location: _ Tarbush Disturbance Site

Transect no. **Direction:**

Point	meter	**CYN**	**LIC**	**MOS**	**PLT**	**BAR**	**R**
1	*3*	*5*	*2*		*2*		
2	*6*	*5*	*2*		*0*		
3	*9*	*4*	*2*		*2*		
4	*12*	*5*	***3***		*1*		
5	*15*	*5*	*2*		*1*		
6	*18*	*5*	*2*		*1*		
7	*21*	*5*	*2*		*0*		
8	*24*	*4*	*1*		*1*		
9	*27*	*4*	*3*		*1*		
10	*30*	*5*	*2*		*1*		
11	*33*	*6*	*1*		*1*		
12	*36*	*4*	*3*		*0*		
13	*39*	*5*	*1*		*2*		
14	*42*	*5*	*2*		*1*		
15	*45*	*5*	*2*		*2*		

Class	**Code**	**factor**	**x #**	**=**	**factor**	**x #**	**=**	**factor**	**x #**	**=**	**factor**	**x #**	**=**	**factor**	**x #**	**=**	**factor**	**x #**	**=**
0%	**0**	**0.0**	0	0	**0.0**	0	0	**0.0**	0	0	**0.0**	3	0	**0.0**	0	0	**0.0**	0	0
1-5%	**1**	**2.5**	0	0	**2.5**	3	7.5	**2.5**	0	0	**2.5**	8	20	**2.5**	0	0	**2.5**	0	0
6-25%	**2**	**15.0**	0	0	**15.0**	9	135	**15.0**	0	0	**15.0**	4	60	**15.0**	0	0	**15.0**	0	0
25-50%	**3**	**37.5**	0	0	**37.5**	3	113	**37.5**	0	0	**37.5**	0	0	**37.5**	0	0	**37.5**	0	0
51-75%	**4**	**62.5**	4	250	**62.5**	0	0	**62.5**	0	0	**62.5**	0	0	**62.5**	0	0	**62.5**	0	0
76-95%	**5**	**85.0**	10	850	**85.0**	0	0	**85.0**	0	0	**85.0**	0	0	**85.0**	0	0	**85.0**	0	0
96-100%	**6**	**97.5**	1	97.5	**97.5**	0	0	**97.5**	0	0	**97.5**	0	0	**97.5**	0	0	**97.5**	0	0
	0		**Sum:**	1198		**Sum:**	255		**Sum:**	0		**Sum:**	80		**Sum:**	00264173(50)]TJ/TT4 1 Tf8.			

Method 4. Stratified line-point Intercept: soils 5/3/02 *Shaded cells for calculations*

Soil name: ________________________________ **Ecological site:**______________________

MUSYM:______ **Line #:**__________ **Observer:**_______________ **Recorder:**____________

Direction:_______________ **Date:**_____________ **Page** ___**of**___

Location: ____

Point	Top Canopy	Lower Canopy Layers Code1	Code2	Code3	Soil Surface	Point	Top Canopy	Lower Canopy Layers Code1	Code2	Code3	Soil Surface
1						26					
2						27					
3						28					
4						29					
5						30					
6						31					
7						32					
8						33					
9						34					
10						35					
11						36					
12						37					
13						38					
14						39					
15						40					
16						41					
17						42					
18						43					
19						44					
20						45					
21						46					
22						47					
23						48					
24						49					
25						50					

Subtotals:		Subtotals:	
CYN(CYN)		CYN(CYN)	
LC(LIC)		LC(LIC)	
M(MOS)		M(MOS)	
BASAL(PLT)		BASAL(PLT)	
BS(BAR)		BS(BAR)	
RF+BR(R)		RF+BR(R)	

Note: codes in parenthes = Method 1-3 codes

Top Canopy

Sp. Code or NONE (no can.)

Unknown Sp. Code

AF = Annual Forb
PF = Perrenial Forb
AG = Annual Grass
PG = Perennial Grass
SH = Shrub
TR = Tree

Lower Canopy Layers

Sp. code or English name
L = Herbaceous Litter on soil

Soil Surface (don't use litter)

Sp. code or Eng. name (for basal int.)
RF = rock fragment (> 5mm (1/4") diam.)
BR = bedrock
M = Moss on soil
LC = Visible lichen crust on soil
but can have litter above
CYN = Cyanobacteria, algae
W = Woody debris (>5mm (1/4" diam.)
EL = embedded litter (O horizon)
BS = bare soil, without any of the above

TOTALS	# points*	%Cover pts x 2
CYN(CYN)		
LC(LIC)		
M(MOS)		
BASAL(PLT)		
BS(BAR)		
RF+BR(R)		
Total % CYN+LC+M =		

* For 100 points, # pts = percent

Crust Cover Stratified by Canopy Presence and Type

Crust cover under perennial herbaceous canopy:

Subtotals:

Note: codes in parenthes = Method 1-3 codes

CYN(CYN)	
LC(LIC)	
M(MOS)	
BASAL(PLT)	
BS(BAR)	
RF+BR(R)	

Subtotals:

CYN(CYN)	
LC(LIC)	
M(MOS)	
BASAL(PLT)	
BS(BAR)	
RF+BR(R)	

count only crust hits where "Top Canopy" = PF or PG

* For 100 points, # pts = percent

TOTALS	# points*	%Cover pts x 2
CYN(CYN)		
LC(LIC)		
M(MOS)		
BASAL(PLT)		
BS(BAR)		
RF+BR(R)		
Total % CYN+LC+M =		

Crust cover under tree canopy:

Subtotals:

Note: codes in parenthes = Method 1-3 codes

CYN(CYN)	
LC(LIC)	
M(MOS)	
BASAL(PLT)	
BS(BAR)	
RF+BR(R)	

Subtotals:

CYN(CYN)	
LC(LIC)	
M(MOS)	
BASAL(PLT)	
BS(BAR)	
RF+BR(R)	

count only crust hits where "Top Canopy" = TR

* For 100 points, # pts = percent

TOTALS	# points*	%Cover pts x 2
CYN(CYN)		
LC(LIC)		
M(MOS)		
BASAL(PLT)		
BS(BAR)		
RF+BR(R)		
Total % CYN+LC+M =		

Crust cover under shrub canopy:

Subtotals:

Note: codes in parenthes = Method 1-3 codes

CYN(CYN)	
LC(LIC)	
M(MOS)	
BASAL(PLT)	
BS(BAR)	
RF+BR(R)	

Subtotals:

CYN(CYN)	
LC(LIC)	
M(MOS)	
BASAL(PLT)	
BS(BAR)	
RF+BR(R)	

count only crust hits where "Top Canopy" = SH

* For 100 points, # pts = percent

TOTALS	# points*	%Cover pts x 2
CYN(CYN)		
LC(LIC)		
M(MOS)		
BASAL(PLT)		
BS(BAR)		
RF+BR(R)		
Total % CYN+LC+M =		

Crust cover under no canopy:

Subtotals:

Note: codes in parenthes = Method 1-3 codes

CYN(CYN)	
LC(LIC)	
M(MOS)	
BASAL(PLT)	
BS(BAR)	
RF+BR(R)	

Subtotals:

CYN(CYN)	
LC(LIC)	
M(MOS)	
BASAL(PLT)	
BS(BAR)	
RF+BR(R)	

count only crust hits where "Top Canopy" = NONE

* For 100 points, # pts = percent

TOTALS	# points*	%Cover pts x 2
CYN(CYN)		
LC(LIC)		
M(MOS)		
BASAL(PLT)		
BS(BAR)		
RF+BR(R)		
Total % CYN+LC+M =		

Method 4. Stratified line-point Intercept: soils 5/3/02 *Shaded cells for calculations*

Soil name: ______________________________ **Ecological site:**_____________________

MUSYM:______ **Line #:**_________ **Observer:**_______________ **Recorder:**____________

Direction:_______________ **Date:**_____________ **Page** ___**of**___

Location: ____

Point	Top Canopy	Lower Canopy Layers Code1	Code2	Code3	Soil Surface	Point	Top Canopy	Lower Canopy Layers Code1	Code2	Code3	Soil Surface
1	PG				LIC	26					
2	none				CYN	27					
3	none				CYN	28					
4	none				BS	29					
5	none				CYN	30					
6	none				CYN	31					
7	PG	L			RF	32					
8	PF				PG	33					
9	SH	AF	AG	L	MOS	34					
10						35					
11						36					
12						37					
13						38					
14						39					
15						40					
16						41					
17						42					
18						43					
19						44					
20						45					
21						46					
22						47					
23						48					
24						49					
25						50					

Subtotals: CYN(CYN)		**Subtotals:** CYN(CYN)	
LC(LIC)		LC(LIC)	
M(MOS)		M(MOS)	
BASAL(PLT)		BASAL(PLT)	
BS(BAR)		BS(BAR)	
RF+BR(R)		RF+BR(R)	

Note: codes in parenthes = Method 1-3 codes

Top Canopy

Sp. Code or NONE (no can.)

