Soil Change Guide: Procedures for Soil Survey and Resource Inventory

USDA

NRCS
Natural Resources Conservation Service

Agricultural Research Service

TABLE OF CONTENTS

Soil Change Guide: Procedures for Soil Survey and Resource Inventory

Version 1.1, 2008

By
Arlene J. Tugel
Skye A. Wills
Jeffrey E. Herrick

Cover Pictures

Land use and management can affect soil properties. Examples include rain-fed annual cereal crops (upper center), an annual row crop of irrigated chili peppers (lower left), and mechanically harvested timber (lower right). Soil samples and vegetation observations are collected along transects across scrubland (upper left). Simple field measurements can be made to document management-induced changes in near-surface dynamic soil properties, such as aggregate stability (upper right).

Soil Change Guide: Procedures for Soil Survey and Resource Inventory

Version 1.1, 2008

By
Arlene J. Tugel
Skye A. Wills
Jeffrey E. Herrick

With contributions from:
Susan Andrews, Brandon T. Bestelmeyer, Pete Biggam, Karl W. Hipple, Marta D. Remmenga, Judy P. Ward, and Larry West

Meeting customer needs:

Producers, land managers, and decision-makers need information about soil and ecosystem change in order to assess and monitor the soil resource, predict management effects on soil, and plan for long-term productivity and sustainability.

Acknowledgements

This **Guide** was initiated by the Jornada Experimental Range (USDA-Agricultural Research Service), the USDI-National Park Service, and the USDA-Natural Resources Conservation Service. Other organizations including the USDA-Forest Service, the USDI-Bureau of Land Management, and universities assisted with the development of this **Guide**. The authors sought broad involvement through the **National Cooperative Soil Survey** and other collaborators in order to produce scientifically sound procedures that are relevant to each agency's needs. Many individuals and organizations assisted through manuscript review and advice:

Academic Institutions

Delvin S. Fanning, University of Maryland at College Park
John Galbraith, Virginia Polytechnic Institute and State University
Wayne Hudnall, Texas Tech University
Jay Noller, Oregon State University
A. Toby O'Geen, University of California, Davis
Daniel D. Richter, Jr., Duke University
Stefan Seiter, Linn-Benton Community College, Oregon
Joey Shaw, Auburn University
Larry West, formerly with the University of Georgia

Federal agencies

Agricultural Research Service--Ray B. Bryant, Alan J. Franzleubbers, Douglas Karlen
Bureau of Indian Affairs--Patricia Wright
Bureau of Land Management--Lisa Bryant, Bill Ypsilantis
Forest Service--Randy L. Davis, Deborah S. Page-Dumroese, Tom Rice, Wayne Robbie
Natural Resources Conservation Service--Ellis Benham, Joel Brown, Sam Brown, Craig Ditzler, Jon Gerkin, Ed Griffin, Erik Hesketh, Darrell Kautz, Leonard Jolley, Amanda Moore, George Peacock, Alan Price, Thomas Reedy, Thomas Reinsch, Michael Robotham, Cathy Seybold, Christopher W. Smith, Ken Spaeth, George Teachman, Lyn Townsend, Fred Young.

The individuals who provided leadership for the pilot projects through which the sampling procedures were developed and tested include:

Lynn Loomis, NRCS, TX
Cathy Scott, Vic Parslow, Dana Truman, NRCS, UT
Fred Young, Alan Johnston, Jon Preston, NRCS, MO
Brian Gardner, Frank Gariglio, Dave Hoover, NRCS, ID
Deborah Page-Dumroese, USFS, ID
Mark Kimsey, Intermountain Forest Tree Nutrition Cooperative (IFTNC), ID

Special appreciation is expressed to the staff of the NRCS in Texas, Utah, Missouri, and Idaho, the USDA-FS Rocky Mountain Research Station, Idaho, and Missouri Department of Natural Resources who collected the data for the pilot projects. Additional assistance or laboratory services for the projects were provided by: Big Bend, Arches and Canyonlands National Parks staff; Jayne Belnap, USGS, UT; April Ulery, New Mexico State University; University of Missouri Soil Characterization Laboratory; Paul McDaniel and Anita Falen, University of Idaho; Charles Kome, NRCS Soil Quality Team, Greensboro, NC; and the NRCS National Soil Survey Laboratory.

Authors

Arlene J. Tugel is a soil scientist with the USDA-Natural Resources Conservation Service, National Soil Survey Center, and located in Las Cruces, NM.

Skye A. Wills is a research soil scientist with the USDA-Natural Resources Conservation Service, National Soil Survey Center, located in Lincoln, NE.

Jeffery E. Herrick is a research scientist with the USDA-Agricultural Research Service (USDA-ARS) Jornada Experimental Range in Las Cruces, NM.

Contributors

Susan Andrews is the Team Leader, National Soil Quality Team, with the USDA-Natural Resources Conservation Service in Greensboro, NC.

Brandon T. Bestelmeyer is a research scientist and **Judy P. Ward** was formerly a research technician with the USDA-Agricultural Research Service (USDA-ARS) Jornada Experimental Range in Las Cruces, NM.

Pete Biggam is the Soils Program Manager with the USDI National Park Service, Denver, CO.

Karl W. Hipple is the National Leader for Soil Survey Interpretations, and
Larry West is the National Leader for Soil Survey Research and Laboratory, USDA-Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

Marta D. Remmenga is a mathematical statistician with UDSA-Animal and Plant Health Inspection Service (USDA-APHIS) in Fort Collins, CO and formerly with New Mexico State University, Las Cruces, NM.

Proper citation for this document is:

Tugel, Arlene J., Skye A. Wills, and Jeffrey E. Herrick. 2008. Soil Change Guide: Procedures for Soil Survey and Resource Inventory, Version 1.1. USDA, Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

Foreword

Soil survey databases and dynamic soil properties

Many soil properties have changed and can change as a result of management, historical land use, or even natural factors, such as drought, interacting with land use. National soil survey databases currently include soil property information for the relatively static soil properties, such as texture, and also for properties affected by management, such as soil organic matter. The databases do not, however, distinguish the values of dynamic soil properties (e.g., organic matter, bulk density, infiltration rate) according to their land use, management system, ecological state, or plant community.

"Dynamic soil properties" as defined in this **Guide** are soil properties that change within the human time scale. Differences that may exist in these properties can affect the performance of the soil. Furthermore, some dynamic soil properties change very little in response to management and disturbances. Some change after a disturbance and then quickly recover, while others change significantly and are unlikely to recover under the current climate without significant resource inputs. Information about what changes and what can recover is crucial for achieving short- and long-term soil management goals and maintaining soil quality

Evolving customer needs

Over the centuries, human activities and climate change have affected and will continue to affect the soil resource. Many government agencies implement programs to help protect, enhance, and wisely use natural resources. Most were established in response to severe threats to the soil or other resources, such as the Dust Bowl of the 1930s.

Today's policy makers and land managers are still concerned about threats to the soil resource. Loss of productivity, bio-terrorism, and environmental degradation are only a few issues. Other complex issues include sustainable agriculture, bio-energy, and ecosystem services. Land managers, producers, and others strive for high-quality soils, a productive landscape, and a healthy environment. With information about management effects on the soil, they can select and apply sustainable practices. With a better understanding of how soils change, policy makers can develop programs that will limit undesired change.

Soil survey can meet emerging needs related to the protection, long-term management, and ecological function of soil. It will meet these needs by providing data and information about how soils change. Data about dynamic soil properties, in combination with existing soil survey information, will be used to interpret and predict the effects of human activities and management on soil function within the human time scale.

Soil survey customers can use information about dynamic soil properties and ecosystem change in order to:

- Plan for long-term productivity and sustainability,
- Protect and restore ecosystem functions and services provided by soil,
- Design monitoring plans and interpret assessments of resource conditions,
- Predict land use and management effects on soil, and
- Adjust management practices for changes in near-surface conditions.

Capturing information about these changes and communicating it to a wide variety of audiences will require new procedures and new technologies for soil survey. This **Guide** lays out key concepts and protocols that will enable soil scientists and other resource specialists to examine and quantify changes that affect soil and its ability to function.

The Guide

This **Guide** is designed for soil survey, vegetation, and ecological site or unit inventory work in order to help soil scientists and other inventory specialists collect interpretable data about soil change within the human time scale. This **Guide** describes a sampling system to measure dynamic soil properties for all major land uses (except urban lands where the land and soil have been significantly reshaped). The **Guide** includes instructions for project planning, field execution, and data analysis and storage. Procedures for gathering general management history on croplands and vegetation data on other lands are included to verify and validate the management regime or plant community where dynamic soil property data are collected. Vegetation data are also collected to provide context for interpreting dynamic soil properties and contribute to the interpretation of soil-plant-hydrologic interactions.

The **Guide** describes procedures for replicated data collection. Statistically based sampling requirements are included to help in the collection of useful information that meets soil survey goals for the desired level of precision or acceptable error rates. In summary, the **Guide** answers such questions as what, when, where, and how many items to sample and provides information that helps to interpret the data.

Pilot studies and future versions

The initial pilot studies that provided experiences for the development of this **Guide** were conducted on grassland, shrubland, and forest land. These land cover types were purposely selected to ensure that ecological principles were the foundation of the **Guide**. Extrapolation of these principles, where valid, to crop and pasture land is the next step. Currently, this version of the **Guide** accommodates, either partially or at least in concept, data collection on all lands. Future versions will provide more guidance for cropland and pastureland.

Chapter 1 Using This Guide

Figures

Tables

Chapter 1 Using This Guide

1.1 About This Guide

Properties included in this Guide

This **Guide** addresses dynamic soil and vegetation properties necessary for interpreting the effects of soil change on the capacity of the soil to function. The three kinds of properties to be measured are soil horizon properties (e.g., soil organic carbon, and pH), features of the air-soil interface (e.g., soil surface stability, surface displacement, and infiltration rate), and vegetation characteristics (e.g., cover, vegetation gap sizes, and site index for wood production). In this **Guide**, dynamic soil properties are those that change within the human time scale (see Chapter 5, Figure 5-1).

New soil survey paradigm

Characterizing management effects on soil systems requires a new paradigm for soil survey. The paradigm focuses on soil properties that 1) change over time scales of centuries and decades, 2) are important for soil function, 3) reflect management effects as well as soil and vegetation dynamics, and 4) can be documented with measurements recorded at one point in time. The spatial variability of these properties is characterized at multiple scales. Implementing this paradigm requires specific data-collection strategies.

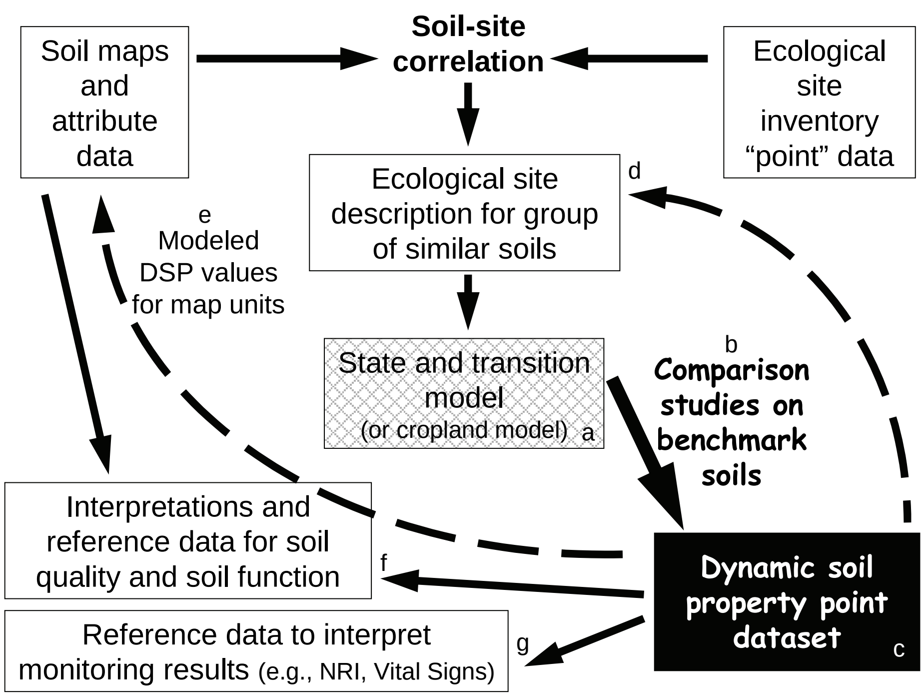
Comparison studies, the primary soil survey procedure described in this **Guide**, will be used to measure and infer soil and ecosystem changes resulting from natural and human factors for soil map unit component phases. In order to determine management effects and soil change over time, all comparison studies conducted according to this **Guide** will compare field sites with similar initial soil conditions and subsequent differences in disturbances or management. In most situations, data will be collected for systems that have achieved near steady-state conditions and will be used to interpret how the changes and departures from inherent or attainable conditions (see Chapter 5.4) affect soil function, resilience, and sustainability.

The comparison study can be supplemented with other sampling strategies. A comprehensive sampling strategy that uses a spatially unbiased sampling design to inventory soil property variability is described in Appendix 4. Short-interval monitoring methods that document fluctuations in soil properties, such as moisture content, are not currently in the **Guide** but could be added to future versions.

Soil survey updates and resource inventories

This **Guide** supplements existing soil survey procedures and is designed primarily for soil survey update activities. The procedures can also supplement inventory work for ecological site descriptions and Terrestrial Ecosystem Unit Inventories. These procedures can be used in benchmark soil-landscape studies or range and forestry inventory work not associated with a soil survey. On range and forest lands, integrated collection of soil and vegetation data is a key feature. The data collected through comparison studies will be used to populate a point data set, develop interpretations, develop ecological site descriptions, and serve as reference data for monitoring (Figure 1-1).

Figure 1-1. Relationships of Comparison Studies and Dynamic Soil Property Data to Ecological Sites, Soil Interpretations, and Monitoring Data. A simple conceptual model (a) is used to design comparison studies (b). Dynamic soil property data derived from these studies are used to populate a point dataset (c). The point data are then available to include in ecological site descriptions (d), model dynamic soil property values for similar soils (e), develop interpretations (f), and interpret monitoring data collected through programs (g), such as the Natural Resources Inventory (NRI), Vital Signs, and Forest Inventory and Analysis (FIA).



Not a monitoring guide

Protocols for monitoring resource conditions for decision-making purposes are not described in this **Guide.** Many of the measurement methods, however, are suitable for monitoring. Protocols and design for field monitoring programs are addressed in Herrick et al. (2005) and Elzinga et al. (1998).

1.2 Getting Ready

Before you start

Each person using this **Guide** needs a fundamental understanding of soil change concepts, the comparison study approach, and simple conceptual models of soil and vegetation dynamics. Soil change concepts are described in Chapter 5, “Interpreting Soil Change and Soil Function.” Key concepts include soil function, the human time scale, dynamic soil properties, and factors that cause soils to change (disturbances and stressors).

Measuring soil change requires a systematic approach, which is discussed in Chapter 2, “Measuring Soil and Ecosystem Change.” The comparison study technique and methods that overcome its limitations are described. This technique is contrasted with long-term monitoring and other techniques. Familiarity with the components of simple state-based conceptual models and the use of these models in comparison studies is a prerequisite for users of the **Guide**. Locate this information and frequently asked questions about comparison studies in Chapter 2.3.

Any concepts that are new to you will become more familiar and easier to apply after you get involved in a project. Additional resources available to you include the Glossary, the people of other disciplines who are participating in your project, cooperators, and agency specialists. The exhibits at the end of the chapters also provide supplemental information about topics discussed in the **Guide**.

Conducting a project

The **Guide** is organized to allow easy access to the information you need to plan and conduct a project. Once you have a basic understanding of the information provided in Chapters 5 and 2, you can begin your project. Proceed to Chapter 3, “Managing Comparison Studies.” This chapter describes required planning documents and the roles of a variety of discipline specialists and cooperators. Projects have six steps (Table 1-1). Refer to Chapter 3, Table 3-1, for a list of the specific tasks in each of the project steps.

When you are ready to prepare the workplan for your project, proceed to Chapter 4,“Planning and Conducting a Comparison Study.” Follow instructions for project Steps 1 through 3 in Chapter 4 and enter the necessary information in the Workplan Worksheet located in Appendix 1. Instructions for selecting sampling locations and collecting field data are in Chapter 4, Step 4. After the field work is complete, refer to instructions for data preparation, analysis, and reports in Steps 5 and 6.

Appendices include additional information needed to design a project and collect and analyze data. A procedure to determine sampling requirements and evaluate sampling adequacy is in Appendix 2. Standard methods, field data collection forms, and data entry sheets for interim storage are described in Appendix 3.

An important outcome of a project will be data that can be used to describe how soils change in response to management and disturbances. The reports and deliverables that can be developed for a project are described in Chapter 4, Step 6. The data will increase our ability to characterize, predict, and interpret management effects on the capacity of the soil to function for the intended use. Refer to Chapter 5.4 for a discussion of techniques that can be used to develop function-based and soil change interpretations.

Table 1-1. Project Steps.

Step	Project activity
1	Project Scope
2	Sampling Design
3	Sampling Requirements
4	Field Work
5	Data Preparation
6	Data Analysis and Reports

Chapter 2 Measuring Soil and Ecosystem Change

Figures

Exhibits

Chapter 2 Measuring Soil and Ecosystem Change

2.1 Comparison Studies

Comparison studies: method of choice for resource inventories
A number of systematic techniques can be used to document and provide information about soil change over the human time scale (Exhibit 2-1). For inventory work and soil survey, the comparison study approach has been selected for documenting the effects of anthropogenic and non-anthropogenic disturbances on soil over time.

As applied in this **Guide**, a comparison study is one in which two or more different management conditions on the same kind of soil are compared. Using the space-for-time substitution technique, the differences between a reference state and some other management system will be used to make inferences about how soils have changed over time. Similarities or differences among management systems can also be used to inform a simple conceptual model of cause and effect and quantify its state components (See Chapter 2.2).

The length of time that each condition has been in place will commonly be different. An example is a comparison study of a 150-year old forest stand and a stand planted 40 years ago. In some cases, the management systems to be compared will be the same “age.” For example, land-use effects of a 20-year old irrigated pasture may be compared to a 20-year old dry-farmed grain system.

Where available, long-term studies and research provide useful information that augments comparison studies (Pickett, 1989). They can be used to confirm trend, identify early warning indicators and mechanisms of change, and quantify rates and thresholds of change. For a catalogue of existing long-term soil ecosystem studies in your area and around the world, refer to http://ltse.env.duke.edu/

The same kind of soil
Soil map units are used to identify the same kind of soil. All similar soil phases of an individual soil map unit component (e.g., series) in one or more soil map units are considered the same kind of soil. In this **Guide**, the term representing the same kind of soil is “soil map unit component phase.”

Comparison studies versus monitoring

The comparison study approach meets soil survey needs primarily because of its efficiency and simplicity. Some constraints of long-term studies and monitoring are also overcome. In particular,

- The time required to document change is only as long as it takes to locate plots, collect samples and field measurements, and analyze the data. Waiting for decades to obtain results from long-term experiments or monitoring is not required.
- The inability of holding management constant into the future on privately owned land does not interfere with the outcome.
- The costly organizational support required for repeating observations over many years and for managing and controlling the quality of a monitoring program is unnecessary.
- Limited resources can be used to disperse numerous sample locations throughout the map unit rather than repeating data collection at the same location over many years. This approach provides information about the spatial variation across map units and not just temporal variation at a few selected locations.

Overcoming limitations of comparison studies

Comparison studies conducted according to this **Guide** evaluate change by substituting space for time. This is an important technique for documenting change through time as a part of inventory work, but there are limitations to the approach. Both space for time substitution techniques and comparison studies fail to distinguish the effects of space (differences in spatial variability) from time (differences in the history of the field site) (Pickett, 1989). They require an assumption that all locations were initially equal, something that is difficult to verify. In addition, variability owing to different historical legacies, including the kind and sequence of disturbances, practices, or management experienced at the sampling location, are commonly unknown.

Proper application of comparison studies is required to minimize the limitations of the approach (Pickett, 1989). The effects of differing initial soil conditions and spatial variability that may occur across the extent of the map unit are minimized by sampling a well defined soil map unit component phase and replicating data collection at multiple spatial scales. Thus, underlying variability in soil properties or starting conditions can be averaged for each state or management system.

Three conditions must be met to help manage the limitations.

1. Sample the same kind of soil but under different current conditions. Carefully verify sampling locations to ensure that each location is the same or similar soil map unit component phase.
2. Use a conceptual model that represents how soils change. Obtain a simple conceptual model that describes the management-affected dynamics for the particular soil that will be sampled. The model should describe what is currently understood or assumed about the causes and effects of change. Through space-

for-time substitution, states within the model will be compared to the state representing the reference or starting conditions. The results of the comparison will be used to make statements about how soils have changed over time in response to anthropogenic factors.

3. Incorporate knowledge of past management or conditions. Gather general information about land use legacies, such as prior land uses, by examining repeat aerial photography. Also gather information about management history over the last 10-20 years, if possible. The general nature of this information is not ideal, but it will help in interpreting data. Incorporate assumptions about the management history into the model.

2.2 Conceptual Models

Conceptual models

A conceptual model is a simple representation of reality that provides a mental picture of how something works (Starfield et al., 1993). Conceptual models help organize information and understanding and improve communication. State-based models provide a framework to help organize cause-and-affect relationships among management systems (states), natural stressors or disturbances, practices (anthropogenic stressors or disturbances), and dynamic soil properties. The importance of using a conceptual model to organize and control comparison studies cannot be understated. Without a conceptual model to consistently define a finite number of “states,” the numbers of possible conditions to sample would be unmanageable for inventory purposes.

Care should be used when a model is applied. If the model does not take into account important variables or fails to properly account for the impact of critical variables, conclusions may be incorrect. The model should be periodically evaluated to ensure that data are interpreted correctly. In some instances, it may be prudent to use data from a comparison study to modify the model or develop a new model.

Using conceptual models in comparison studies

In this **Guide**, state-based conceptual models are used to:

1. Stratify the map unit component phase into multiple states that can be randomly sampled;
2. Provide descriptions of states and state phases to help verify suitable sample locations in the field;
3. Describe relationships between soil and vegetation data;
4. Describe management effects on soil in cropland systems;
5. Describe management effects on soil and plant communities in rangeland and forested systems;
6. Provide management context to help interpret dynamic soil property data;
7. Facilitate data extension to similar soils;

8. Organize relationships among management, dynamic soil properties, and plant communities (where present), for the interpretation, storage, and delivery of data; and

9. Serve as a decision aid for conservation planning by illustrating alternative states and predicted soil responses to disturbances and practices.

State and transition models for rangeland and forest land

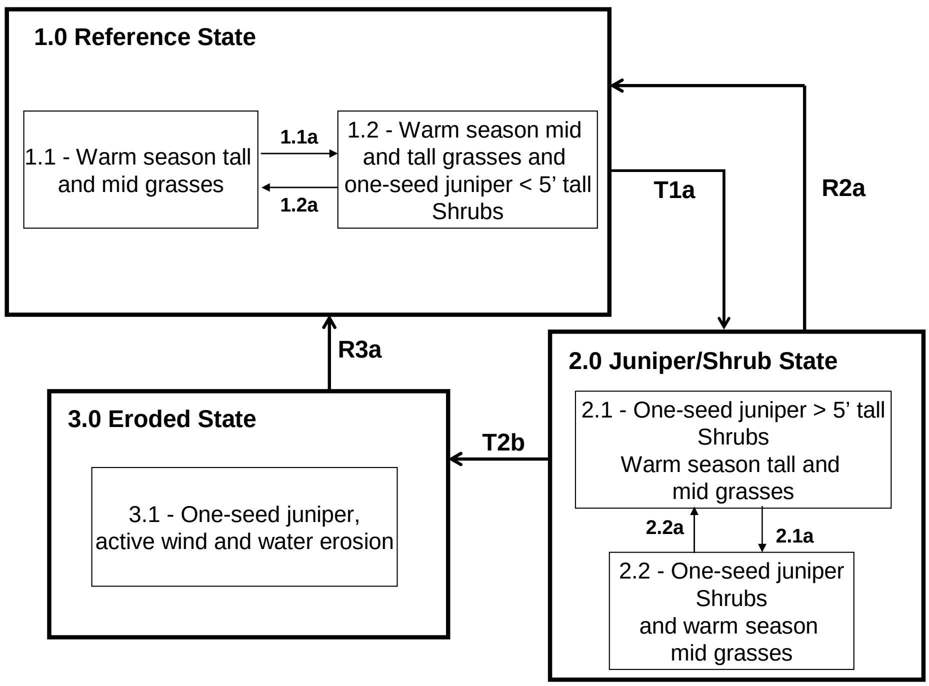
State and transition models as presented in ecological site descriptions are the primary kind of model used in comparison studies on range and forest lands. For more information, refer to the National Range and Pasture Handbook, Chapter 3, Section 1, Part 600.031(c) (USDA, 2003). These state and transition models (Westoby et al., 1989; Bestelmeyer et al., 2003; Stringham et al., 2003) are conceptual models of soil and vegetation dynamics. Each state and transition model synthesizes informal knowledge and information from the literature and is tied to a particular ecological site. See Figure 2-1and 2-2 for examples of state and transition models. Other conceptual models, such as those prepared for National Park Service (NPS) Vital Signs efforts, can be used provided that they describe soil and plant community dynamics of the map unit component phase that is sampled (http://science.nature.nps.gov/im/monitor/).

State and transition models describe our current understanding of ecosystem dynamics. Each state and transition model represents hypotheses about the causes of changes in soil and plant communities. The models describe states, plant communities within states, and transitions between states and communities. The transitions represent mechanisms, thresholds, and triggers of change, including management actions, which drive change. Easily reversible changes in soil and vegetation are described within each state. Transitions between states represent changes that are subject to thresholds beyond which reversal is costly or impossible. For the purposes of this **Guide**, plant communities within a state will be referred to as state phases (see Glossary).

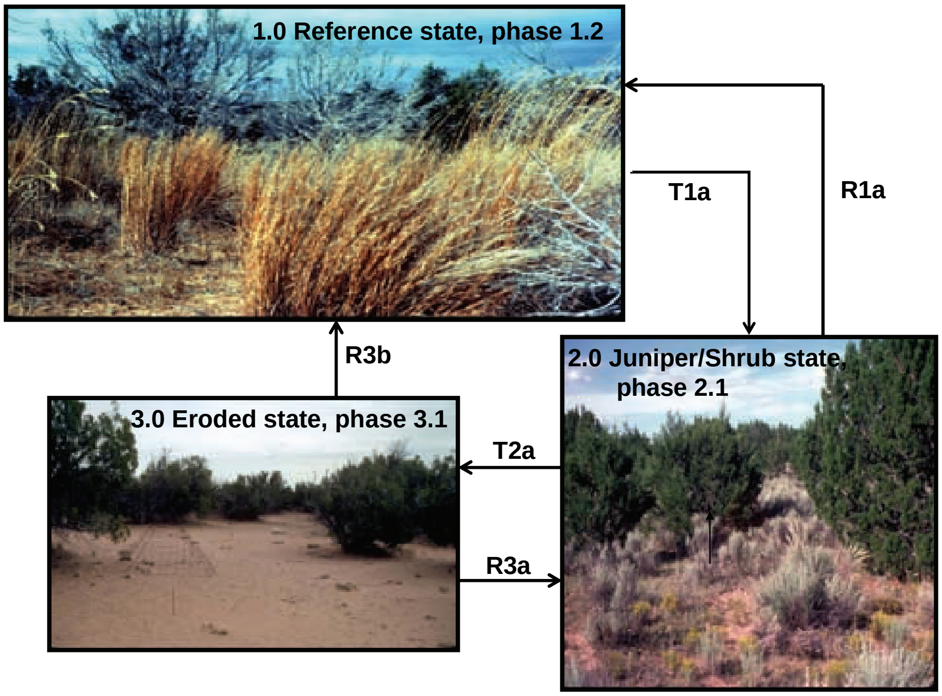
State and transition models describe the predicted responses of soil and plant communities to management-induced or natural disturbances. States and plant community phases (i.e., state phases) reflect the responses. Consequently, they can be used to present 1) management options of how to achieve or avoid change and 2) corresponding dynamic soil property information. State and transition models can also be used by researchers to develop new testable hypotheses that will improve the understanding of soil and vegetation change.

Figure 2-1. State and Transition Model and Legend for the Deep Sand Savanna Ecological Site in MLRA 70C. (G70CY123NM, personal communication, Pat Shaver). This model utilizes recent concepts for model descriptions as described in Briske et al., (2008). Figure a) includes all plant community phases, and b) is an example showing only one phase per state. The large numbered boxes represent states. The small boxes within the large boxes represent plant community phases. The arrows represent transitions, restoration pathways, and community pathways within a state. Refer to the legend for descriptions.

a)



b)



Legend for Deep Sand Savanna Ecological Site in MLRA 70C (G70CY123NM)

Reference state 1.0
Two community phases, 1.1 and 1.2, maintained by frequent fire (6 to 20 years) and weather fluctuations (drought and wet years).

> **Plant community indicators:** High perennial grass cover and production. Litter accumulation.
> **Feedbacks:** Organic matter inputs allow for increased soil moisture, production, root turnover, and litter, increasing soil surface stability.
> **At-risk community phase:** Either community phase is at risk when bare ground increases and organic matter inputs decline.

Alternative state 2
Juniper canopy cover controls the soil moisture, herbaceous production, and organic matter inputs. Management practices applied to maintain current canopy cover and herbaceous production. Manipulation of brush species and prescribed fire and grazing management planned to maintain or improve warm-season mid grass production.

Plant community indicators: Juniper canopy cover >15%, bare ground >35% and <50%.
Feedbacks: Juniper use of moisture, decreasing herbaceous production, decreasing organic matter inputs.
At-risk community phase: Either community phase is at risk if juniper seedlings increase and canopy cover increases.