Unknown Sp. Code

- AF = Annual Forb
- PF = Perrenial Forb
- AG = Annual Grass
- PG = Perennial Grass
- SH = Shrub
- TR = Tree

Lower Canopy Layers

Sp. code or English name

L = Herbaceous Litter on soil

Soil Surface (don't use litter)

Sp. code or Eng. name (for basal int.)

RF = rock fragment (> 5mm (1/4") diam.)

BR = bedrock

M (MOS) = Moss on soil

LC (LIC) = Visible lichen crust on soil but can have litter above

CYN = Cyanobacteria, algae

W = Woody debris (>5mm (1/4" diam.)

EL = embedded litter (O horizon)

BS = bare soil, without any of the above

TOTALS	# points*	%Cover pts x 2
CYN(CYN)		
LC(LIC)		
M(MOS)		
BASAL(PLT)		
BS(BAR)		
RF+BR(R)		
Total % CYN+LC+M =		

* For 100 points, # pts = percent.

Notes: Method 4, from the Montioring Manual for Grassland Shrubland and Savanna Ecosystems, Herrick et al, in press) is designed to monitor changes in Ecosystem functions and can be modified to meet soil survey needs. Most of the Method 4 codes were not changed for this test. Dual codes are listed on the data sheet (e.g. LC (LIC) to show the relationship between Methods 1, 2 and 3, and Method 4. This method can be modified to attain consistency.   One suggested change is the replacment of greater than 5mm rock fragment size with size classes from the soil survey manual.

Appendix 4. Soil Descriptions
First group.

By: MN, JB May 8, 2002 Moab, UT
PARENT MATERIAL – Eolian deposits from Navajo sandstone

Horizon	Depth cm	Color dry	Color moist	Texture (% clay)	Structure	Consistence			Reaction pH‡	HCl
						Dry	Moist	Wet		
A	0-3	5YR 5/4	5YR 4/4	LFS (9)	1 vf gr/ 1 n pl†	sh/	vfr	so po		st
Bw1	3-7	5YR 5/4	5YR 4/4	LFS (9)	1 m sbk¥	sh	vfr	so po		st
Bw2	7-11	5YR 5/4	5YR 4/4	FSL (9)	1 m sbk	s	vfr	so po		st
R	11+									

Horizon	"Roots" cyanobacteria sheaths	Pores‡	Concentrations					Coarse Fragments	Boundary	Notes
			%	Size	Shape	Kind	location			
A	2 vf							0	as	¶
Bw1	2 vf							0	cs	
Bw2	1 f		1	f	f	SK	In ped	0	as	
R										#

† MN described 1 vf gr; JB described1 n pl
¥ 15% of horizon is sg
‡ not described
¶ NOTES: Soil Depth ranges from 8 to 13 cm; 8 cm is depth in valley of pinnacled biological crust, 13 cm is soil depth measuring from top of the crust. Average distance between pinnacles is 5 cm. Biological soil crust consists dominantly of cyanobacteria (light and dark), some lichens, few moss.
# Root mat on bedrock.

Second group.

NOTES: Area is 20% slickrock. Biological crust is pinnacled consisting of light and dark cyanobacteria, gelatinous lichen and mosses. About 30 % pinnacled, 40% interpinnacle, balance of surface is plant bases or litter.
By: SP, VP May 8, 2002 Moab, UT
VEGETATION: JUOS, PIED, CORA, EPHD, GUSA2
PARENT MATERIAL: EOLIAN MATERAIL FROM SANDSTONE
SURFACE ROCK: 5% GR, trace of CB

Horizon	**Depth cm**	**Color dry**	**Color moist**	**texture**	**Structure**	**Consistence**			**Reaction**	
						Dry	**Moist**	**Wet**	**pH**	**HCl**
A bc *	0-1	60% light cyano 5YR 6/6	5YR 4/4	LFS	1npl > sg	s	vfr	so po	7.8	e
		40% dark cyano 5YR 2.5/2	7.5YR 2.5/1							
Bw	1-5	5YR 5/6	5YR 4/4	LFS	1vfsbk	sh	vfr	so po	8.2	es
Bk	5-12	5YR 5/4	5YR 4/4	LS	1vfsbk > sg	s	vfr	so po	8.2	ev
R	12+									

Horizon	**"Roots" cyanobacteria sheaths**	**Pores**	**Concentrations**					**Coarse Fragments**	**Boundary**	**Notes**
			%	Size	Shape	Kind	location			
A bc *	3vf throughout	3vfi	finely disseminted CaCO3						cw	**
Bw	3vf throughout	3vfi, 2vft	2	f	R	CAM			cw	
Bk	3vf throughout	2vf,f i	1	f	IR	CAC		10 % GR	ai	
			2	vf	IR	CAM				
R										

* bc denotes biological crust
** biocrust pedestals up to 6cm high. Horizon thickness ranges 1-7cm thick

Third group

Biotic Crust Description

BY: DR, BJ May 8, 2002, Moab, UT

FORM: ***Pinnacle***

SIZE: HORIZONTAL X axis: ***4 cm.*** Y axis: ***9cm.***
VERTICAL: ***1cm***. to ***5 cm***.

SPACING: ***4 cm.*** PERCENT OF SURFACE : ***60%***

ORGANISMS:

Cyanobacteria	***30%***
Dark Cyanobacteria	***55%***
Lichen	***10%***
Moss	***5%***

CRUST THICKNESS: ***8 mm***.

ROUGHNESS: % Crust: ***30*** % Interspaces: ***70***

COLOR

	Color	Percent
Mineral soil, Dry :	***5YR 4/4***	***60%***
Crust Organisms ***:***	***5YR 3/1***	***35%***
	5Y 8/4	***3%***
	10R 6/8	***2%***

FILAMENTS (cyanobacteria sheaths)
Quantity : ***Very many*** *(Use or modify root terms)*
Size: ***Very fine***

Fourth group

The fourth group acknowledged that there was merit in describing the biological crust as both a horizon and a soil surface feature. Because some important information may be lost if the crust is lumped with underlying soil, a 1-cm crust was split out and the pinnacle height was included in the range of horizon thickness. They suggested that the surface of the soil (0 cm) could possibly start at the base of the "rind" (crust), but most others did not agree. The crust could be identified with a special suffix in the horizon designation ("u" for crust, for example). Soil surface spatial features should also be described; a table for all types of soil crusts is probably needed in NASIS.