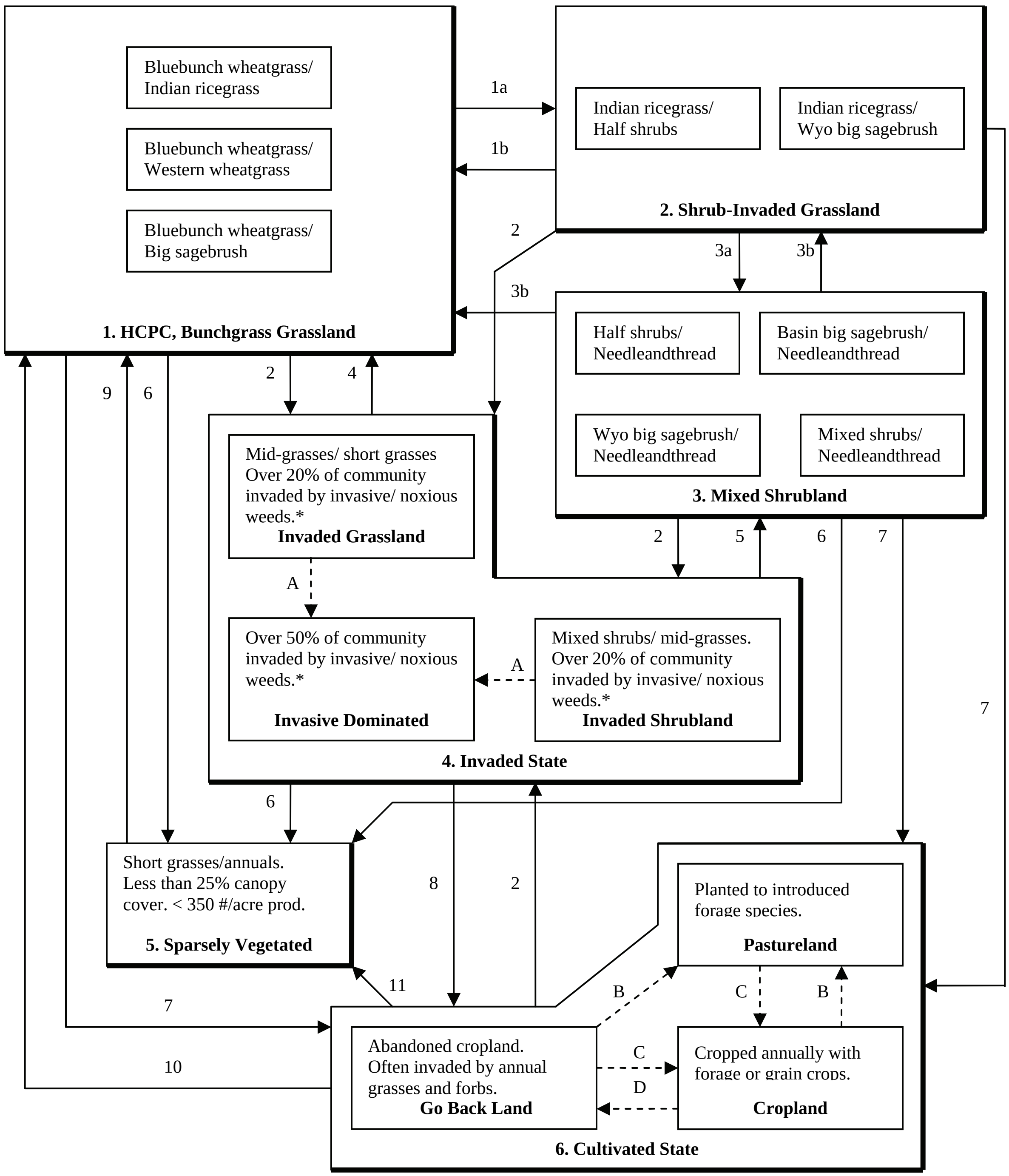
Alternative state 3
Active wind and water erosion taking place.
Plant community indicators: Juniper canopy closed, soil surface stability indicators <3.0, active wind and water erosion prevalent.
Feedbacks: Juniper use of all available moisture, eliminating organic matter inputs and causing decreased soil surface stability.

Community pathways
1.1a: Dry years followed by wet years or infrequent fire both allow juniper establishment.
1.2a: Frequent fire to remove juniper <1.5 m tall.
2.1a: Elimination of fire and increasing juniper canopy allow shrubs and tall grasses to decrease; dry years followed by wet years allow increase in juniper establishment.
2.2a: Prescribed burning or chemical or mechanical brush management; grazing management to increase herbaceous and shrub production.

Transitions
T1a: Trigger: elimination of fire and overgrazing. Threshold: increased bare ground amount not yet determined and increased juniper canopy to 15%.
T2a: Trigger: increased juniper seedling establishment and/or juniper canopy cover; decreased herbaceous production and decreased organic matter inputs into the soil. Threshold: bare ground >50% and soil surface stability <3.0

Restoration pathways
R2a: Reduction of juniper canopy cover to <5% with minimal soil surface disturbance and grazing management that favors herbaceous production and establishment.
R3a: Management and restoration with little or no soil surface disturbance to decrease juniper canopy to <5%; grazing management that increases herbaceous production, litter accumulation and soil organic matter to stabilize surface.

Figure 2-2. State and Transition Model and Legend for the Loamy Ecological Site in MLRA 43B. (R043BA032MT). The large numbered boxes represent states. The small boxes within the large boxes represent plant community phases. The solid-line arrows represent transitions and restoration pathways. The dashed-line arrows represent pathways within a state. Refer to the legend for a description of each arrow.



Legend for Loamy Ecological Site in MLRA 43B (R043BA032MT)
* Species composition based on dry-weight annual production.

A. Invasive tendencies of weeds coupled with lack of control or prevention measures.

B. Planting of introduced and/or native forage species.

C. Crop cultivation.

D. Cropland is abandoned, left idle.

1a. MFI (mean fire interval) 25-50 years, overgrazing (excess critical season grazing; excess intensity; repeated, long-term growing season defoliation), warming climate;
1b. MFI <25 years and treatment to reduce or remove shrub spp.

2. Introduction of weedy propagule with or without aid of overgrazing and/or fire.

3a. MFI >50 years for big sagebrush to reach full maturity, persistent reduction in grasses, competition by shrubs, overgrazing.
3b. MFI 25-50 years, treatment to reduce shrub spp.

4. Treatment to reduce/remove invasive/noxious spp.

5. Treatment to reduce/remove invasive/noxious spp. with special care given to not diminish shrubs.

6. Persistent reduction in grasses, competition by shrubs, erosion and soil truncation. Severe overgrazing and/or protracted drought conditions.

7. Plowing of native range for planting crops or introduced forage species.

8. Treatment to reduce/remove invasive/noxious spp. or plowing of the native range for planting crops or introduced forage spp.

9. Land rehabilitation, restoration/replacement of topsoil, shrub removal, grass seeding under favorable growing conditions.

10. Seeding of native species under favorable growing conditions. Subsequent multiple years of proper grazing and management.

11. Loss of topsoil from wind/water erosion due to poor farming practices or overgrazing and/or drought.

Soil degradation and transitions

Some transitions involve soil degradation. Soil degradation can be physical (e.g., erosion, compaction, crusting, and structural degradation), chemical (e.g., salinization, and toxification with heavy metals), biological (e.g., depletion of soil organic matter and decline in diversity and abundance of soil biota), or mineralogical (e.g., oxidation of sulfidic soil materials). Knowledge of the type of degradation (see Chapter 5.3 for a full discussion of types and causes of soil degradation) can give insight into the ecological processes and soil functions that need repair and thus the treatment needed to achieve recovery. Information about the severity of degradation and the appropriate restoration practices can be used to gauge the reversibility of the transition. For example, an eroded state is commonly more difficult to restore than one that has surface crusting. With knowledge of the type of soil degradation, the dynamic soil properties that reflect the type of soil degradation can be identified and included in a project.

Conceptual models for cropland and pastureland

Note: A summary of one approach to create models for cropland and pastureland is provided here. The procedure for classifying cropland management systems is under development and will be evaluated through a pilot study. It is subject to revision or replacement.

Groups of similar management systems will be created and used to identify multiple alternative cropland systems that could be sampled. Primary management practices that affect the additions and losses of soil organic matter will be the basis for classifying and grouping cropland management systems. The type and intensity of tillage as well as the crop rotation will be included. The prototype system uses a STIR-based tillage classification and the RUSLE2 SCI OM maintenance sub-factor. The stresses or transitions that drive one management system to another will also be described. Using current knowledge, multiple cropland management systems and the effects of management on the soils will be presented in a simple conceptual model. The objective is to develop conceptual models for similar soils within crop management zones. A number of models will be needed in each crop management zone.

2.3 Frequently Asked Questions About Comparison Studies

How do comparison studies relate to other soil survey conventions for soil change?

In soil survey, there are four conventions for measuring soil change (Figure 2.3). Soil change reflecting past management has been traditionally addressed through classification (I) and phase distinctions (II) that represent various degrees of change in soil morphology, soil chemistry, hydrology, and behavior. Repeat measurements through short-interval monitoring (IV) have also been conducted to reflect seasonal variation in soil properties, such as average monthly water table depth. The new convention presented in this **Guide** uses conceptual models of change (III) that relate dynamic soil properties to various management regimes, ecological states, or plant community phases of soil map unit component phases. The three traditional conventions and a new one for documenting soil change are summarized below.

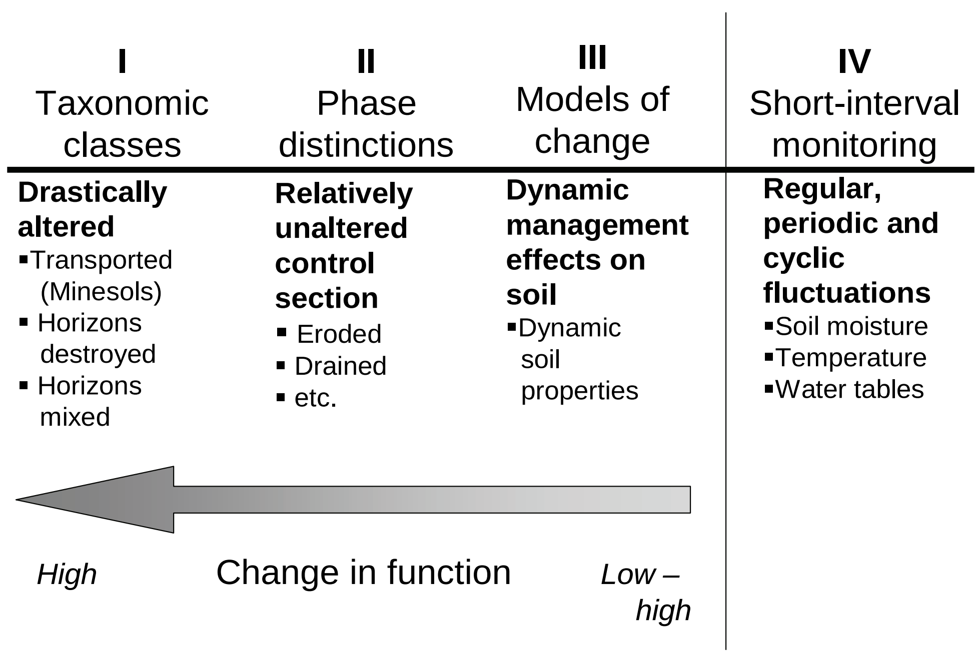
I. Taxonomic classes. Soils are reclassified when diagnostic horizons or features important to the use and identification of the soils have been removed or destroyed (e.g., Arents). Existing classification paradigms apply use-neutral criteria that specifically avoid reclassification on the basis of soil properties that change in response to management (e.g., a cultivated soil with mixing in the surface layer can be classified the same as its uncultivated counterpart).

II. Phase distinctions. Phases are created for soil that 1) has been altered by management and 2) is relatively unaltered in the control section (e.g., drained, eroded).

III. Models of change. The dynamic effects of management on soil are presented in conceptual models of change. State and transition models on range and forest lands are examples. Cropland systems can also be represented in simple models of the effects of management practices.

IV. Short-interval monitoring. Regular, periodic, and cyclic fluctuations in soil properties are determined with regular measurements recorded at set intervals over time (e.g. soil water table depth).

Figure 2-3. Soil Inventory Conventions for Soil Change. Changes in morphology and function are commonly high in category I. Change in function is, by definition, high to moderate in category II. In category III, management effects on soil function may be low to high in response to changes in dynamic soil surface properties, such as soil organic matter, aggregate stability, and moisture content.



What does a comparison study look like?
An individual project is conducted for an important or extensive soil (benchmark soil) within an important ecological site (benchmark ecological site) or crop management zone. Two or more management systems or plant communities are sampled according to the **Guide**. Projects may also include the associated soils in a catena. Data are collected to document the central tendency and range of variability in dynamic soil properties and vegetation characteristics (where present) within a soil map unit component phase. The variability within management systems or plant communities that occurs on a specific soil map unit component phase is determined through replicate sampling. Projects include multiple plots. Multiple samples and field measurements are collected from each plot to characterize soil properties and vegetation characteristics. Data for each management system that is sampled are summarized and compared. Summary reports are developed for each project.

How do comparison studies relate to ecological site inventory procedures?
Data collection procedures for ecological site inventory vary in intensity and detail of observations recorded. Three levels of intensity can be recognized (Bestelmeyer et al., in review):

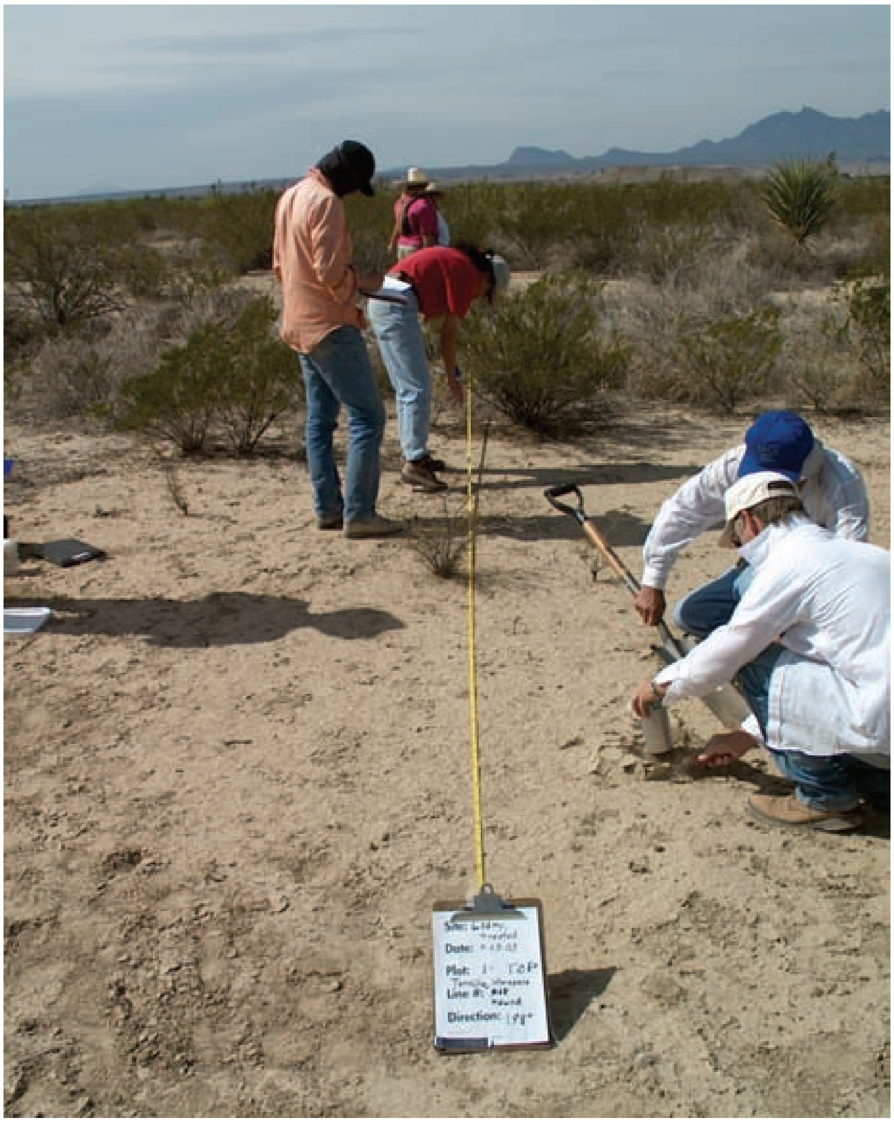
- Low-intensity traverses to explore and record relationships among plant communities, landforms, land uses, and soils within a climatic zone;
- Medium-intensity inventory of georeferenced locations, including broad transects to quantify and describe vegetation and soils within plant communities, ecological sites, and soil map units; and
- High-intensity data collection using stratified random sampling to establish characteristic values for the inherent (reference) state or other attainable states where state concepts have been proposed or defined in the state and transition model.

Initial work for map unit design is part of the low-intensity procedures. Transects for map unit design and composition are part of the medium-intensity work. Comparison studies to document dynamic soil properties for soil survey, benchmark soils, and ecological inventories are the high-intensity procedures.