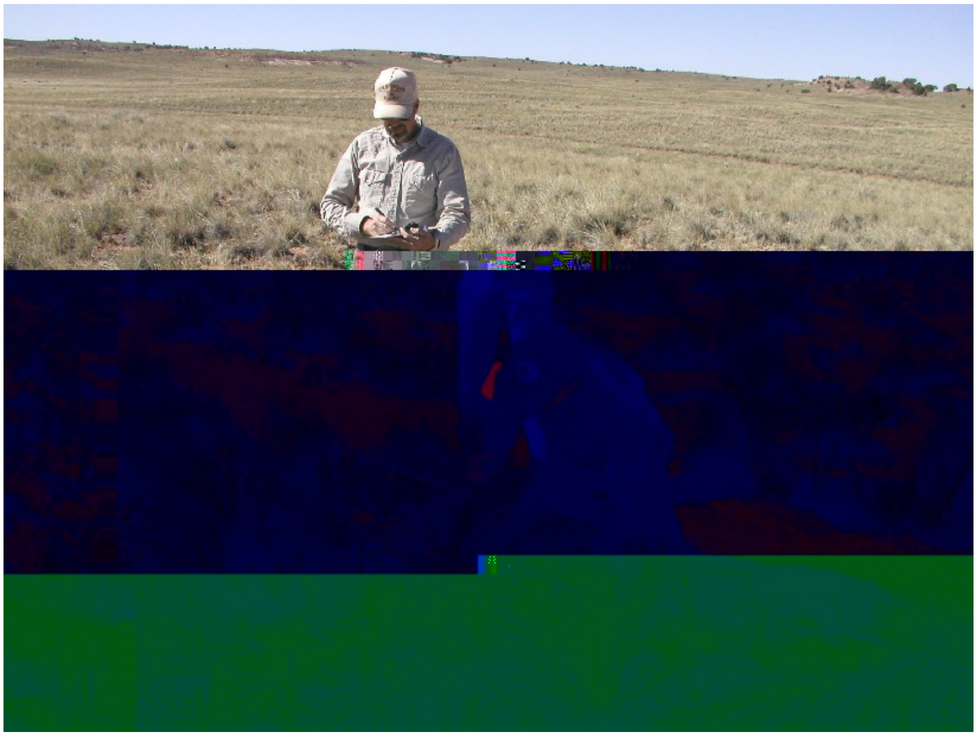
Appendix 5. Photos

Lichens and mosses on gypsiferous soil

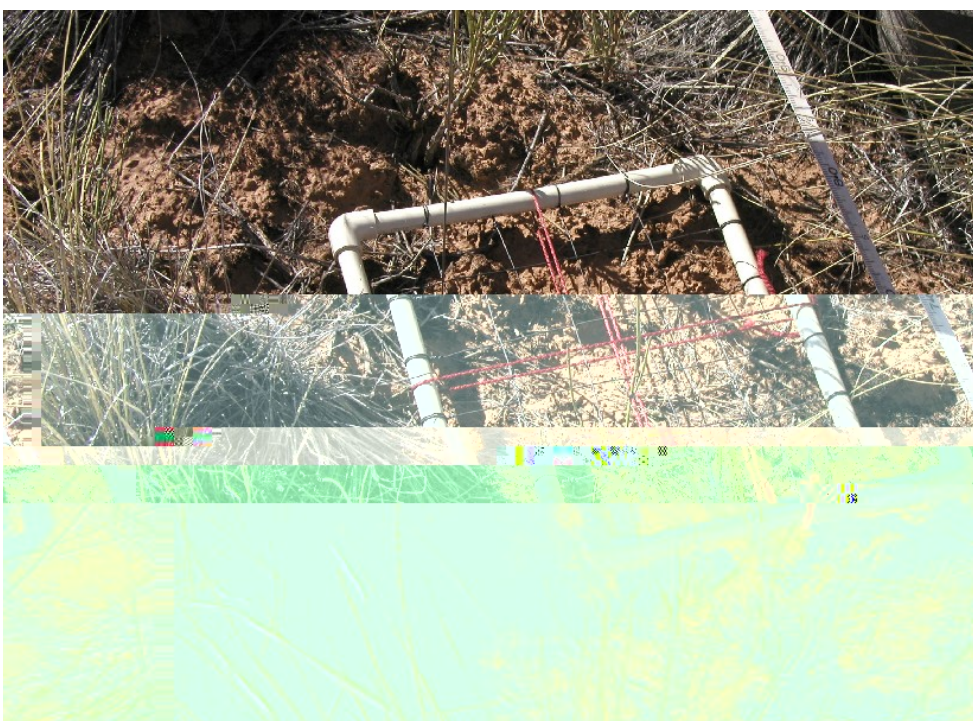
Smooth dark cyanobacterial crust

Pinnacled cyanobacteria and lichen crust

Pinyon and juniper landscape with pinnacled biological soil crust and rock outcrop (white-colored slick rock).



Mehod 3. Line-point quadrat



Quadrat frame (25cm square, 20-hit frame)

Method 4. Stratified line-point intercept

Soil surface stability test kit.

Biological Soil Crust Task Force, May 6-9, 2002, Moab Utah

Response to July 2002 Final Report
of the
Standards Committee
Standing Committee of the West Regional NCSS Conference
Telluride, CO

To: Duane Lammers, FS, Chair

From: Soil Crust Task Force Members

Date: May 22, 2003

Thank you for your interest and comments on the Soil Crust Task Force proposal. The Task Force agrees with your recommendation, i.e. that a standard protocol for identification and description of biological crusts is needed and that methods should be attempted on a few soil surveys. This will insure realistic testing of the methods for soil survey.

Responses to the questions posed by the Committee are provided below. We hope the additional information and explanations will clarify the issues. The report questions have been numbered 1 through 5. For your reference, the original findings of the Standards Committee are attached.

A discussion of ongoing business carried out by the Task Force after July 2002 will be sent to you in a separate report at a later date. We are continuing to work with the Soil Survey Standards staff on the procedures and the proper placement of biological crust information in the updated Soil Survey Manual. The line-point method was used by the soil survey crew in Big Bend National Park in April, 2003. Other concerns that were raised by the Committee including the relationship of these methods and concepts to bedrock, transect objectives and correlation should be reviewed when the methods are tested in a soil survey. If you have further questions, please contact Arlene, Tom or Janis.

Responses

1. **Are biological soil crusts plants, soil or combination of both?**
   Biological crusts are a plant feature, a soil feature and an integrated feature. They are a combination of both biological material and mineral soil material. The integrated nature of crusts is described in selected sentences from Appendix 2 – Biological Crusts for the Soil Survey Manual. "*Biological soil crusts are a living community of cyanobacteria, mosses and lichens that occur in most arid and semi-arid regions. They are a part of, and can heavily influence, the morphology of the near-surface zone of soils in these regions.*" An example is the pinnacled surface soil morphology that develops in soils of the Colorado Plateau where cyanobacteria and lichen occur (Figures 1 and 2). The irregular nature of the surface provides mini-catchments for water that increase the residence time of water on the surface and thus slow runoff and increase infiltration.
   The binding function of crusts is analogous to that of roots and root exudates. "*Cyanobacteria ("blue-green algae") are primitive filamentous or single-celled*

bacteria that come in a variety of sizes and shapes. However, *"only the filamentous species can be seen without a microscope. They look like fine threads that dangle and twirl when fragments of the soil surface are held aloft (unlike roots, which are often too stiff to blow as freely). These threads often have small soil particles attached"* (Figure 3). Small root-like structures of lichen and mosses can also be seen without a microscope.

Additional sentences state *"The polysaccharide material extruded by these organisms binds soil particles together, providing protection from raindrop-induced erosion and physical crusting and creating soil aggregates."* Figure 4 shows cyanobacterial sheaths binding sand grains (90x).

"The presence of a physical crust often aids biological soil crust establishment, as the physical crust provides a stable surface for colonization." In these cases, it is often difficult to distinguish the physical from the biological crust, it is actually a bio-physical crust.

Figure 1 Pinnacled cyanobacteria-lichen crust, UT

Figure 2 Landscape for Fig. 1

Figure 3 Cyanobacteria crust

Figure 4 Cyanobacteria sheaths

2. Is it appropriate to think of these crusts as plant communities with potentials, state and transition?

First we need to review the relationship between crusts and components of an ecosystem. Crusts are a non-vascular plant community having potentials. It is also true that crusts are a part of a broader plant community of vascular and non-vascular plants and a part of the soil environment. Ecosystems include soil and all living organisms both above and below ground. Plant communities are a part of ecosystems. Plant communities can be subdivided into functional groups (warm season grass, cool-season grass, shrubs and trees). As a biological parameter, biological crusts can be considered a functional group. In addition, as a soil constituent, biological crusts can be considered a soil surface property that extends into the soil and affects the soil-air, soil-water interface.

State and Transition Models are used to depict dynamics, including potentials. Plant dynamics and soil dynamics can both be represented by a state and transition model for an ecological site. For example, in a Black Brush- Biological Crust Site, each state can have more that one plant community. Various conditions of shrub, grass and crust composition and coverage can be depicted as separate plant communities within a state. If the difference in the plant community (shrub-grass-biocrust) affects the ecological processes greatly, it can be depicted in a different state.

3. Should aerial extent be monitored to determine disturbance from footprints or tire tracks?

Activities that determine and monitor aerial extent of disturbances such as footprints or tire tracks are not soil survey activities.

Clarification of the term monitoring as used in this response is provided below. The dictionary definition of monitoring that best fits resource monitoring concepts is "keeping track of the operation of (as a machine or process)". In this sense, the soil is the medium (machine) in which numerous processes are carried out (ie, nutrient fixation, immobilization and mineralization; partitioning water flow thru infiltration; etc.). The *Internet Glossary of Soil Science Terms* (SSSA, 1997) does not include the word "monitoring". Therefore, we have borrowed from *"A Glossary of Terms Used in Range Management"* (Society for Range Management, 1999). The SRM defines monitoring as "The orderly collection, analysis and interpretation of resource data to evaluate progress toward meeting management objectives. The process must be conducted over time in order to determine whether or not management objectives are being met." In this context, the management objective may be to maintain or improve certain soil and ecological processes affected by foot and tire traffic. In summary, monitoring is a procedure to track changes in a system and is used to describe trend. We do not consider monitoring to be a soil survey function.

4. How would biological crusts be described in map units, if they have been obliterated in one area and undisturbed in another area of the same polygon or map unit?

Other properties affected by disturbance (organic matter, bulk density, etc.) are included in soil survey. The Task Force is proposing that the expected dynamics of a temporal soil property be characterized and described for a soil survey map unit. This would include, for example, information on the potential occurrence of biological crusts and the predicted changes in kind and cover of biological crusts that result from disturbances. This is important because changes in crusts affect, among other things, aggregate stability, runoff and the capacity of the soil to resist erosion.

Developing and including soil dynamics information for a state and transition model is a way of describing the temporal changes; doing so is not a monitoring program nor is it point data. The description of the temporal dynamics in relation to disturbances would then be linked to, or included in, the soil survey map unit description. Information on the occurrence of biological crusts in different states of a map unit would be provided in descriptive or tabular form (from databases). The various states within a map unit would not be spatially mapped, i.e. as phases, unless required by some other mapping convention.

5. Can we afford the additional cost of describing biological soil crusts in standard soil surveys?

This is an important question because soil survey has always strived to provide information requested by the customers. It is up to us as scientists to determine how to collect reliable data with adequate documentation to meet the needs.

It is reasonable that biological crust information would not be included in all soil surveys. The need for biological crust information is greater in some surveys and less in others. This need relates to the varying importance of biological crusts in different environments. In areas with minimal vascular plant cover, biological crusts perform necessary functions. They increase soil stability thus minimizing soil erosion. In some systems, they provide mineral nutrition for plants. Where crusts are important, cost effective methods should be developed so data and information can be included in soil surveys.

Customer needs, the costs and the benefits should all be considered. Collecting all surface features with the same transect method will increase the efficiency. Further testing of the methods and necessary refinements are needed before we can determine how much it will cost. Current time estimates suggest the cost of gathering data will be low, and there are no laboratory costs. The cost should then be compared to the benefits of providing soil information to support emerging resource management needs. BLM and NPS have emphasized the need for describing biological crusts and consider this a critical item for soil survey. The client’s willingness to pay for the desired information is also a factor.

A related question is: *“Can soil survey afford to exclude dynamic soil property data that is needed for resource management?”*

Response prepared by:

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Co-Chair: Tom Reedy, Soil Scientist, National Soil Survey Center, NRCS, Lincoln, NE
Co-Chair: Dr. Janis Boettinger, USU, Logan, UT
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Bill Ypsilantis, Soil Scientist, BLM, Denver, CO
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Attachment

From Standards Committee Report on Tasks Assigned by the Steering Committee of the West Region NCSS Conference, 2002

This is extracted from the Final Report, July, 2002.

3. Review and discuss findings and recommendations of Soil Crust Task Force.

The Soil Crust Task Force Report was presented to the Standards Committee, by Arlene Tugel, during the two-hour committee break-out session at the conference.

In the limited time for discussion, several issues surfaced concerning description of biological soil crusts.

- Are biological soil crusts plants, soil or combination of both?
- Is it appropriate to think of these crusts as plant communities with potentials, state and transition?
- Should aerial extent be monitored to determine disturbance from footprints or tire tracks?
- How would biological crusts be described in map units, if they have been obliterated in one area and undisturbed in another area of the same polygon or map unit?
- Can we afford the additional cost of describing biological soil crusts in standard soil surveys?

The Standards Committee recognizes that a standard protocol for identification and description of biological crusts is needed and recommend that this protocol be proposed as a change to the Soil Survey Manual. The Committee also supports incorporating field methods with those for other surface features. These methods may be appropriate as an appendix to the Manual or as a section on field methods for surface features. Methods for monitoring soil compaction, soil displacement, or other soil disturbance are similar to monitoring for soil crusts. Data elements will need to be added to the Field Guide for Describing Soils and data fields added to NASIS.

The Standards Committee does not unanimously agree that collection of biological soil crust information is a soil survey activity. Biological crusts are susceptible to disturbance. The present condition (kind and occurrence) could be monitored like is done with present vegetation and soil disturbance.

The Committee recommended that description of biological crusts be attempted on a few progressive soil surveys to evaluate the utility of collecting these data.

The concept of a potential biological crust with state and transition needs evaluation. A potential crust could be correlated to map unit components of soil survey.

Extent of biological crust degradation as an indicator of a threshold to ecosystem integrity is worthy of further development.

Although text has been written for the Soil Survey Manual, there is no indication of where this fits or how it affects other text in the Manual. The Manual makes reference to transect methods to determine surface features, and also to determine map unit composition. Clarification is needed. Can the two be combined into one field effort? Rock outcrop and badland are miscellaneous areas (i.e. map unit components); bedrock is listed as a species code for a soil surface feature. Not a good idea. Roughness is being used to refer to crust micro-topography. Roughness is already defined in the Manual. The ocular method for collecting crust information was not included in the report.

The Committee recommends the Soil Biological Crust Task Force work closely with Soil Survey Standards staff to clarify terms and to incorporate soil crust methodology in the SSM.

National Cooperative Soil Survey Conference
Plymouth, MA
June 16 - 20, 2003

Biological Soil Crust Task Force
Status of ongoing business

A. FY 2003 business overview

1. Pedon descriptions
2. Surface roughness
3. Surface features and topographic features: a nested hierarchy
4. Objectives and scale of methods
5. Big Bend field test

B. FY 2004 activities

A. FY 2003 Business Overview

Task Force Business was carried out through teleconferences in FY 2003. Tom Reedy served as Chair. The discussions on “Pedon descriptions” and “Surface roughness” fulfill action items listed in the Task Force Report made at the 2002 West Region Soil Survey Conference.

Additional topics that need clarification were identified during Task Force discussions and are presented below. These include “Surface features and topographic features: a nested hierarchy” and “Objectives and scale of methods.” A report on the use of Method 4 in Big Bend National Park is also included.

<u>This Status Report was prepared by</u>

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1. Pedon descriptions

Rev. 5/2003

Purpose:

The Biological Soil Crust Task Force has already presented draft methods and procedures to systematically record (i.e. by transects) the important parameters of a suite of key surface features (i.e. cyanobacteria, lichen, and mosses, plant base, litter mat, bare soil, structural aggregates, rock, woody debris, physical and chemical crusts)[1]. The purpose of this section is to discuss and recommend procedures for describing biological crusts in pedon descriptions.

Discussion:

Pedon descriptions provide a method for recording the nature of soil features resulting from soil forming factors and processes. An understanding of the genesis and importance of the soil properties is necessary to develop meaningful and consistent methods for describing biological soil crusts. A brief discussion of the composition, morphology, continuity, genesis, terminology and the importance of biological crusts is below.