Why are soil and vegetation data collected together?
Integrated soil and vegetation data collection meets multiple program objectives, thereby increasing efficiency. It also improves the quality of information. Both soil inventories and vegetation inventories require verification of the corresponding soil or plant community at the data collection site to ensure correct interpretation of the data. Integrated data collection meets this goal. From the perspective of soil inventory, plant community data provide context for interpreting dynamic soil property data. Through use of information from the same plot, soil-plant relationships can be clearly established for soil-site correlation requirements. In addition, the relationships between patterns, processes, and dynamic soil and vegetation properties can be established to support predictions of soil change. This information will improve existing interpretations, provide

data for ecological site descriptions, and allow the development of new interpretations for soil map units and ecological sites.

Figure 2-4. Interdisciplinary Crews Collect Soil Samples and Vegetation Data for the Same Plot at the Same Time.



What are the benefits of comparison studies?

- Information about how soils change in response to management and disturbances is a value-added product of soil survey updates and ecological inventories.
- Point data are available for such uses as model calibration and research.

- Colocating soil and plant community data overcomes problems of interpreting soil-plant relationships where corresponding soil or plant community data are not available.
- Projects can be designed in response to important resource issues, such as altered soil hydrology after land use conversion.
- Collaboration by soil scientists, range specialists, foresters, agronomists, and biologists enhances skills and knowledge for improved conservation assistance and technical soil services.
- Experiences in data collection will help refine or expand this **Guide**.
- Multiagency projects strengthen partnerships and bring together collaborators for improved technology development, training, and research.

How large is the study area of a project?
The study area should be as large as possible but not so large that environmental factors, such as precipitation or temperature, are broader than the concept for the soil map unit component phase or ecological site. Ideally, the project extends across all polygons of the selected map unit(s). Statistical inferences from the project data can be made only for locations within the study area.

Why collect replicate data?
Soil and vegetation properties can be highly variable at one or more different scales. They can vary throughout the extent of the soil map unit component, according to landform component, and across distances of a few meters. For simplicity, two levels of replication are included in the protocols in this **Guide**. Replication of plots captures the variability of properties across the landscape, and collection of multiple samples within a plot captures the variability of properties within plots. By increasing replications, study increases the proportion of possible situations sampled within a soil map unit component phase. Replicate sampling is necessary in order to provide data that meet acceptable levels of certainty and to obtain an estimate of error (certainty of the mean). Small numbers of samples can produce results that are not accurate or precise enough to meet user needs (Figure 2-5). Replication also allows project data to be tested for statistical differences between state phases or management systems.

Figure 2-5. Illustration of the Effect of Numbers of Replicate Samples Within One Plot on the Dispersion of Sample Values and the Plot Mean From a Study of Infiltration. As the number of samples increases, the mean estimate becomes more accurate (as illustrated by small changes in the mean with additional sampling). The mean also becomes more precise (as illustrated by narrowing of the standard error of the mean with additional sampling). Increasing the number of replicates also better captures the full range of values for the infiltration rate within this plot. The dashed line and “x” represent plot mean; solid lines are at +/- one standard error (SE) from the mean. (Source: unpublished data for Yucca taxadjunct, loamy fine sand, plot 5, Dona Ana Co., NM.)

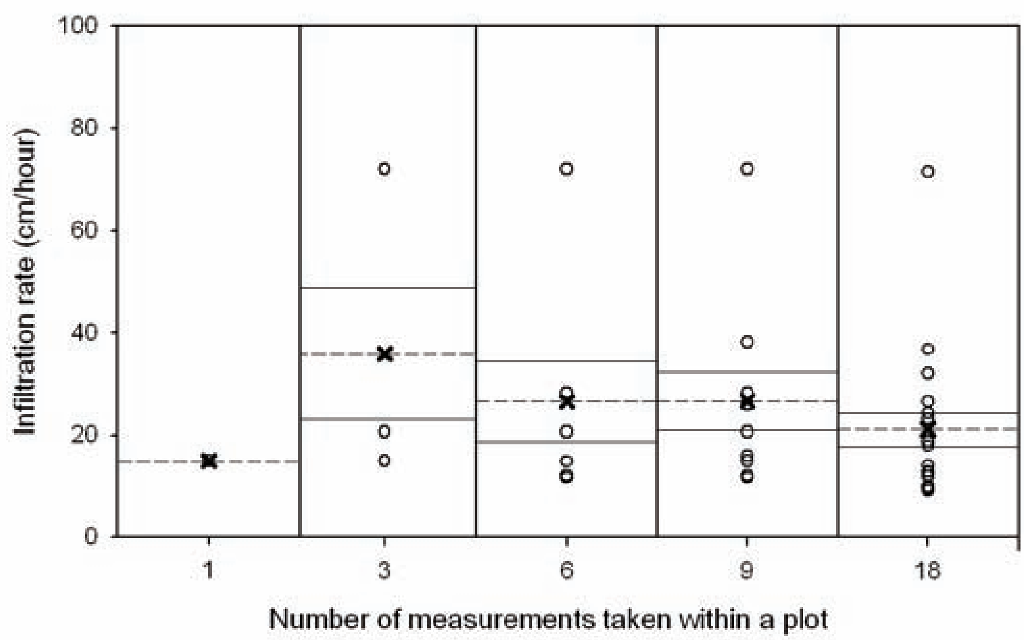


Exhibit 2-1. A Summary of Techniques for Documenting Soil Change

Following procedures in this **Guide**, comparison studies of two or more different management systems place sample sites on the same kind of soil. They allow the length of time that each management system has been in place to differ, although “time” may be the same in some cases, such as comparisons of different land uses. Other techniques for documenting soil change include chronosequence studies (studies that compare management systems of different “ages” are also called space-for-time studies), short- and long-term experiments, long-term monitoring, short-interval monitoring, and repeated soil surveys (Richter et al., 2007). These techniques, as well as space-for-time studies, are described below.

Chronosequence studies. Chronosequence studies differ from comparison studies (Richter and Markewitz, 2001). Chronosequence studies following the State Factor Analysis approach hold all soil-forming factors equal, except for time (Jenny, 1961). Traditional chronosequence studies evaluate soil profile development over time by comparing different soils on similar deposits or landforms but of different pedogenic ages (Birkeland, 1999). The near impossibility of ensuring that all soil-forming factors except for time are equal is a limitation of this type of study (Buol et al., 1997). For example, in most chronosequence studies, the staggered onset of soil formation among the sites of differing ages is a concern because climate is most likely not constant (Stevens and Walker, 1970). For chronosequence studies where the offset time between sites is short, the climatic variations are assumed to be ineffective (Yaalon, 1975). In comparison studies that follow this **Guide**, the kind of soil is the same, management systems are not equal, and differences in time since initiation of new conditions is relatively short. These characteristics all differ from the characteristics of chronosequence studies of soil genesis. A modified approach of the chronosequence study that 1) holds climate and the kind of soil equal and 2) studies separate locations with identical management systems but different “ages” would be similar to a comparison study as described in this **Guide**.

Space-for-time studies. Space-for-time studies evaluate trend by examining field sites of different ages (Pickett, 1989). Space-for-time substitution is commonly used in ecological studies to evaluate plant succession over time. In some, but not all, space-for-time studies, the kind of soil at all locations is the same. Space-for-time substitution has limitations that ecologists have attempted to overcome (Pickett, 1989). Strict application of this technique requires that 1) climate, soils, and historical factors are equal and 2) a model accounting for the operational environment, such as management effects on succession or soil productivity, is available to describe assumptions about past management. These requirements also apply to comparison studies of soil map unit component phases. According to the procedures in this **Guide**, variation in climatic features (e.g., mean annual precipitation and air temperature) is allowed as defined for a particular kind of soil.

Long-term experiments. A long-term study is research conducted to determine the long-term effects of a variety of treatments, such as practices or disturbances, by making periodic measurements on established plots (Richter et al., 2007). Initiated in 1856, the Park Grass study in Rothamsted, England, is an example (Tilman et al., 1994). For information on designing long-term studies to document soil change, refer to *Understanding Soil Change: Soil Sustainability over Millenia, Centuries, and Decades* (Richter and Markewitz, 2001).

Long-term monitoring. Long-term monitoring can be designed for many objectives. For example, land managers and conservation agencies, both private and federal, are interested in monitoring to 1) report changes in the condition of the land; 2) document the effects of newly applied practices; or 3) provide early warning signs of degradation. Monitoring to meet the objectives related to resource condition requires specific procedures that differ somewhat from those presented in this **Guide**. For information on how to monitor in support of resource decision making, refer to *Measuring and Monitoring Plant Populations* (Elzinga et al., 1998), *Environmental Monitoring* (G.B. Wiersma, ed., 2004), *Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems* (Herrick et al., 2005), and *Sampling for Natural Resource Monitoring* (de Gruitjter et al., 2006). Examples of natural resources monitoring programs include the NRCS Natural Resources Inventory (http://www.nrcs.usda.gov/technical/NRI/), the National Park Service Vital Signs Monitoring Program (http://science.nature.nps.gov/im/monitor/index.cfm), and the Forest Service National Forest Health Monitoring Program (http://fhm.fs.fed.us/index.shtm).

Short-interval monitoring. Short-interval monitoring is conducted to document fluctuations in soil properties, such as redox potential, microbial respiration, and soil moisture content. Monitoring intervals are commonly hours, days, months, or seasons, or the monitoring can be continuous. In soil survey, some types of soil properties require that a series of measurements over a number of years be used in calculation of an average value. For example, soil temperature and water tables are often “monitored” monthly or continuously over a period of a few to many years to determine mean annual soil temperature or mean monthly water table depth. Procedures for short-interval monitoring are not covered in this version of the **Guide**.

Chapter 3 Managing Comparison Studies

Tables

Chapter 3 Managing Comparison Studies

3.1 Project Steps

Managing a project

Comparison studies of dynamic soil properties are managed as projects. This approach facilitates planning and data interpretation. Plots sampled as a part of the same study will be used to determine property averages and variability for the conditions sampled. In the future, non project protocols may be developed when more is understood about the year-to-year variability of dynamic soil properties.

Comparison study project steps

Projects are comprised of six primary steps, which include Project Scope, Sampling Design, Sampling Requirements, Field Work, Data Preparation, and Data Analysis and Reports. Following this systematic approach is important. It promotes efficiency, an effective project, and high-quality data that can be used to generate useful interpretations. The tasks in each step are listed in Table 3-1 and described in this **Guide**.

Table 3-1 Tasks Within the Six Project Steps of Dynamic Soil Properties Studies. The project steps and tasks are listed in approximate order, although most are iterative.

Project Step	Tasks
1 Project Scope	1. Establish Project Objectives 2. Identify Cooperators and Project Personnel 3. Select Soils and Ecological Sites or Crop Management Zones to Sample 4. Gather Available Data, Information, and Imagery
2 Sampling Design	1. Review Elements of the Sampling Design 2. Select State Phases or Management Systems 3. Select the Soil Map Unit Component Phase 4. Estimate Sources of Spatial Variability 5. Select Soil and Vegetation Properties 6. Select Standard Methods and Laboratory Services*
3 Sampling Requirements	1. Use Statistically-Based Sampling Requirements 2. Determine Plot Type, Size, and Elements 3. Determine Sample Position and Numbers of Samples 4. Assign Sample Identification Numbers

4	**Field Work**	1. Locate Plots; Verify Soil and State Phase or Management System 2. Collect Data, Samples, and Management Information
5	**Data Preparation**	1. Enter and Error Check Raw Field Data; Merge Field and Laboratory Data 2. Make Necessary Calculations
6	**Data Analysis and Reports**	1. Data Analysis Overview 2. Summarize the Data 3. Evaluate the Data 4. Evaluate the Sampling Sufficiency 5. Test for Differences Using Statistics 6. Look for Differences Using Other Techniques 7. Develop Reports

* For NRCS projects, request NSSL laboratory assistance.

Project duration

Data collection for a project should extend over a period of no more than a few years to ensure comparability of the data. Depending on the number of staff available, data collection for all plots within a project can be completed within a few weeks or months. If large numbers of plots are to be sampled, it may be desirable to spread the sampling workload over a period of a few years. The temporal variation in soil properties over periods of a few years can be minimized by following two rules: 1) select plots with management systems that have been in place long enough to attain steady-state conditions (see Chapter 4, Step 2, Figure 4.2-1)) and 2) include dynamic soil properties that have characteristic response times of 5 to 10 years or more (see Exhibit 5-2). If extreme weather events occur during a project, consider these when summarizing and interpreting the data. If knowledge of the temporal variation from year to year is desired, specific plots may be sampled repeatedly over numerous years (monitored), but summary of this data may require different parameters in statistical tests. Consult with cooperators or National Soil Survey Center (NSSC) staff for assistance on the collection, summarization, and interpretation of monitoring data.

3.2 Project Participants

Include multiple disciplines and cooperators

Both soil scientists and discipline specialists are needed to help plan a project and collect and interpret data. An interdisciplinary sampling crew is needed for projects on range, pasture, forest, and wild lands. An agronomist or conservationist can provide valuable management information for plot selection and data interpretation on cropland. The minimum crew consists of two soil scientists and an appropriate discipline specialist. The ideal size of the sampling crew depends on the methods used and the number of samples to be collected. In some cases, a vegetation crew of two or three may be helpful. Adequate personnel should be available to complete sampling of at least one plot per day. Collaborators from the National Cooperative Soil Survey, universities, and the USDA Agricultural Research Service may be able to provide staff to assist with projects.

3.3 Project Planning Documents

Prepare a Project Outline

Prepare a Project Outline for each project. The Project Outline can serve as a project proposal. It should be brief and emphasize what will be done, not how. The Project Outline is required by the National Soil Survey Center when requests for laboratory and other assistance are made. Follow the standard Project Outline provided by the NSSL (Appendix 1.2). For guidance, review Chapter 4, Step 1, Project Scope; Step 2, Sampling Design; Step 3, Sampling Requirements; and Step 4, Field Work.

Prepare a project workplan

After the Project Outline is completed and the project is approved, begin developing the Workplan Worksheet (Appendix 1.3). The completed Workplan Worksheet and the Project Outline serve as the workplan. Prepare one for each project. The Workplan Worksheet is essentially an expanded version of the Project Outline and is developed as the details of the project are determined. Use the Workplan Worksheet to record information about the project area and decisions concerning where, what, when, and how to sample and the number of samples. Also document laboratory selections, equipment needs, and collaborator roles. For guidance and instructions, review Chapter 4, Step 1, Project Scope; Step 2, Sampling Design; Step 3, Sampling Requirements; Step 4, Field Work; and Appendix 3, Methods, Field Forms, and Data Entry Sheets. Use the tools described in Appendix 2 (including Excel worksheets) to calculate sampling requirements. General information about work plans is described in NSSH 631.05.

The Workplan Worksheet should be developed with input from partners. The record of decisions will serve as a reference to ensure that the sampling design is followed during Step 4, Field Work. Modifications required during sampling should be added to the Workplan Worksheet after sampling is complete. The Workplan Worksheet is also designed to provide information helpful in answering questions that may arise during Step 5, Data Preparation, and Step 6, Data Analysis and Reports.

Chapter 4 Planning and Conducting a Comparison Study

Step 1 Project Scope

Step 1 Project Scope

4.1.1 Establish Project Objectives

Overarching objectives
With respect to soil change, the overarching soil survey objectives are to inventory and predict soil change over the human time scale, determine the mechanisms, and interpret the consequences of those changes. Information about management effects on dynamic soil properties is needed to address these objectives. The results of individual projects along with other data and research will be used to help build knowledge and awareness of soil change and its consequences. Keep these soil survey objectives in mind throughout the project.

Describe project scope and objectives
The first step in project planning is to establish the objectives. Begin by holding discussions with collaborators about comparison study procedures, potential objectives, and deliverables. Information in Chapter 2.2, Frequently Asked Questions about Comparison Studies, can be help with the initial planning. A primary challenge will be to keep the projects small and manageable. Given limited time and resources, it is unlikely that all states and state phases or management systems that occur on the selected soil map unit component phase will be sampled in a project. At a minimum, two state phases or management systems will be sampled (see Chapter 4, Step 2.2, for specific instructions). Throughout the planning process, record project decisions on the Workplan Worksheet. Begin by entering basic information about the scope of the project, including the project name and the collaborating agencies, on the Workplan Worksheet: Item 1. Continue to develop the workplan by following instructions in Steps 1, 2, 3, and 4 of this chapter.