Composition and morphology. Biological soil crusts have a biotic component and a physical component. The biotic component is the biological community, and includes organisms such as cyanobacteria, lichens and mosses. In the cyanobacterial dominated crust observed by the Task Force, the physical component is the upper few millimeters to few centimeters of the mineral soil surface (i.e. the crust proper, figure 1).

The Task Force made biological crust observations for only one of the three broad morphological groups of biological crust organisms. We described soil pedon features associated with the well developed cyanobacteria-dominated biological crusts of the Colorado Plateau. However, the observable features of the mineral component of the biological crust vary depending on the crust organisms present, the geographic region, the plant community and the past management. In some systems the physical presence of the mineral soil layer is indiscernible if only cyanobacteria are present. In other systems, it may have a platy appearance or it may appear as a thin mineral layer that is not platy but parallels the soil surface. In other systems, it appears as a bio-physical crust of thin plate-like peds with curled margins. These are only examples, other expressions of the physical component also occur.

Continuity. The biological soil crust layer is discontinuous in many cases, that is it has broken horizon topography. The mineral component of the biological crust may or may not be continuous throughout the pedon, but in most cases it is not continuous across the map unit component. Distribution across the landscape is an important feature for soil function that cannot be addressed at the pedon scale and is thus described at a broader scale by transects of soil surface features.

Genesis. Biological soil crusts observed on the Colorado Plateau are thin mineral soil horizons with accessory properties that are influenced by physiologic processes attributed to the crust biological community as well as by soil forming processes acting on and within the soil surface. Frost heaving, cyanobacterial sheath extension into the upper centimeter of soil and differential erosion of

[1] Report and Recommendations of the Soil Crust Task Force, West Regional Soil Survey Conference, Presented July 8, 2002, Telluride, CO.

unprotected microsites produces the rough surface topography of the cyanobacterial dominated crust in Figure 1. Soil forming processes operate differently in other regions.

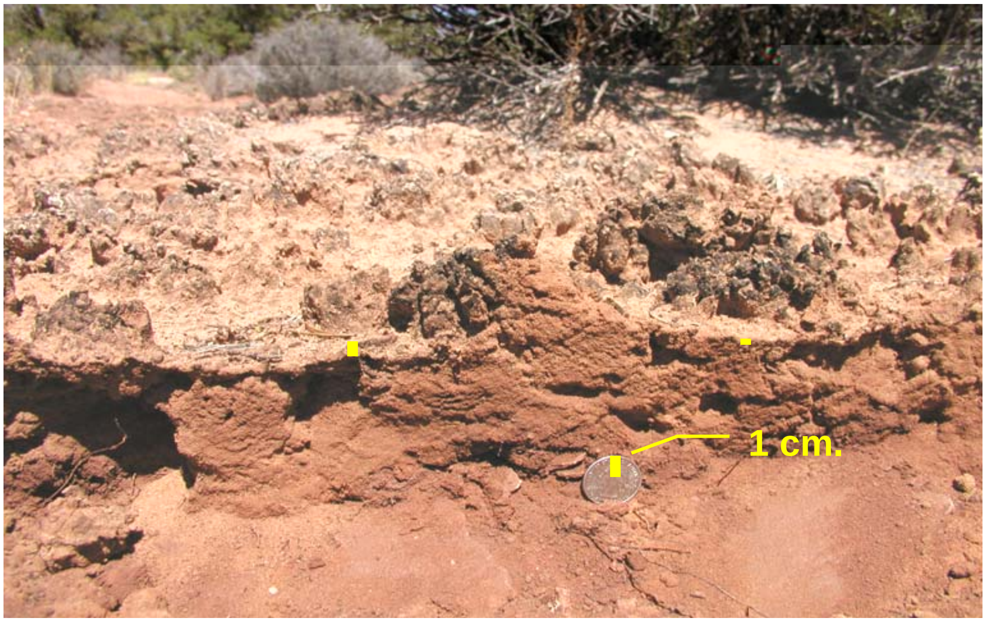

Figure 1 - Thickness of this biological soil crust horizon is about .3 to .8 cm. (Colorado Plateau, Moab, UT. May, 2002)

Terminology. Referring to these thin mineral soil horizons as "biological soil crusts" may be a bit of a misnomer, because to the uninitiated it tends to conjure up visions of biological matter and not mineral soil. However, the term biological soil crust serves as a generalized term that can be used to refer to soil/air interface features associated with a variety of crust organisms. Developing terminology that can be used consistently when applied to the variety of biological crust forms is of primary importance. Observations of biological crusts in other environments are needed to fully meet terminology needs for the various combinations of biological-physical-chemical crusts that exist.

Importance. Information gathered in pedon descriptions and surface feature transects will be used to characterize and predict the role of biological crusts in soil and ecosystem functions. The physical/chemical/morphological characteristics of the mineral soil surface layer and surface roughness (discussed later) have a combined effect on infiltration, detention, runoff, erosion, dust accumulation, seedling germination, nutrient cycling, pH, bulk density, and aggregate stability. Describing these horizons will assure that their properties will be accounted for in soil interpretations, functional descriptions, pedon mass balance calculations and other quantitative determinations of mass of soil constituents per area.

Pedon attributes

Biological crust soil horizons can be quite thin, oftentimes less than 1 cm. thick (figure 1). Yet, due to their soil/air interface, these extremely important surface horizons have unique properties that impact air permeability, infiltration, runoff, soil stability, erosion, and nutrient cycling. In order to develop an understanding of crusts (biological, physical and chemical) and to advance the science of pedology, thin surface horizons should be described in pedon descriptions, and their depth recorded to one decimal place in centimeters (e.g. 0.4 cm). This does not imply that all horizons (i.e.

subsurface horizons) be described to one decimal place, and therefore does not preclude subsurface horizon depths from being recorded in integers, as is currently done.

The attributes listed below are important in the description and laboratory analysis of biological soil. Item a, “biological crust composition,” is needed to determine relationships between biological crust type and other attributes of the soil surface horizon.

a. Biological crust composition (percent organisms by broad morphological group (i.e. cyanobacteria, lichens, and mosses) at the pedon scale. Broad morphological groups are defined in Appendix 2 and 3 of the Task Force Report.
b. Depth
c. Color
d. Texture
e. Structure
f. Rupture resistance
g. Pores
h. Roots and root-like structures, (for example hyphae and mycelia (fungi), sheaths (filamentous cyanobacteria), and rhizines or rhizoids (lichens and mosses)).

   NOTE: It is difficult and sometimes impossible in the field to correctly distinguish the root-like structures from each other or from very fine roots". The term "roots and root-like structures" would be used to describe the examples given, with no need for further detail.
i. pH
j. Electrical conductivity
k. Organic carbon content
l. Bulk density
m. Horizon boundary, percent continuity: enter estimate of percent continuity
n. Thickness: enter min./max (0.1 cm)

The examples of horizon descriptions given below suggest ways in which the upper part of a pedon could be described. The objective of any pedon description is to impart information in a manner that helps the reader to conjure up a mental image of the pedon. In example #1, the pedon-scale surface features are incorporated with the surface soil horizon. Example #2 separates the two, thus the surface soil horizon description is preceded by a brief discussion of the pedon-scale surface features. The consensus of the Task Force is that example #2 provides the clearest mental image.

Example #1

A--0 to .8 cm; light red (5YR 5/4) fine sandy loam, reddish brown (5YR 4/4) moist; weak medium platy structure; soft, very friable; very fine roots and root-like structures; many medium interstitial pores; strongly effervescent; carbonates are disseminated; moderately alkaline (pH 8.2); 60 percent of surface pinnacled, 60 percent 5YR 6/4 mineral surface and 35 percent 5YR 3/1, 3 percent 5Y 8/4, 2 percent 10R 6/8 organisms, 4x9x1-5 cm; 4cm spacing, 30 percent dark cyanobacteria, 55 percent cyanobacteria, 10 percent lichen, 5 percent moss; very abrupt broken boundary (70 percent continuous)[2]. (.3 to .8 cm thick).