The primary objective of a project is to gain information about the effects of management on soil over the human time scale. Measurements of dynamic soil properties at (or near) steady-state conditions will be used to determine and interpret how the changes and their departure from inherent or attainable conditions affect soil function, resilience, and sustainability. Projects should relate to local resource management issues that are affected by changes in dynamic soil properties. These issues include, but are not limited to, the following: productivity, sustainability, nutrient management, carbon sequestration, soil, water or air quality, water quantity, human or animal health, ecosystem function, and invasive species. Briefly state the project objectives with respect to the effects of management on soil change and identify the resource management issues that relate to the project. For example, *"The primary objective is to document soil properties on ash-capped soils in Northern Idaho that have changed as a result of forest management practices over the last century. Vegetation data will be gathered to provide context for interpreting the soil data and to develop ecological site descriptions. Resource concerns* *addressed by this project include soil quality and long-term soil productivity."* Record this information on the Project Outline and Workplan Worksheet: Item 2.

Describe project deliverables
For those soils and properties that are sampled, a summary report of dynamic soil and vegetation properties will be provided for states and state phases (e.g., plant communities or management systems). The report will include summary statistics describing the central tendency and variability of the properties measured. These data can be used to evaluate sampling sufficiency, determine differences among state phases or management systems, describe change over time, and develop interpretations. Project reports and deliverables are discussed in detail in Chapter 4, Step 6. Describe any additional deliverables on the Workplan Worksheet: Item 3.

If large numbers of samples are collected at multiple scales, the data can be used in other ways. They can be used to develop new specific sampling requirements for similar soils and management systems. Large data sets can be examined for relationships between the dynamic soil properties and the plant community or crop management systems (e.g., soil organic matter content of the surface layer is 1.5 times greater for no-till systems than conventional systems on the specified soil). Procedures beyond those provided in this **Guide** may be needed to examine these kinds of relationships.

4.1.2 Identify Cooperators and Project Personnel

Cooperator participation
Cooperators and discipline specialists can provide valuable assistance throughout a project. Collaborators can contribute expertise, resources, and personnel. Cooperators may have access to laboratory services and data. To the extent possible, cooperator needs with respect to dynamic soil properties and related products should be addressed. Basic needs for soil survey include dynamic soil property data used in the development of soil interpretations and ecological site descriptions. Other cooperator needs should be identified to help focus project objectives and sampling design. If there are a number of interested cooperators, a scoping meeting can be held to refine project objectives and identify collaborator roles.

Identify cooperators and describe their roles on the Project Outline. As more details become available about specific project personnel, add this information to the Workplan Worksheet: Item 28.

Project supplements
Some cooperator needs may actually be questions (or hypotheses to be tested) that require a research design beyond the scope of the procedures in this **Guide.** Experiments involving manipulations and controlled treatments are examples. Partners may be able to meet these needs by conducting research as a supplement to the comparison study

project. Examples of questions that are not addressed by the procedures in this **Guide** include:

- What are root-limiting bulk densities of soils with high amounts of volcanic ash?
- How well do visual indicators relate to measured values?
- What is the best time of year for measuring active soil carbon?
- What causes the decline in productivity?
- How many years of cultivation are required to form a plowpan?

4.1.3 Select Soils and Ecological Sites or Crop Management Zones to Sample

Select soils and ecological sites to sample
Most projects will include one soil. The ultimate goal is to sample two or more states or management systems within the same ecological site or crop management zone on the same soil map unit component phase. When selecting soils to include in a project, place an emphasis on those that can provide inferences for similar soils. Benchmark soils (NSSH 630.02) and benchmark ecological site descriptions are good candidates. If staff and funds are available, select multiple components in a complex, association, or catena to aid in the development of landscape-scale interpretations. With respect to soil maps, the procedures in this **Guide** apply specifically to phases of series. In areas mapped with phases of higher taxonomic units, the procedures may apply if the same kind of soil can be located for sampling, but caution should be used.

The suggested criteria for suitable soils and ecological sites include:

- Represent extensive kinds of soils, ecological sites, or crop regions.
- Include soil or vegetation dynamics that relate to priority resource issues.
- Represent soils that support important specialty crops or critical ecological zones.
- Support at least two contrasting land uses, plant communities, or management systems.
- Have information on land use, including estimates of presettlement conditions and length of time under current management systems.
- Select a wide area.
- Select soils that have similar morphology, even though they may classify differently. For example, include soils that have a Mazama ash mantle of at least 12 inches and are moderately deep to a fragipan. Possible series include Kauder, Threebear, and Helmer, which have slightly different ash mantle thicknesses.

Use resources suggested in Chapter 4, Step 1.4, to guide selections. Where possible, comparison studies should be conducted on soils for which long-term study data are available. Record the soil and ecological site selected for the project on the Workplan Worksheet: Items 4 and 5. If relevant, the forest habitat type should be entered on the Workplan Worksheet: Item 6. Although of limited availability, long-term study data are helpful in interpreting results and understanding rate of change. Long-term soil ecosystem studies from around the world are catalogued online (http://ltse.env.duke.edu/). Refer to this site for information about existing data.

Identify location of project
After the soil and ecological site have been selected, record information about the location of the study area on the Workplan Worksheet: Item 7. Enter the Major Land Resource Area (MLRA) and the Common Resource Area (CRA), crop management zone, or other appropriate agency designations. Provide State and county names and their corresponding Federal Information Processing Standards (FIPS) codes. Also provide soil survey area names and symbols as well as information about the soil survey update status.

4.1.4 Gather Available Data, Information, and Imagery

Obtain existing information and data
Existing information related to the project objectives and study area should be evaluated and used to help select soils and ecological sites or crop management zones, prepare the sampling design, and interpret project results. Basic information includes SSURGO (or STATSGO) soil data, digital elevation models, Landsat or ASTER imagery (multiple dates), temperature and precipitation data (PRISM, weather station, etc.), and surficial or bedrock geology maps. Knowledge of historical land uses is helpful for interpreting changes in soil and vegetation. Requirements for cropland management information are discussed in Chapter 4, Step 4.1 and 4.2. Probable sources of information about historic ranges of variability for the selected or similar soils and ecological sites include:

- Soil laboratory data
- Ecological site descriptions
- Recent and old imagery of the study area for documenting vegetation and land use changes
- Repeat photography for multiple years to show vegetation or land use changes
- Historical land use information (recorded, expert knowledge, or anecdotal)
- Maps of existing and historical vegetation
- Published and unpublished literature on soils and vegetation of the study area
- Long-term study reports
- Studies on soil property variability
- Interviews of persons knowledgeable in history, culture, archaeology, settlement, and traditions

Review ecological site needs
On range and forest lands, the state and transition model for the ecological site will provide a road map serving a number of purposes. It will be used to help verify suitable sample locations in the field and explain the effects of management. It can also be used to develop testable hypotheses for data analyses. Review the state and transition model of the ecological site description for each soil under consideration to ensure that it includes proper information about soil degradation in the transitions (see Chapters 2.2 and 5.3),

and update it if necessary. If a state and transition model does not exist, work with the appropriate discipline specialist (range, forestry, pasture management, or agronomy) to prepare one prior to completing the design of the project. These specialists have expertise in the development and use of ecological site descriptions and should be included in project planning and implementation. Instructions for ecological site descriptions are in the NRCS National Range and Pasture Handbook (available online at http://www.glti.nrcs.usda.gov/technical/publications/nrph.html) and the NRCS National Forestry Handbook (available online at http://soils.usda.gov/technical/nfhandbook/).

In some cases, soil-site correlations may be in question. All soils correlated to an ecological site are presumed to respond in a similar manner to similar disturbances. Procedures in this **Guide** can be used to test this hypothesis by sampling a number of soil phases correlated to a single ecological site. If differences in dynamic soil properties or plant community data reflect differences in function, the soil-site correlation should be reevaluated.

Review crop management zone model needs

To be developed.

Chapter 4 Planning and Conducting a Comparison Study

Step 2 Sampling Design

Figures

Tables

Exhibits

Step 2 Sampling Design

4.2.1 Review Elements of the Sampling Design

Purpose and content of the sampling design
The sampling design describes the details of a project so that project objectives can be met. It includes the following information:

1. State phases or management systems
2. Soil map unit component phase
3. Sources of variability
4. Minimum, supplemental, and experimental properties
5. Time of year to sample
6. Methods
7. Sampling depths
8. Sampling requirements (see Chapter 4, Step 3)

The project objectives and the selected soil and ecological site or crop management zone are needed in the development of the sampling design. Record these on the Workplan Worksheet before proceeding with this project step. Then follow the instructions in this section and enter decisions on the Workplan Worksheet.

4.2.2 Select State Phases or Management Systems

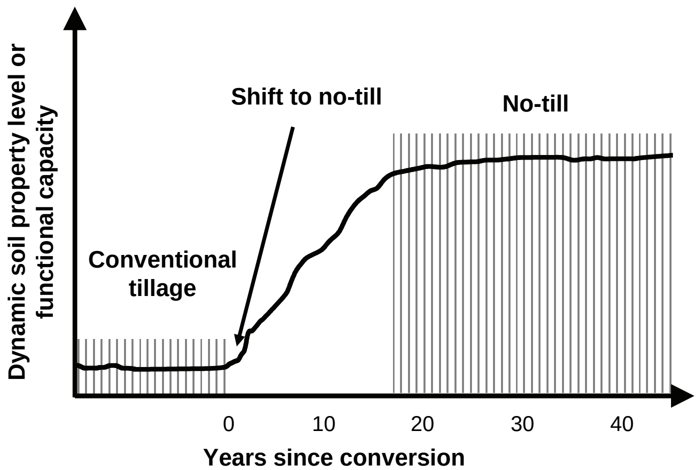
Select the ecological states and state phases to sample
Refer to the state and transition model or cropland model for information about states, state phases, and management systems that could be included in a project. Select the state phases or management systems prior to selecting plot locations, and record them on the Workplan Worksheet: Item 8. Depending on the objectives and resources for sampling, include two or more ecological states or management systems in the project. For range and forest lands, the primary focus will be on characterizing the reference state as identified in the ecological site description. Select one state phase (plant community) from within the reference state for sampling. For comparison purposes, the second state phase should be selected from a different state. If the reference state or an attainable state cannot be determined, states that represent extremes in condition should be sampled. Plant communities of minor extent can be selected if replicate plots can be located. If the minor community is of particular interest or is considered a reference area, a relict area, or a good representation of the historic plant community, then including these nonextensive areas in the project is recommended.

Select cropland and pastureland management systems to sample
Once the primary crop management systems in a cropland zone are defined, the systems become the pool of management systems that could be selected for a project. Record the management system to be sampled on the Workplan Worksheet: Item 8. For cropland, management systems that represent good and poor soil-building systems should be selected. Include at least two. Ideally, soil property data gathered for the two selected management systems should contribute information related to priority resource management issues.

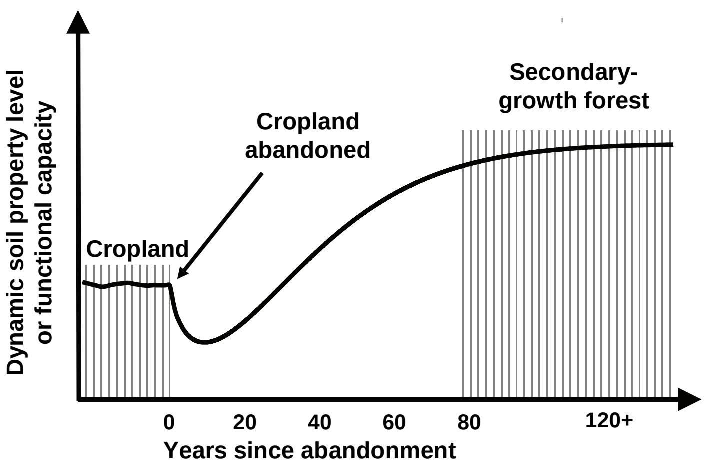
Guidance on when (what) to sample after a change in management
In addition to selection of the type of management system or plant community to sample, the length of time since management has changed is an important consideration. Because comparison studies will be used to document conditions that are possible or attainable, sampling should be conducted on fields, pastures, or stands that are as near to steady-state conditions as possible. Steady-state conditions include natural variation resulting from short-term seasonal and daily fluctuations, but conditions should not be trending in one direction over time. The time required to reach steady-state conditions varies by state phase and management system. While no single recommendation can accurately identify "when" a system is ready to sample, some general guidelines can be provided. For cropland, sample 15-20 years or more after a shift in management, and for grassland, shrubland, savanna, forest land, or abandoned cropland, sample when the plant community has achieved a steady-state condition. These guidelines may not be applicable to all properties or management systems. Refer to the examples illustrating how soil properties or functional level can change over time (Figure 4.2-1). In the Minnesota example, sampling near the end of the curve (>70 years) will produce the most relevant information for documentation of attainable conditions. Changes that occur in additional systems are discussed in Exhibit 4.2-1.

Figure 4.2-1 Level of Dynamic Soil Property or Functional Capacity After Change in Management. Sampling should be conducted at steady-state (hatch marks) conditions before or after changes in state phase or management system. a) Conversion from conventional tillage to no-till. West and Post (2002) found that maximum SOC accumulation occurred within 15 to 20 years after conversion to no-till. They report an average increase of 0.6 kg m^2. b) Secondary forest succession after field abandonment. Curve from 1 to 80 years based on soil N level in a Minnesota chronosequence (Zak et al., 1990). SOC followed a similar trajectory and increased from 1.25 kg m^2 to 2.10 kg m^2 during the same period. c) Change from reference state after grazing and absence of fire in a grassland system. Adapted from Tugel et al., 2005, based on data from Archer et al., 2001. Archer et al., (2001) simulated a SOC reduction of 16% in a sandy loam and 29% in a clay loam over a period of about 50 years after the onset of heavy grazing and fire suppression.

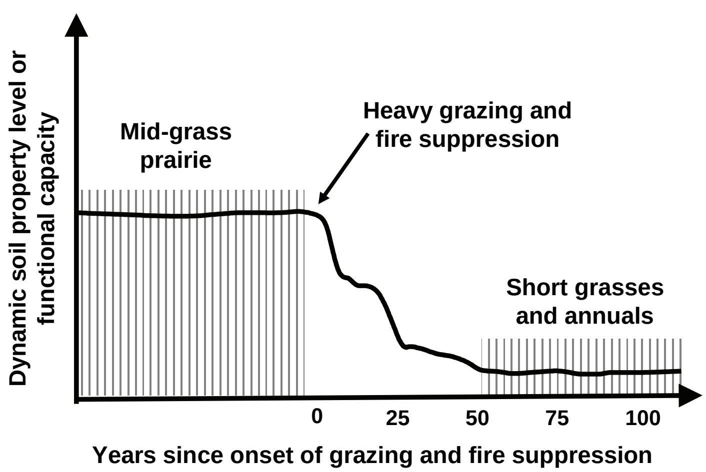
a)


Dynamic soil property level or functional capacity
Shift to no-till
No-till
Conventional tillage
0
10
20
30
40
Years since conversion

b)


Dynamic soil property level or functional capacity
Secondary-growth forest
Cropland abandoned
Cropland
0
20
40
60
80
120+
Years since abandonment

c)


Dynamic soil property level or functional capacity
Mid-grass prairie
Heavy grazing and fire suppression
Short grasses and annuals
0
25
50
75
100
Years since onset of grazing and fire suppression

4.2.3 Select the Soil Map Unit Component Phase

Define the target phases
The soils to be sampled were identified while the project scope was planned (Chapter 4, Step 1.3). All map unit phases of these soils are not likely to be included in a project. Furthermore, it may be necessary to include only a subset of mapped phases. Use specific ranges of the phase or other features to define the target population that will be sampled. Include ranges for such features as surface layer texture, slope, aspect, and elevation that correspond to the unique capacity of the soil to function. Document these on the Workplan Worksheet: Item 9.