[2] Horizon topography is the cross-sectional shape of the boundary between horizons. Discontinuous horizons are designated as "broken." At this time, there is no option to modify "broken," such as the "degree of discontinuity." For example, a "very abrupt broken boundary" could be descriptively improved by including an estimate for percent continuity, i.e. "very abrupt broken boundary, 50 percent continuous."

Example #2

Pedon-scale surface features: Soil surface morphology is about 60 percent pinnacles, each pinnacle approximately 2 to 4 cm wide, 6 to 9 cm long, and 1 to 5 cm in height, spaced about 4 to 12 cm apart. Surface roughness index is 35 (1 - ratio of ground chain length to actual chain length). Surface features are 30 percent bare mineral soil (5YR 6/6 dry), 30 percent light cyanobacteria (5YR 6/6 dry), 10 percent dark cyanobacteria (color optional), 10 percent lichen (color optional), 5 percent moss (color optional), 10 percent plant bases, and 5 percent pebbles.

A--0 to .8 cm; light red (5YR 5/4) fine sandy loam, reddish brown (5YR 4/4) moist; weak medium platy structure parting to single grain; soft, very friable; very fine roots and root-like structures; many medium interstitial pores; strongly effervescent; carbonates are disseminated; moderately alkaline (pH 8.2); very abrupt broken boundary (70 percent continuous) . (.3 to .8 cm thick).

2. Surface roughness

Rev. 5/2003

Introduction:

The Soil Survey Manual (Soil Survey Staff, 1993) defines roughness as "*a ground surface configuration with a repeat distance between prominences of less than 50 cm and for areas less than about 10 m across. Roughness, as used here, pertains to the ground surface and includes rock fragments on the surface. It does not include vegetation. This scale applies to most tillage operations and affects aspects of land surface water flow such as detention, infiltration, runoff, and erosion.*" This same application of scale can certainly be extended to the highly pinnacled surfaces on the Colorado Plateau, where spatial variability in both the vertical and lateral dimension is very striking (figures 2 and 3).

Figure 2 - Biological soil crust community in an area of sandy soil, very shallow to Navajo sandstone in a complex with bedrock, dominantly composed of cyanobacteria and lichen on a highly pinnacled soil surface in southeastern Utah. The pinnacles are formed by frost heaving, and are resistant to erosion due to the stabilizing effect of the biological crusts. A stand of Pinyon-Juniper is in the background; black brush and prickly pear species are in the foreground.

Because of its effect on infiltration and surface runoff, the Biological Soil Crust Task Force listed surface roughness as the most important physical attribute (Table 1)[3]. Notwithstanding the need to describe surface roughness associated with the biological soil crusts of the Colorado Plateau, it is essential for the National Cooperative Soil Survey to describe roughness under various land uses in a manner that conveys interpretive usefulness for runoff, infiltration, and wind and water erosion predictive models.

Table 1. Biological crust attributes and their importance.

Priority	Attribute	Function or Importance
1 – high	Surface roughness	Runoff and infiltration
2 – high	Cover by kind (CYN, LIC, MOS) and total cover	Soil stability, nutrient cycling, infiltration
3 – medium	Location of crust in relation to canopy cover	Disturbance impacts, soil stability
4 – low	Color of biological crust organisms	Genus or species present, N-fixation potential

Figure 3 - Close-up of biological soil crust community depicts striking surface roughness (.2cm scale). Vertical differences from the tops of pinnacles to their base are on the order of a few centimeters to 8 or 10 cm. Lateral distance between pinnacles is about 5 to 30 centimeters.

[3] *Report and Recommendations of the Soil Crust Task Force*, West Regional Soil Survey Conference, Presented July 8, 2002, Telluride, CO.

Measuring surface roughness:

There is no formally accepted standard method for measuring and describing surface roughness for the National Cooperative Soil Survey. The Agricultural Research Service has studied ways of reporting surface roughness as a means to improve soil loss predictive models (Renard et al., 1997). Renard states that "at this time, no rapid, inexpensive technique is available to measure random roughness in the field. Frequently roughness is estimated as either a mean or a range in clod size. It has also been estimated in terms of the number of hits on clods of greater than a given size using a beaded line. Neither technique provides a value of random roughness as needed by Revised Universal Soil Loss Equation or other models."

Laser microrelief meters effectively measure the surface statistics of roughness (Römkens et al. 1988). Surface roughness characterization by use of acoustic backscatter has been used for many years in the underwater acoustics community. Oelze et al. (2002) has taken this acoustic technology and applied it toward characterizing surface roughness of porous soil. However, both devices are expensive, require calibration, and are time consuming. Both are probably beyond the scope of the National Cooperative Soil Survey.

The challenge of the Task Force is to propose an inexpensive, expedient protocol for measuring and describing surface roughness that will apply to all surfaces, not just those with biological soil crusts.

<u>A review of one-dimensional methods:</u>

The Agricultural Research Service defines (and measures) random roughness as "the standard deviation of elevation from a plane across a tilled area, after oriented roughness is accounted for by appropriate statistical procedures. Random roughness can be determined by mechanical profile meters or by more sophisticated devices such as laser profilers" (Renard et al., 1997).

An unpublished one-dimensional method by Grossman and Paetzold, National Soil survey Center, reports a roughness value similar to the standard deviation of Renard et al. (1997). The procedure is to record the distance from points incrementally spaced along the horizontal crossbar to the soil surface (figure 4). The data are reduced by computation of the standard deviation of the vertical distances as adjusted for the slope overall along the length measured. The first step is to regress the vertical distances against the horizontal distances along the reference line. The regression gives the overall slope of the soil. The difference between the measured vertical distance and the reference line and the calculated vertical distance from the reference line at a point based on the regression line is a residual. The standard deviation of the residuals is computed. It is an estimate of soil surface roughness corrected for the slope of the soil.

Other scientists have used their own versions of microrelief meters and report the surface roughness as the standard deviation of the elevation (Kuipers 1957, Burwell et al. 1963, Allmaras et al. 1966).

The Task Force has not tested Grossman's method (or any other method), but there is some concern that the 2 cm.-minimum increment may not effectively capture the intricate detail of the pinnacled surface. Also, although standard deviation is calculated for the vertical dimension, it is questionable as to whether or not the procedure is able to interpret spatial variability.

The U.S. Geological Survey has used a technique to measure surface roughness as follows: At 10-cm increments along a transect, measure the low and high spot within 1 cm. Then subtract the low from the high, and add the differences to come up with an index.[4]

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[4] Communication from Dr. Jayne Belnap, Research Ecologist, USGS, Moab, Utah

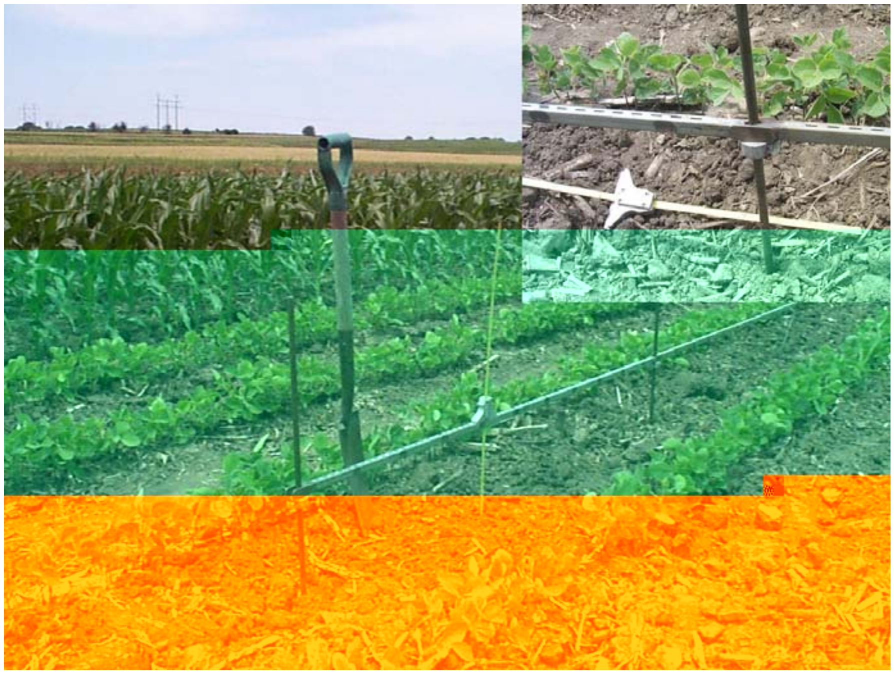

Figure 4 - Grossman's transect apparatus for surface roughness. Slots in the crossbar are in 2.5 cm. increments (see inset).