For example, the same soil taxonomic unit may occur in a number of different soil map units within an MLRA or ecological subregion. For some of these map units, the slope or other phase designations may differ. In a hypothetical situation, the Alpha soil is mapped with slope phases of 5-20, 15-30, and 15-50 percent in three different map units. Either the full range or a more narrow range in slope can be selected for sampling. In this example, Alpha soils on 5-30 percent slopes are correlated to the same ecological site because they function in a similar manner. Alpha soils on slopes of greater than 30 percent cannot support the same plant communities as those on lesser slopes and are thus excluded from the project.

Identify the selected map units and size of the target area
List all map units that include the target phase properties on the Workplan Worksheet: Item 10. For range and forest land, include only soil map unit component phases of the selected soil that are correlated to the selected ecological site. Compute the estimated acres of the target soil map unit component phase over its full extent from the map unit component percent and total map unit acres. The total acres of the target soil map unit component phase within the study area represent the target population and area for data application as well as the acres benefited by a project.

4.2.4 Estimate Sources of Spatial Variability

Consider three scales of spatial variability
Knowledge of the spatial variability of soil (Table 4.2-1) and vegetation properties within the soil map unit component is helpful for developing an efficient and effective sampling design. Three scales of variability, regional-, local-, and fine-scale, are considered in this **Guide**. Record information on the Workplan Worksheet: Item 11 (A), (B), (C), and (D), for each of the scales. First describe (A) features that are likely sources of variability and (B) the degree to which each feature is presumed to affect the soil property. Then describe (C) conclusions and (D) any special instructions for sampling. Refer to additional instructions on the Workplan Worksheet and the sections below.

Table 4.2-1 Expected Spatial Variability of Common Soil Properties Within Landscape Units of a Few Acres or Less. (From Wilding and Drees, 1983)

Variability of property	Property
Least	Soil pH
	Thickness of A horizon
	Total silt content
Moderate	Total sand content
	Total clay content
	Cation-exchange capacity
	Depth to calcium carbonate equivalent
Most	Solum thickness
	Exchangeable hydrogen, calcium, magnesium, and potassium
	Soil organic matter content
	Soluble salt content

Estimate regional-scale sources of spatial variability

Regional scale as used in this **Guide** refers to distances and areas large enough to include the entire extent of the map unit. It encompasses environmental gradients that may occur across all of its polygons within an MLRA, Common Resource Area, or other broad geographic area. Information about sources of variability at this scale is used to 1) ensure the various sources are captured through plot selection or 2) to restrict the target area to be sampled. On the Workplan Worksheet: Item 11, identify the environmental factors, including elevation, temperature, precipitation, and wind, that are the likely sources of variability at this scale.

All environmental features vary to some degree. If the environmental features of the target area extend beyond the concepts for the soil map unit component phase or ecological site, it may be necessary to modify the study area. Either restrict the study area or divide it into separate projects. For example, elevation was restricted in one project to low-elevation areas only. High-elevation areas of the target map unit component phase were excluded from the project. The remaining high-elevation areas could be studied in a separate project if needed. Statistical inferences cannot be made to areas excluded from the project.

Estimate local- and fine-scale sources of spatial variability
Local scale refers to distances or areas represented by landform features within a single map unit polygon. Sources of variability at the local-scale include physiographic features that comprise the landform. These commonly vary within individual polygons and include landform component, aspect, slope percent, and slope shape.

Fine scale refers to distances or areas with dimensions or radii of a few meters to roughly 20 meters. Fine-scale variability occurs across polypedons within individual plots. Patterns of vegetation and soil microtopography within the plot may indicate variability of near surface soil properties. Certain management practices may create fine-scale features or patterns. Examples are shrub and intershrub patches on rangeland; skid trails and soil surface displacement in logged forests; rows and furrows, terraces, and compacted wheel tracks on cropland; and shade and water features on pastures. (See also mircrofeatures and anthropogenic features of the Geomorphic Description System in Schoeneberger, et al., 2002.)

Provide information about sources of variability at the local-and fine-scales on the Workplan Worksheet: Item 11. Under special instructions, describe 1) the need to locate plots or collect soil samples within a plot by individual strata (e.g., shoulder and back slope; shrub and intershrub, or row and furrow) and 2) conditions to avoid at a soil sample location.

Determine the need to stratify sampling
Stratified random sampling is a method that takes into account differing features (strata) within the sampling area prior to sampling. For projects following this **Guide**, strata that may be considered include those described as local- and fine-scale sources of variability. For example, on hillslopes, the shoulder and backslope may be designated as different strata. In another example, for plant communities that have repeating patterns of shrub patches and intershrub patches, each kind of patch may be designated as a stratum.

Evaluate information about local- and fine-scale sources of variability to help determine the need to stratify. Stratified random sampling is advantageous over simple random sampling in situations where the soil properties respond very differently to the individual strata. It also increases the sampling workload and the complexity of data analysis. Record decisions related to stratified random sampling on the Workplan Worksheet: Item 11, under “Special sampling instructions.”

If plots or soil sample locations are not stratified, information about the features that are likely sources of variability may still be useful for data interpretation. During sampling, record these features for each plot and each soil sample location as indicated on data collection forms.

4.2.5 Select Soil and Vegetation Properties

Purpose of specific kinds of properties

Three kinds of properties are useful when soil change and the effects of management on soil are characterized. Soil horizon properties, pedoderm features, and plant community characteristics, where present, will be measured in each project. Descriptions of each kind of property and their patterns are as follows:

- Soil horizon properties. These include physical, chemical, mineralogical, biological, and hydrologic properties that reflect ecological processes, water relations, and productivity. Properties of the forest floor also are included.

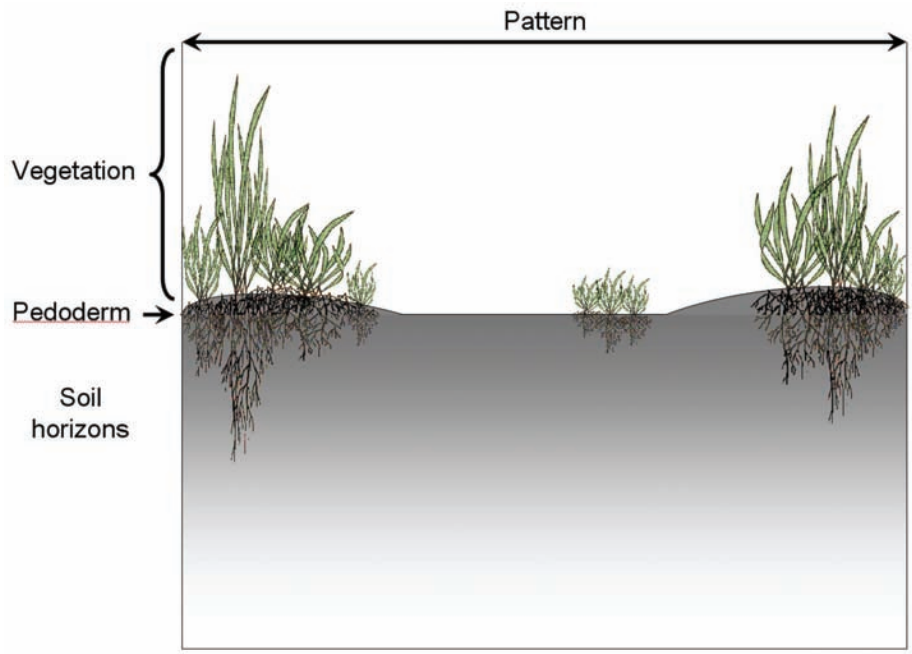
- Pedoderm features. These include such properties as soil surface stability and surface crusts that characterize the air-soil interface (Mills and Fey, 2004). These are important in descriptions of resistance to erosion and of air and water movement into the soil and may be valuable for future remote sensing applications.

- Plant community characteristics. Examples include cover and plant community composition. These characteristics can be considered in the development of information about protection from erosion, soil productivity, biological diversity, and hydrologic function.

- Pattern information. Pattern information, such as plant gap sizes or the pattern of soil erosion is included to help describe processes, such as fragmentation of vegetation and erosion, at the polypedon scale.

For more information on patterns, see Chapter 4, Step 2.4, under "Estimate local- and fine-scale sources of variability." In combination, the various kinds of data can be used to help evaluate soil-plant interactions and the effects of management (Figure 4.2-2).

Figure 4.2-2 Plant Community, Pedoderm, and Soil Horizon Properties and Their Patterns. Examples of pattern in this figure include mound, intermound surface topography and associated grass patches and bare spaces.



Selection criteria and the minimum data set
Because the cost of measuring every soil property subject to change would be very high, only a few properties can be measured. Dynamic soil and vegetation properties included in a project should meet a number of criteria.

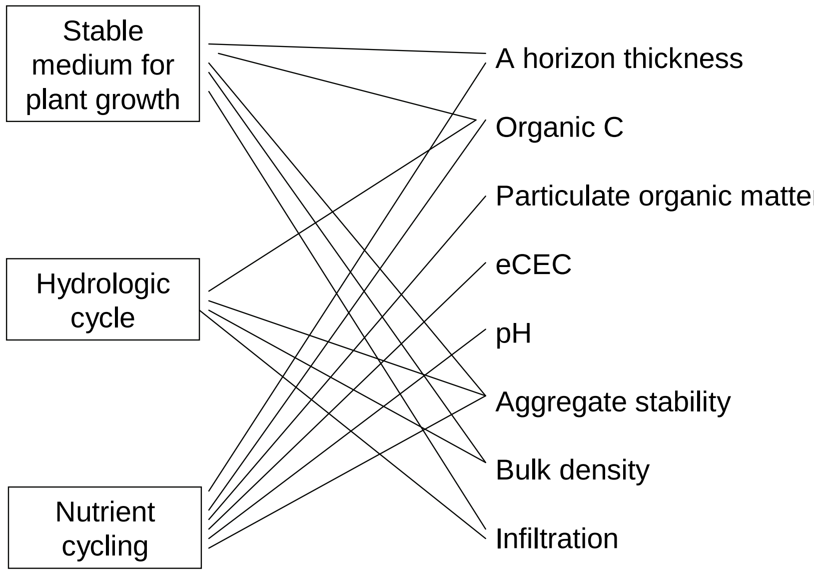
- First, the properties should be sensitive to disturbances or management. The properties could recover within a few hundred years in the absence of anthropogenic disturbance or under proper management, or the change may be nearly irreversible.

- Second, the relationships between the properties and the processes or functions they reflect should be clearly defined (Figure 4.2-3).

- Third, they should be relatively insensitive to daily or seasonal fluctuations in environmental conditions of moisture, temperature, and light, or such fluctuations are well-understood and can be quantitatively predicted.

- Fourth, they should be easy to measure accurately and precisely by different people and by the same person at different times. Fifth, the cost and time, both in the field and the laboratory, to obtain the required number of measurements is low.

Figure 4.2-3 Relationship Between Key Functions and Some Important Dynamic Soil Properties.



In order to ensure consistency and comparability of data, a minimum data set of soil properties for all land cover types is provided in the Workplan Worksheet: Item 12. It includes dynamic soil properties as well as properties that may be relatively stable and are important for interpreting dynamic soil properties. Dynamic soil properties of the minimum data set include the following: soil organic matter, pH, EC, bulk density and soil porosity, structure and macropores, aggregate stability, and total N. The properties important for data interpretation will depend upon the kind of soil sampled and commonly include soil horizon thickness, particle-size distribution, properties used in lieu of texture, rock fragments, CEC, and mineralogy.

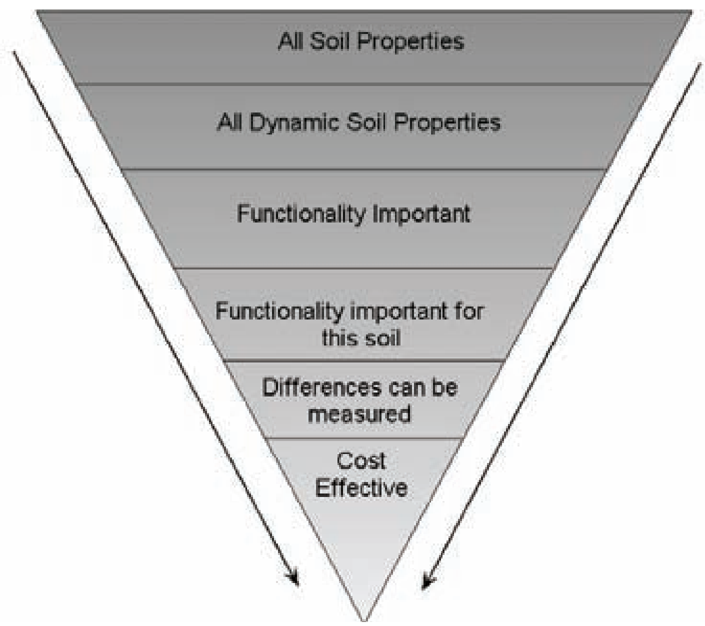
Supplemental and experimental properties

Some dynamic soil properties are functionally important for some but not all soils (e.g., SAR and forest floor carbon). Others are important, but do not meet all the criteria for the minimum data set, commonly because of cost or limited reproducibility of the measurement. Supplemental properties listed in the Workplan Worksheet can be included if the benefits are high, if including the properties is cost effective, and if the data can be effectively interpreted (Figure 4.2-4). Use caution when selecting properties that have high spatial variability, such as infiltration and hydraulic conductivity. Such properties require large numbers of measurements if mean values with the necessary level of certainty are to be developed. Large numbers of measurements increase costs. For some state phases, functionally important soil properties may not be included on the Workplan Worksheet. These properties can be included if a standard protocol is available from another source.

Experimental properties are those for which the relationship between the property and the function they represent is poorly understood or the method is not standardized. A number of biological properties can be considered experimental. Include these properties if they meet unique partner objectives, funds are available, and a specialist is available to interpret the data.

Record both supplemental and experimental properties selected for a project on the Workplan Worksheet: Item 13 and describe the justification for including properties not in the minimum data set.

Figure 4.2-4 Selecting Supplemental and Experimental Properties. Include only those properties that are functionally important and easy and cost-effective to measure.



Select vegetation properties to measure

In addition to soil properties, vegetation properties will be measured where a plant community is present. Select the minimum data set table for the appropriate land cover type from the Workplan Worksheet: Item 14. Add supplemental or experimental properties if they are needed and their benefit/cost ratio is high.

Identify desired environmental conditions and time of year to sample
Many properties fluctuate seasonally (Chapter 5, Table 5-2). Schedule the time of year for sampling on the basis of desired soil moisture and temperature conditions and plant growth stages. Biological soil properties often vary in response to the plant growth stage. Consider critical times of the year for plant identification and for residue and production measurements. If sampling is extended over more than one year, sampling should be conducted at the same time of year (unless the project objectives require a comparison of seasonal differences). Record desired conditions and the time of year to sample on the Workplan Worksheet: Item 15 .

4.2.6 Select Standard Methods and Laboratory Services

Use standard methods
Use standard methods for soil and vegetation sampling. Appropriate field methods as well as the sources for acquiring the methods are described in the Workplan Worksheet: Item 14 and Appendix 3.

Laboratory analyses can be performed by any professional laboratory that uses standard methods similar to those in the *Soil Survey Laboratory Methods Manual*, Soil Survey Investigation Report No. 42, Version 4.0. Make arrangements for funding and numbers of samples with the appropriate laboratory before sampling begins. Suggested laboratories include the NRCS Soil Survey Laboratory, university pedology laboratories, Forest Service Research Stations, and USDA Agricultural Research Stations, as well as private laboratories. Identify laboratories that will be used on the Workplan Worksheet: Item 16. Request assistance from the NRCS Soil Survey Laboratory to determine appropriate analytical procedures and special handling and shipping requirements. Samples for most biological soil analyses should be kept cool in the field and during shipping.

Identify layers and depth to sample
Procedures in this **Guide** use a combination of prescribed depths and actual horizon depths for sampling. Sampling by horizon provides the greatest flexibility in reporting results. Horizon data can be reported directly or converted to a per cm basis and used to compute weighted average values for any specified layer (e.g., 0-10, 10-25, 25-40, or 0-40 cm). Sampling at standard depths however, is more efficient and repeatable.

The description and thickness of the horizons themselves are important for interpreting the data and commonly help to reveal differences. On the other hand, many practices promote a surface build-up of organic matter in the first few centimeters of all but tilled soils. Collecting a thick A horizon as one sample will not allow this important difference to be observed. To overcome this limitation, the A horizon at the mineral surface soil will be divided and sampled except in soils that are cultivated every year. Follow the instructions for sampling layers and horizons (Appendix 3.5). For each project, identify the horizons and layers to sample on the Workplan Worksheet: Item 17.

Using the same lower depth or mineral soil thickness for all pedons within a project simplifies data analysis and interpretation. The arbitrary figure of 40 cm was selected to minimize the time spent on soil excavations and descriptions. If functionally important, 60 cm may be established in the sampling design. In particular, a depth of 60 cm is appropriate if the effects of management on the hydrologic soil group are important. In semiarid and arid systems, 25 cm may be an adequate sampling depth. Approval from the MLRA Office Leader, State Soil Scientist, or someone in an equivalent position is required for a sampling design that uses a depth other than 40 cm.

Sampling and reporting data by prescribed depths
The objectives of the data collection, skill levels of sample collectors, and time available for sampling should be considered when the choice is made to sample by horizon versus prespecified depths. Standard prespecified depths can be used in special projects or where technicians or other non-soil scientists collect the samples. Approval from the MLRA Office Leader, State Soil Scientist, or someone in an equivalent position is required.

Select horizons to analyze
Most soil properties will be measured for all layers that are sampled. Exceptions include biological soil properties and a few others (see Workplan Worksheet: Items 12 and 13). Data from 2 or more layers will enable interpretation of the vertical distribution of soil properties and identification of changes in that vertical distribution. Stratification ratios are an example of this type of interpretation (Franzleubbers, 2002). For each soil property to be measured, identify the corresponding layers for which they will be measured on the Workplan Worksheet: Items 12 and 13.

Comprehensive soil characterization
Comprehensive soil characterization data should be developed for one pedon representing each state phase (not each plot) unless appropriate data already exists. This representative pedon should be sampled to a depth of 2 m or to bedrock. Record information for existing pedon data and comprehensive characterization needs on the Workplan Worksheet: Item 18.

Determine amount of sample needed for analyses
The amount of sample collected for each layer sampled depends on the analyses requested. For comprehensive characterization by the SSL (Burt, 2004), collect the standard 3 kg (3 qt). For analyses limited to dynamic soil properties, collect only 1.5 kg. Include this information in the summary for Workplan Worksheet: Item 17.

Exhibit 4.2-1. How Long Does it Take to Reach Steady-State Conditions?
Some information regarding the time required for cropland to reach steady-state conditions has been developed through long-term studies. The cultivation of forest or grassland can lead to a rapid loss in functional capacity. Soil organic carbon can decline by 20% to 40% within a decade (Davidson and Ackerman, 1993). Cultivation may lead to rapid changes, but areas with changes in tillage practices or reestablished vegetation may

take decades or more to reach a new steady-state. Conversion from conventional to no-tillage systems can slowly increase the functional capacity of the soil. For instance, in a comprehensive review of carbon sequestration rates, West and Post (2002) report that the majority of soil organic carbon changes occur within a period of 10 to 15 years following conversion to no-till. Changes in crop rotation can also change levels of SOC. The effect of the change and the period during which that change takes place, however, are much more variable than for systems converted to no-till. West and Post (2002) speculate that slow increases in soil organic carbon may continue for 40 to 60 years.

Steady-state conditions may be harder to pinpoint in systems that have experienced major shifts in management and plant communities. On abandoned farmlands, functional capacity may initially decrease then increase over long periods of time. Zak et al. (1990) report increasing levels of soil C and N more than 70 years after fields have been abandoned in Minnesota. Richter et al (1999) found a similar trend in soil organic carbon concentrations after reestablishment of loblolly pine in South Carolina. In such cases, sampling should be done as near to steady state as possible.

Chapter 4 Planning and Conducting a Comparison Study

Step 3 Sampling Requirements

Figures

Tables

Step 3 Sampling Requirements

4.3.1 Use Statistically Based Sampling Requirements

Sampling

Sampling is the process of selecting locations to sample. There are many different ways to sample, and each depends on the type of information to be developed. The procedures in this **Guide** use design-based sampling (de Gruijter et al., 2006). Design-based sampling incorporates random sampling with the use of expert knowledge to select sites for sampling. This kind of sampling allows us to generate summary statistics and apply statistical tests (Chapter 4, Step 6). Expert knowledge can be used to reject potential sample locations that do not meet certain criteria (see Chapter 4, Step 4.1). Expert knowledge should not be used to locate 1) "ideal" plots selected because of their convenience or 2) plots that are assumed to be representative. This kind of selection would bias the results and may invalidate some statistical comparisons.

Sampling requirements

Sampling requirements are developed so that proper sampling procedures can be followed and project objectives can be met. Sampling requirements specify the following information:

1. Sampling unit
2. Type, size, and elements of the sampling unit (plot configuration)
3. Position and numbers of sampling units and samples
4. Sample identification system

Follow instructions in this step to develop sampling requirements for a comparison study.

Sampling units, replication, and mean values

For the procedures in this **Guide,** the primary sampling unit is the plot. Secondary sampling units, such as transects, subplots, or soil sample locations, may occur within the plot. The secondary sampling units are called plot elements. Both primary and secondary sampling units are replicated during data collection. This replication captures variability at multiple scales and provides information about the certainty of the mean.

The plot mean is derived from the means of the secondary sampling units. For example, if eight soil sample locations are placed on a plot, the mean value of total carbon for the A horizon on the plot is computed from the carbon values for the eight A horizon samples collected from the plot. If sampling is stratified within a plot, separate plot means can be reported for the individual strata. If the variability of soil properties within a plot is of interest, soil samples can be considered as nested within plots in more complicated statistical analysis.

4.3.2 Determine Plot Type, Size, and Elements

Select plot type and size

In this **Guide**, plot configurations are standardized as much as possible. Standardization promotes efficient, unbiased data collection; facilitates data aggregation; and allows comparison of state phases or management systems. Plots may be rectangular, circular, or linear (transects). Recommended plot types are provided for a variety of land cover types and ecosystems in (Appendix 3). Consider patterns and patchiness when choosing the plot configuration. A plot should be large enough to encompass the fine-scale variability in soil and vegetation properties that are important for function, but not so large that more than one kind of soil occurs on the plot.

When the comparison study includes state phases or management systems that require different plot configurations, special attention should be paid to plot size. For example, a forested plot may be circular as required for standard forest vegetation methods, whereas the plot configuration for a different land use may be comprised of multiple transects (i.e., subplots) within the soil map unit component phase in a given field. The linear dimensions or area of the plots should be similar so that on-plot variability can be compared between state phases or management systems. Document the plot type (primary sampling unit) and dimensions on the Workplan Worksheet: Item 19.

Select plot elements

In most cases, the properties that will be measured and the methods that are used to sample them dictates the kind of elements that will be in the plot. Refer to information about methods and typical plot configurations (Appendix 3). The number of each type of plot element and the number of observations involved in the plot element (e.g., points along a transect for canopy cover) are dependent on fine-scale variability across meters. Record the type, dimensions, and numbers of plot elements to be sampled on each plot on the Workplan Worksheet: Item 20.

4.3.3 Determine Sample Position and Numbers of Samples

Determine position of plots and samples

Plots will be widely dispersed across the target area to be sampled, and samples will be randomly or systematically distributed on individual plots. Sampling across the full extent of the target area is necessary in order to 1) capture the range of variability and 2) apply the data to other locations in the target area. Use stratified random sampling only if the differences in the dynamic soil properties among strata are presumed to be high and the variability is related to observable patterns at the local (polygon) or fine (plot) scales (Figure 4.3-1). Refer to decisions about special sampling instructions for stratified sampling that were recorded on the Workplan Worksheet: Item 11. (See also Chapter 4, Step 2.4.)

Figure 4.3-1 Observable Patterns and Stratified Sampling at the Fine Scale. If patterns, such as skid trails, can be recognized, consider stratified sampling to distinguish samples collected in skid trails from those in areas between skid trails. In situations where second growth vegetation obscures the location of skid trails and the trails cannot be consistently identified without digging a hole, samples should not be stratified prior to sampling.

Estimate numbers of plot replicates and soil sample locations

In each project, the numbers of plots (primary sampling units) and soil sample locations on a plot need to be specified in the workplan. The required number of plots and samples is based on a number of factors. These factors are 1) the spatial variability of the selected property, 2) the magnitude of the difference we would like to detect (minimum detectable difference, MDD) and 3) the desired level of precision and acceptable error rates. Refer to Appendix 2 for information about these factors and instructions to determine the variance, the number of samples per plot, and the number of plots. Record the source of the variance information and the number of samples to be collected on the Workplan Worksheet: Items 21 and 22.

The tools in Appendix 2 for determining sampling requirements are designed to account for the variability in properties for a specific project. The statistical measure “variance” is used in the computation of the required number of samples. In each project, numerous soil properties may be sampled and each may have different variances at different scales. For practicality purposes, sampling requirements will be based on the organic carbon in the A horizon or the upper 10 cm of the mineral surface soil. Organic carbon was selected because it is one of the more variable properties that are commonly analyzed in the laboratory (Chapter 4, Step 2; Table 4.2-1). If available information indicates that another property to be measured is more highly variable, that information can also be used to determine the number of samples needed.

In most situations, the same number of samples and plots will be sampled for each state phase in a project. This number can be modified, however, when one or both state phases have two strata within a plot that need to be analyzed separately. To determine the number of samples needed for the two strata, first determine the sampling requirement as you would for a single stratum. Then evaluate the adequacy of that number of samples for two strata and adjust the number as needed. At least 3 samples should be expected per stratum for statistical analysis. Increase the total number of samples per plot until the samples expected in each stratum are adequate. Avoid moving samples to the “proper” strata while laying out the plot. This could bias the samples and lead to incorrect conclusions. Record the strata of each soil sample location as the samples are collected, and refer to this information for statistical analysis purposes.

Follow the steps to evaluate the adequacy of the one stratum sampling requirement for two strata sampling:

1. Determine the sampling requirement for samples within a plot as if you were sampling only one stratum.
2. Make an estimate of the extent (%) of each stratum at the fine scale within the state phases that are to be sampled by stratum.
3. Use these estimates to evaluate the likelihood that the samples (as determined for one stratum) would randomly fall in each stratum. For each stratum, multiply the total number of samples to be collected by the extent (%) of that stratum.
4. If the total number of samples times the extent (%) is less than 3, increase the number of samples per plot to reach the necessary 3 expected samples per stratum. The percentage increase in numbers of samples should be the same for each stratum.

For example, a state phase with 30% shrubs and 70% grass patches and a sampling requirement of 5 samples per plot would likely result in 1.5 samples in the shrub stratum for each plot and 3.5 samples in the grass stratum. Two (2) times as many samples are needed in the shrub stratum to reach the necessary 3 samples. Using the same multiplier (2 in this case) for the grass stratum indicates that 7 samples would likely fall on grass. Use the adjusted numbers to compute the total number of samples per plot. The number of samples needed is 3 + 7 = 10 to reach the necessary 3 expected samples per strata. This calculation will not guarantee that this number of samples is obtained for each stratum.

The success of this method depends both upon the accuracy of extent estimates for within plot strata and a certain amount of chance.

Number of plots (plot replicates) and samples per plot to get started
If information about soil property variability is not available and cannot be acquired with preliminary sampling as described in Appendix 2, sample a minimum of 5 plots (plot replicates) for each plant community phase or management system and a minimum of 5 soil sample locations per plot. After the project data has been summarized (Chapter 4, Step 6), use the tools in Appendix 2 to determine if additional plots are needed to meet project objectives. It is important to sample the same number of plots for each state phase at the same number of sample locations per plot. If unequal numbers of plots are sampled among state phases, advanced statistical procedures not described in this **Guide** will be needed to compare state phases.

It is important to note the proper use of the term "plot replicates." Plot replicates are those plots within one state phase. If a project includes 5 plots for the shrub state phase and 5 plots for the grass state phase for a total of 10 plots, how many plot replicates are included in the project? ANSWER: 5.

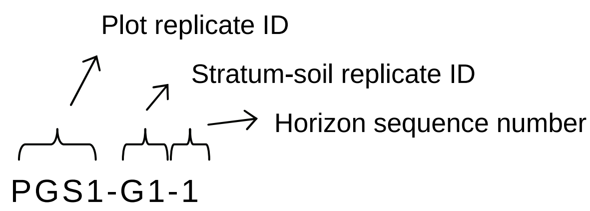
Compute total number of samples to be collected
The workplan should include an estimate of the total number of samples to be collected for workload planning. The number should incorporate an estimate of the number of horizons that will be sampled at each soil sample location, the number of locations, and the number of plots. Enter the number of samples for laboratory analysis on the Workplan Worksheet: Item 23. Then provide a narrative summary of the sampling design on the Workplan Worksheet: Item 24. For example, *"The project will include two plant community phases, 6 plots each, 6-8 soil sample location on each plot, and 3 soil horizons per soil sample location. Sampling will not be stratified on plots. One representative pedon for the reference state will be sampled for comprehensive characterization. Previously sampled pedon S98XXxxx-001 will be used to represent the other state phase. Vegetation data will be collected."*

4.3.4 Assign Sample Identification Numbers

Assign identification numbers for plots, sample locations, and samples
The sample identification system described in this **Guide** ties together related observations and data collected for a project. Within a project, sample identification codes should be unique and represent the relationships 1) among plots of the same state phase, management system, or local-scale strata; 2) among plot elements and strata within a plot; and 3) between a plot and its plot elements. The system will allow easy identification of plot replicates, strata within plots, and multiple soil samples for the same strata. It can also be expanded to identify the relationships between a plot and its vegetation measurements (e.g., transects and subplots within a plot). Refer to examples in

Figure 4.3-2 and Table 4.3-1. Then follow the instructions in Table 4.3-1 to develop the ID system for a project and enter the information in the Workplan Worksheet: Item 24.

Figure 4.3-2 Example Identification Number for Horizon Number 1 Collected at a Unique Soil Sample Location Within the Perennial Grass-Shrub Plot.



Also assign a unique pedon number to all samples submitted to the National Soil Survey Laboratory according to instructions in *Soil Survey Laboratory Information Manual*, Soil Survey Investigation Report No. 45, Version 1.0, 1995. The format of the number is 05UT019-001, where

> 05 is the calendar year sampled;
>
> UT is the 2-character Federal Information Processing Standards (FIPS) code for the state where sampled;
>
> 019 is the 3-digit FIPS code for the county where sampled; and
>
> 001 is the consecutive pedon number for the calendar year sampled for the county.

This is the “User Pedon ID” (column J, Table 4.3-1, i.e., 05UT019-001, for the soil sample location. “User Pedon ID” is used for pedon identification in NASIS and PC PEDON programs and for NSSL samples.

Assign sequence numbers to each layer sampled
In order to distinguish each layer sampled, include a sequence number after the pedon number; for example, 05UT019-009-1, 05UT019-009-2, etc. and PGS1-G1-1, PGS1-G1-2, respectively. If a horizon is divided and sampled in two layers, assign a different sequence number to each layer sampled.