Saleh (1993) proposed a chain method for one-dimensional roughness, based on the fact that the shortest distance between two points is a straight line. The theory is that a chain of given length (L1) will traverse a shorter horizontal length (L2) when it follows a rough surface compared to a smooth surface (figure 5). The difference between L1 and L2 is related to the degree of roughness:

$$Cr = (1 - L2/L1) \bullet 100,$$ where Cr is roughness in any direction.

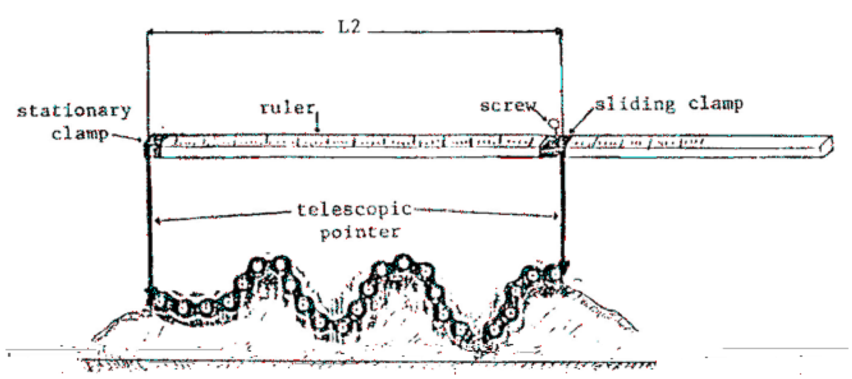

Figure 5 - The components of the chain method: a) roller chain, b) caliper ruler with telescopic pointer as demonstrating the chain method (Saleh, 1993).

In a review of Saleh's chain method, Skidmore (1997) states that at first glance, the procedure is simple to use, inexpensive, and appears to give reasonable results. This is especially true when only one of the two variables (i.e. height or spacing) is allowed to vary. However, a problem occurs when height and spacing vary together. When both variables vary and yet give the same L2, then the ratio L2/L1 would remain constant, yielding unrealistic results. Like Skidmore, the Task Force is also not convinced that Saleh's chain method gives a true depiction of surface roughness.

Because surface roughness is so related to scale, a fractal approach might be the most realistic and worth pursuing. The Task Force has not delved into the fractal dimension, but strongly recommends that the National Cooperative Soil Survey seriously consider the application of fractals and scale in describing surface roughness.

<u>A review of three-dimensional methods:</u>

An expedient technique for rapid field assessment of roughness would be to photograph areas of selected roughness conditions. The photographs could be arrayed from low surface roughness condition to high, and roughness classes could be developed from the array. The photo array could then be used as a visual guide to estimate the roughness class in the field (e.g. none, slight, moderate, and high).

It seems reasonable that digital photogrammetric techniques could be used produce "micro" digital terrain models of the soil surface. Conceptually, this would involve processing digital data from large-scale stereo images (e.g. a few square meters of the soil surface) with the required ground control points. A digital representation would allow for a variety of ways to quantitatively assess roughness. The Task Force recommends that NCSS investigate whether a procedure exists for creating "micro" digital terrain models.

Summary and Recommendations:

Methods that employ laser technology and acoustic backscatter techniques are expensive, highly technical, time consuming, and are considered by the Task Force to be beyond the scope of the National Cooperative Soil Survey.

The Task Force recommends that Grossman's one-dimensional approach be tested, and perhaps modified to accommodate transect increments of less than 2.5 cm. in order to capture the intricacy of the highly pinnacled surfaces encountered on the Colorado Plateau. The usefulness of reporting roughness as a standard deviation of elevation without integrating the lateral spacing seems to be a disadvantage, but this needs to be further evaluated.

The Task Force recommends that Saleh's method be integrated with a narrative description of the vertical and lateral attributes of the surface morphology. This would help to ameliorate the potential getting unrealistic values when both height and spacing vary together.
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An expedient technique for rapid field assessment and relative class placement of roughness would be to photograph-0els ptntial

A "micro" digital terrain model of the soil surface would allow for a variety of ways to quantitatively assess roughness in three dimensions. The National Cooperative Soil Survey should investigate whether this technology exists or can be developed.

3. Surface features and topographic features: a nested hierarchy

Purpose:

The Task Force has focused its attention on surface features (Table 2) that determine the behavior of the soil-air interface (e.g. biological and physical crusts, rock fragments, plant bases, etc). However, there are other properties commonly identified as surface features. The purpose of this section is to propose a nested hierarchy for surface features based on their relationship to each other.

Discussion:

While there may be some important soil-air interface properties that have been overlooked by the Task Force, those currently identified are different from surface *topographical* features such as slickspots, ant hills, tree-tip pits, tree-tip mounds, etc. The simplest way to differentiate the two types of "surface" properties is through a statement of their spatial relationship. *"Soil-air interface properties comprise the surface of topographical and bio-topographical features."* Examples include:

- Fine gravel typically covers an ant hill made by harvester ants.
- A biological crust comprised of cyanobacteria, lichen and moss and having well developed pinnacled roughness covers 60 percent of the interspace between shrubs.

The surface of slickspots is comprised of a physical crust (75 percent) biological crust organisms (15 percent) and non-aggregated, non-crusted soil (10 percent).

Recommended item:

There is a need to distinguish soil surface features addressed by the Task Force from topographical and bio-topographical surface features with larger dimensions. We suggest a nested hierarchy system be developed for all newly proposed "surface features". The hierarchy should include the following, from smallest element to largest: 1) surface features of the soil-air interface and 2) topographical or bio-topographical features. These two could also be nested under the microfeatures element of geomorphic descriptions (microfeatures in Field Book for Describing and Sampling Soils). Developing an exhaustive list of features under the topographical or bio-topographical category is beyond the scope of the Task Force. However, we would like to review any such list that may be developed as well as additions to the proposed surface features list.

Table 2. Surface features at the soil-air interface

Note: Codes marked with * are identical to those used in rangeland monitoring procedures for planning and NRI. These codes should not be changed. Surface features terms marked with ** may be modified after field testing in hot deserts and cold deserts.

Surface feature	Code	Include:	General Description
Cyanobactera (dark)	CYN *	Cyanobacteria	Darker than soil color to black and has small fibers in the soil. Can be green when moist.
Lichen	LIC *	Lichen (crustose, gelatinous, squamulose, foliose, and fruticose), liverworts	All colors. Do not change color when wetted. Black gelatinous species swell when wetted.
Moss	MOS *	Moss	Dark and dull colored. Turn bright green or brown when wetted.
Undifferentiated **	U	Cyanobacteria, algae, incipient physical crust	Presence of small fibers in soil. Soil-colored, can be green when moist.
Biological crust **	BC	Any or all biological organisms present	Use only when morphological group does not need to be specified.
Physical crust **	PC	*Not yet developed*	
Chemical crust **	CC	*Not yet developed*	
Structural aggregates **	SA	Soil structural aggregates or massive at the surface.	A soil surface that does not have a biological, physical or chemical crust; no fibers; but does have surface stability.[2]
Rock fragments	GR, CB, ST, BY, CN, FL	Rock fragments on the surface	Rock fragments are either on the surface or partially embedded in the soil. Use standard size classes.
Pararock fragments	PGR, PCB, PST, PBY, PCN, PFL	Pararock fragments on the surface	Pararock fragments are either on the surface or partially embedded in the soil. Use standard size classes.
Bedrock	BR	Bedrock	Surface exposures of bedrock. May include both hard and soft bedrock
Woody debris	W *	Woody fragments	Dead twigs, branches and logs >5mm diameter (1/4”)

Surface feature	Code	Include:	General Description
Litter mat	LM *	O horizon material in a continuous or discontinuous mat	O horizon with no clear boundary between litter and soil or a mat of litter that is not displaced by rain or wind storms of annual frequency. (Tentative term and definition)
Plant base	PLT; specie s code; or functio nal group code	PLT for plant base; or species; or plant functional group of each plant base	Plant functional groups are: perennial grass (PG), annual grass (AG), perennial forb (PF), annual forb (AF), shrub (SH), tree (TR/
Bare soil	S *	Soil surface that is not stabilized or covered by any of the above.	Loose or weakly aggregated soil; soil with no crust and no fibers, soil in cracks.

4. Objectives and scale of methods

Purpose:

The Task Force has provided draft methods for surface features at two different scales in order to meet different objectives for data analysis and interpretation. One method is the pedon description at a pedon scale, and the other includes transect procedures at the polypedon scale. The purpose of this section is to describe the objectives for utilizing two different scales.

Discussion:

The pedon scale method meets the objective of characterizing the soil surface at the place we actually describe the pedon. The description of the organisms that rest in and on the horizon at this scale will allow us to gather information about the distribution of biological crusts in relation to things such as soil texture, organic matter, $CaCO_3$, gypsum, etc. Such information will be valuable in advancing the study of biological crusts and predicting the potential occurrence of biological crusts in areas that currently lack them.

The multi-meter transect scale meets the objective of interpreting soil function on the scale (landscape) that it actually functions. A meaningful interpretation of soil behavior and function needs to include the heterogeneity of surface properties. Transects allow us to characterize and interpret patterns of spatial heterogeneity.

No recommendation needed.

5. Big Bend Field Test

Purpose:

The purpose of this report is to provide information on the recent field test of methods for dynamic soil property data. The test was conducted on Big Bend National Park by the Soil Quality Institute during April 22-24, 2003. One of the methods used, the line-point intercept method, is the same as Appendix 3, Method 4 in the Biological Crust Task Force Report, July, 2002.

Submitted by:

Arlene Tugel, Soil Quality Institute, Las Cruces, NM. NRCS. May 18, 2003.

Summary:

The Big Bend National Park sampling trip (April 22- 24, 2003) was the first field trial of new procedures for dynamic soil properties. I provided methods, equipment and led the sampling activities. The draft procedures were developed by the Soil Quality Institute and the ARS Jornada Experimental Range to add information on soil change and soil function to soil surveys. Data for soil properties that change in response to management was requested by the Park for planning, restoration and monitoring activities. I would like to emphasize that data on dynamic soil properties can enhance soil survey by meeting function-based information needs of land managers.

Participants*:

Lynn Loomis, Project Leader, Marfa, TX
Derek Milner, Soil Scientist, Marfa, TX
Rusty Dowell, Res. Soil Sci., San Angelo, TX
Cat Crumpton, Big Bend NP, TX
Susan Andrews, SQI, Ames, IA
Nelson Rolong, Soil Scientist, Marfa, TX
Judith Dyess, Range Mgt. Specialist, Marfa, TX
Jim Clausen, Soil Scientist, Marfa, TX
Arlene Tugel, SQI, Las Cruces, NM

*All NRCS except Cat Crumpton, NPS

Methods and accomplishments:

Lynn Loomis pre-selected sites. I provided methods, equipment and coordination to document dynamic soil properties and soil function. We followed the work plan that Lynn and I developed. We used sampling procedures that integrate soil and vegetation properties and topography. This allows us to describe the spatial patterns and variability of soil properties in relation to plants and micro-relief. These relationships are important for understanding and documenting soil function on rangeland.

We completed statistically valid sampling at four locations for three soils and three ecological sites. Transects were used to organize all sampling. Methods used at all locations included 1) line-point intercept for plant/litter cover and soil surface features (biological crusts, rock fragments, physical crust, , bare soil, plant bases), 2) basal and canopy gap, 3) soil surface stability, 4) bulk density, and 5) samples of 0-5 cm for salinity and pH. If funding is available, soil carbon will also be determined.

We achieved a high level of proficiency after only two days of using the methods. Time to complete the full suite of tests at the last location was 3 hours for 6 people (5 soil scientists and 1 range conservationist. Workload estimates in the future will depend upon the tests included and the number of replicates. The numbers of replicates collected in this project may have been greater than normally needed. An analysis of variance based on this and ARS data will help determine the required minimum number for future sampling. Every attempt will be made to maximize efficiency.

Participants' comments:

At each site, we discussed the Park's needs for information on dynamic soil properties and soil function. Participants provided the following feedback on the methods.

- Need to add measures for water movement, e.g. hydraulic conductivity (pressure plate), rainfall simulated infiltration/runoff and penetration resistance.
- Need procedures for cropland.
- These methods are suited to intensively documented locations, such as pedon sites.
- Simpler, less quantitative methods are also needed for day-to-day mapping.
- The gap-intercept procedure is counter-intuitive (ie, observe canopy, but record gap) and was thus confusing.
- Need better equipment for bulk density cores.
- "At first I thought the soil surface stability test was bogus, but it really tells us something about surface stability."
- We need at least one pedon description at a plot. We also need a pedon description for each location where the range conservationist collects ecological site data.
- First we need to learn which near-surface properties to include in soil survey work and how to measure them. We can worry about how they fit into the database later.

What's next?

Susan Andrews will do statistical analyses of the data with input from Jeff Herrick. I will work with Susan and Lynn Loomis to interpret the data for the National Park Soil Survey. Biological crust results will be sent to the Task Force.

B. FY 2004 activities

The Task Force will continue to evaluate and refine the methods, procedures and examples discussed in this status report. Of primary interest is the applicability of methods in areas of the Sonoran, Mohave, and Chihuahuan Deserts. A field tour is being planned for the fall, 2003.

Table 2 - Surface features will be further developed, tested, and distributed for review in 2004.

References:

Allmaras, R.R., R.E. Burwell, W.E. Larson, and R.F. Holt. 1966. Total porosity and random roughness of the interrow zone as influenced by tillage. USDA Conserv. Res. Rep. 7.

Belnap, J. et.al., 2001. Biological soil crusts: Ecology and management. Technical Reference 1730-2. USDI-BLM, CO. Web site http://www.blm.gov/nstc/library/techref.htm

Burwell, R.E., R.R. Allmaras, and M. Amemiya. 1963. A field measurement of total porosity and surface microrelief of soils. Soil Sci. Soc. Am. Proc. 27:697-700.Schoeneberger, P.J., Wysocki, D.A., Benham, E.C., and Broderson, W.D. (editors), 2002. Field book for describing and sampling soils, Version 2.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

Kuipers, H. 1957. A relief meter for soil cultivation studies. Neth. J. Agric. Sci. 5:255-262.

Römkens, M.J.M., J.Y. Wang, and R.W. Darden. 1988. A laser microrelief meter. Trans. ASAE 31(2):408-413

M.L. Oelze, J.M. Sabatier, and R. Raspet. 2002. Application of an acoustic backscatter technique for characterizing the surface roughness of porous soil. J. Acoust. Soc. Am. 111(4):1565-1577.

Soil Survey Staff. 1993. Soil Survey Manual. USDA, Soil Conservation Service, Agricultural Handbook No. 18, U.S. Gov. Print. Office, Washington, D.C. 503 pp. Out of print.

Soil Science Society of America. 1997. Internet Glossary of Soil Science Terms. Madison, WI. http://www.soils.org/sssagloss/

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder, coordinators. 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture, Agriculture Handbook No. 703, 404 pp.

Saleh, A. 1993. Soil surface roughness measurement: Chain method. J. Soil Water Conserv. 48:527-529.

Skidmore, E.L. 1997. Comments on chain method for measuring soil roughness. Soil Sci. Soc. Am. J. 61:1532-1533.