Table 4.3-1 Sample Identification System for a Project. Examples illustrate the system of combining ID codes for a plot and its plot elements in order to uniquely identify soil sample locations (column I) within a project. A unique code is assigned to the state phases, management systems, and local-scale strata within a project (column B). Only those selected for sampling need an identification code. This code, when appended to a consecutive number, becomes the identifier, i.e., "Plot replicate ID" (column D) for each plot replicate. Then a unique code is assigned to each stratum that will be sampled (column E), even if there is only one stratum (see Chapter 4, Step 2.4). This code, when numbered consecutively, becomes the identifier, i.e., "Stratum-soil replicate ID" (column H), for each soil sample location. When combined, the "Plot replicate ID" and the "Stratum-soil replicate ID" become the "Soil sample location ID" (column I) for an individual soil sample location, e.g., PGS1-G1 (column I). This symbol is also used as the "User Site ID" (column I) in NASIS and PC PEDON programs. Horizon sequence numbers are added to the pedon identifier codes (not shown in the table) and then used as labels on sample bags collected in the field.

Plot identifier				Plot element identifier				Unique pedon identifier	
Plot within a project				Soil sample location within a plot				Plot replicate + stratum within plot + soil sample location replicate no.	
Plant community phase (state phase), management system, or stratum at the local scale				Stratum within a plot (fine scale)		Soil sample location within a stratum			
(A) Name	(B) ID	(C) Plot replicate no.	(D) Plot replicate ID	(E) Kind	(F) ID	(G) Soil sample location replicate no.	(H) Stratum-soil replicate ID	(I) Soil sample location ID (User Site ID)	(J) User Pedon ID
EXAMPLE 1; Single fine-scale stratum within a plot									
Invasive grass	IN	1	IN1	Grass	G	1	G1	IN1-G1	S05UT019-001
Invasive grass	IN	1	IN1	Grass	G	2	G2	IN1-G2	S05UT019-006
Invasive grass	IN	4	IN4	Grass	G	1	G1	IN4-G1	S05UT019-047
EXAMPLE 2; Multiple fine-scale strata (grass; shrub) within a plot									
Perennial grass-shrub	PGS	1	PGS1	Grass	G	1	G1	PGS1-G1	S05UT019-009
Perennial grass-shrub	PGS	1	PGS1	Shrub	S	1	S1	PGS1-S1	S05UT019-010
Conventional tillage	CT	1	CT1	Shoulder	S	1	S1	CT1-S1	S07XX123-001
Conventional tillage	CT	1	CT1	Backslope	B	1	B1	CT1-B1	S07XX123-002
EXAMPLE 3; Multiple local-scale strata (shoulder; backslope) not on the same plot									
Conventional tillage, shoulder	CTS	1	CTS1	None	N	1	N1	CTS1-N1	S07XX456-001
Conventional tillage, backslope	CTB	1	CTB1	None	N	1	N1	CTB1-N1	S07XX456-002

Chapter 4 Planning and Conducting a Comparison Study

Step 4 Field Work

Figures

Step 4 Field Work

4.4.1 Locate Plots; Verify Soil and State Phase or Management System

Ideal process for locating and selecting plots
Ideally, a seven-step process would be followed to randomly select plots. First, using soil surveys of the target area, new shape files of the selected soil map units would be created. Second, shape files of plant community phases (current vegetation) or management systems would be created. Third, plant community phases or management systems not selected for sampling would be eliminated from the sampling population. Fourth, potential plots would be selected randomly using GIS. Fifth, oddities, such as plots on top of a road, would be eliminated from the sampling population, and then randomly selected potential plots would be identified from the remaining subpopulation. Sixth, review of the randomly selected potential plots would verify onsite conditions and either reject or accept each plot as a "good spot to sample." Seventh, from the accepted potential plots, the desired number would be randomly selected for sampling and a spatially dispersed distribution of plots would be ensured throughout the study area.

If the sampling design indicates that local-scale features are to be stratified among plots, (not within the plot), additional steps would be inserted after step one. In these additional steps, shape files of the relevant local-scale features (e.g., landform component, aspect, slope percent, and slope shape) would be created and those features not selected for sampling would be eliminated. Furthermore, the number of sampling units (plots) selected for each stratum would be proportional to the extent of the stratum in the target area.

For soil survey work, there are a number of impracticalities to this method. The seven-step process requires complete geospatial data layers for the soil delineations, current land use, management systems, and plant community phases within the study area. Maps of current vegetation and management systems are not, however, commonly available. Visiting all of the potential plots is time consuming. Furthermore, the time to reach a randomly located plot can be excessive if the plot is far from a road. Consequently, a more practical approach is recommended.

Recommended process for locating and selecting plots
A combination of directed and random approaches will be used to select sample locations. Determine areas where suitable plots could be placed using a combination of GIS resources, maps of vegetation and management information, if available, and local familiarity with the target area. Using GIS tools, incorporate any known restrictions (e.g., distance from a road or trail, elevation, slope, and aspect). After the potential areas, fields, or plots are identified, the soil scientist and discipline specialist will visit the area and establish a plot that meets acceptance criteria. Select a spatially balanced distribution

of plots in order to represent the different sources of variation in regional-scale environmental factors and local-scale features within the study area (See Chapter 4, Step 2.4). Consult the Workplan Worksheet: Item 11 for the record of decisions and special sampling instructions related to local-scale sources of variability. If possible, direct the field visits to randomly selected management units, polygons, or points. GIS tools can be used to randomly locate potential points and compute the associated GPS coordinates.

Determine management history of possible fields to sample on cropland
Soil scientists, working with local conservationists, agronomists, or extension agents, should gather enough information to confirm that the pool of locations (e.g., fields, pastures, or stands) that can be used for sampling has the desired management history. Farm records, long-term productivity records maintained by county extension agents, and Natural Resources Inventory data are possible sources of information regarding crop management practices and changes in soil properties. Federal land managers may have management information on individual units of land.

Develop field acceptance criteria for plots
Plots must meet certain criteria to ensure selection of "the right ecological site, right state phase, right soil, right management system, and right plot size." Prior to visiting potential plots, develop field acceptance criteria. The goal is to locate plots that 1) are widely distributed and of sufficient distance apart to be independent of each other; 2) are not impacted by erosion, dust, or altered hydrology because of nearby roads; 3) do not have inclusions of minor components; and 4) are far enough from soil boundaries and inclusions of minor extent that they are not atypical. If the selected soil or state phase occupies a small area (<20 x 20 meters) and is intermingled with other soils, soil phases, or state phases, plot size should be small enough to fit well within the target soil map unit component phase and state phase. If this is not realistic or possible, consider including the intermingled soils, soil phases, or state phases in each individual plot and use stratified random sampling to collect data for each stratum.

Use the acceptance criteria listed below. The criteria can be modified for local conditions, but the same criteria must be used for the entire project. Record plot acceptance criteria on the Workplan Worksheet, Item 26, and include a summary on the plot master field form (Appendix 3).

1. Only one plot of each state phase or management system can occur in a single soil map unit polygon unless the polygon is over 3000 acres in size.
2. Plot boundaries are more than 1 mile from a previously selected plot of the same state phase or management system.
3. If separate plots are to be sampled to capture the variability at the local scale (stratified sampling for aspect, landform component, slope or slope shape), there is only one plot per polygon (i.e., locate each stratum in a different polygon).
4. Plot boundaries are more than 30 meters from a paved or main dirt road or a mapped soil boundary and at least 20 meters from a dirt track (plot must be beyond the impact of all roads).

5. The existing plant community or the management system is representative of one of the selected state phases or management systems and has been in place long enough for dynamic soil properties to reach a relatively stable level.
6. Slope and aspect are within the range of the target properties.
7. No cultural resources occur within the area of the plot.
8. The only soil on the plot is the selected soil map unit component phase. Dig a hole to verify and use expert knowledge to judge entire plot.
9. All points on the plot are more than 20 meters from inclusions of minor components.

Verify soil and state phases in the field
All plots will be visited and evaluated in the field prior to final acceptance and sampling. The soil map unit component phase and the state phase or management system must be verified onsite. Establish a reasonable maximum walking distance to potential plots. Visit and evaluate plots within that distance against field acceptance criteria and then select plots.

4.4.2 Collect Data, Samples, and Management Information

Be organized for efficient data collection
Integrated soil and vegetation data collection requires that many different tasks be completed by a few people over a short period of time. Sampling procedures are designed so that at least one plot can be completed in a day. Advance preparation and coordination among data collectors will help to ensure that projects proceed smoothly and efficiently with a minimum of errors. Assign field tasks to project personnel and arrange for methods training in advance of sampling. Although not essential, concurrent data collection by multiple disciplines promotes efficiency and sharing of expertise. It also provides insights about the method of data collection that can help with data interpretation. Use the information in the Workplan Worksheet and carry out the steps below. Methods, equipment information, and field data forms are in Appendix 3. Record forms to be used are on the Workplan Worksheet: Item 27.

1. Prepare equipment, data sheets, and labels for data collection.
2. Assign field tasks to project personnel.
3. Layout a plot; take plot photographs and GPS readings; conduct soil and vegetation (where present) sampling.
4. Go to next plot and repeat until the required number of plots is sampled.
5. Verify all sample labels, make a sample list, and ship samples to lab.

Photograph and georeference the plot
Place the photocard at the center of circular plots, at the corner of square or rectangular plots (Figure 4.4-1.), and at the beginning of single transect plots. Take photographs of the photocard, the plot, the landscape surrounding the plot, and individual strata within the plot. On the Photo Record field form (Appendix 3), enter plot and photo

identification, compass direction, and notes for each photo. Using GPS, determine coordinates for the plot center (circular plots), plot corner (square or rectangular plots), or transect starting point (transect plots) and record on the Plot Master (Appendix 3).

Figure 4.4-1. Photocard and Plot Photograph of a Square Plot. Include the plot corner and photocard in the photograph. The baseline of the plot is the tape in the foreground. Place the photocard at the 0 mark of transect 1 and the baseline.

Describe, georeference, and sample soils

Describe and georeference one full pedon (to bedrock or to a depth of 1.5 pr 2 meters) for each plot. Georeference each sample location on each plot, and describe each horizon sampled. If adequate full characterization data are not already available, collect samples for full characterization of one full pedon per state phase or management system (not per plot).

Label samples redundantly

Samples should be labeled with two unique sample identification codes. This redundancy reduces the chance that an incorrectly labeled sample must be discarded. Use sample identification symbols recorded on Workplan Worksheets: Item 24, and write the following on each bag:

1. Soil sample location ID with horizon sequence number (e.g., CP1-F1-1),

2. User pedon ID with horizon sequence number (e.g., S05UT019-001-01), and
3. Soil horizon and depth.

For many projects samples are split in the field and sent to different laboratories for different analyses. In these cases, it is helpful to write the analyses and the destination on the bag. For example, “NSSL sample” and “University lab-bulk density.”

Gather management history

Only general information about the management system or disturbances should be recorded for each plot. Much of this information is acquired during the process of plot selection. It is not the goal to document each practice on a field, pasture, or stand. If sample locations are selected properly, there will be a great deal of similarity in both the historical and current management among plots for a given state phase or cropland management system. Consequently, rigorous data collection of management information should not be necessary. It is important, however, to record information relevant to practices and disturbances identified as pathways or transitions in the state and transition model or cropland model.

Chapter 4 Planning and Conducting a Comparison Study

Step 5 Data Preparation

Figures

Step 5 Data Preparation

4.5.1 Enter and Error Check the Raw Field Data; Merge Field and Laboratory Data

Enter and error check the raw field data

Entering the data collected in the field into a spreadsheet or database is necessary for data compilation, calculations, and summaries. Data entry and checking are facilitated if the layout of the spreadsheet or database corresponds to the layout of the field datasheet. An example data entry spreadsheet with example values is displayed in Figure 4.5-1. Data entry spreadsheets for all common methods are provided in Appendix 3 and (eventually at the following web site location: http://here).

Once entered, the data should be checked for errors made during data entry. This process can be most efficiently done with a team of two individuals, in which one reads the field datasheet out loud and the other confirms that what is read is consistent with what has been entered. Teams usually become efficient quickly, and this process should take only a fraction of the data entry time. All the data should be evaluated for obvious inconsistencies or omissions, especially if field data entry tablets are used.

Merge field and laboratory data

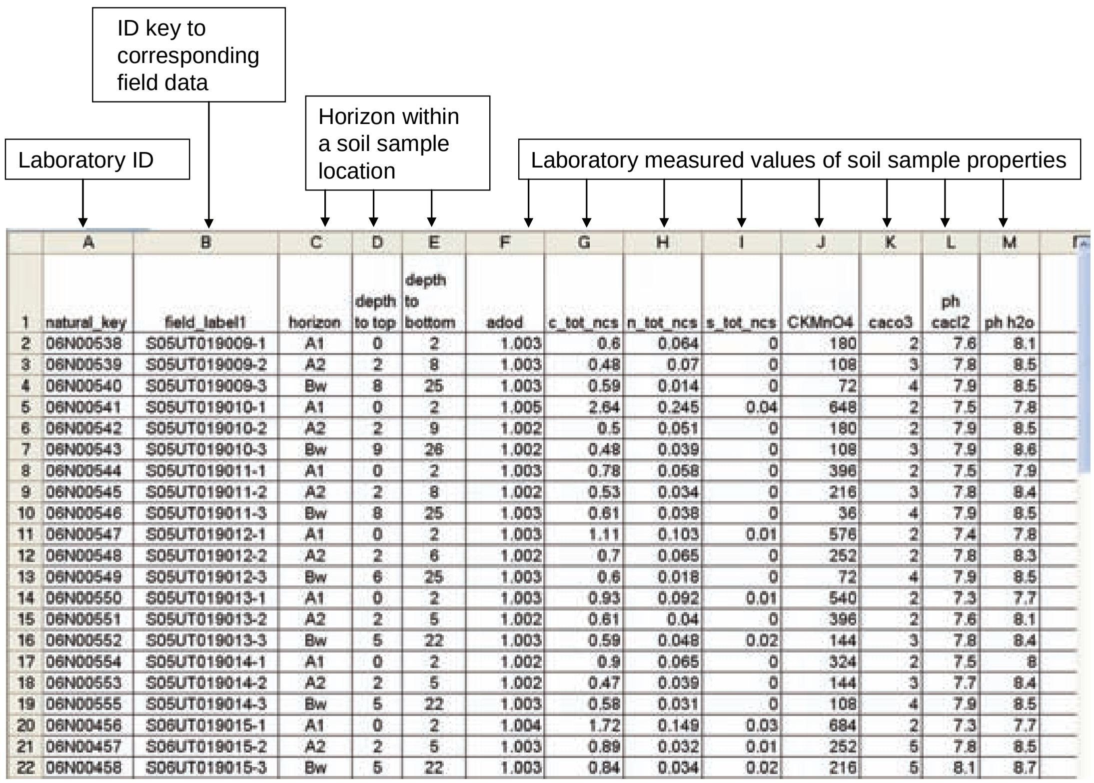
Laboratory data may come from the National Soil Survey Laboratory as well as other laboratories. Each row in the data from the lab will correspond to a unique sampling depth at a unique soil sample location; however, the corresponding identification codes may not be in the laboratory database. Once acquired from the laboratory, the data must be assigned the correct state phase, plot identification, and soil sample location codes to facilitate data analysis. An ID key common to both data sets is necessary to make this assignment and merge the data from the two sources. The most common ID key found in both field and laboratory data sets is the “User pedon ID and horizon sequence number” (column F of Figure 4.5-1). Some laboratory data sets include this same sample identifier in the column named “field_label1” (column B of Figure 4.5-2).

Figure 4.5-1 Example Spreadsheet for Field Measurements of Bulk Density (Core Method). Each row corresponds to a sampled depth. When combined, columns A and B are the soil sample location ID, for example, IN3-G1. When combined, columns A, B, and E, uniquely identify each sample. Columns G and H and K through N are field observations.

Sample within a plot
ID key to corresponding laboratory data
Attributes of the measuring device
Plot ID
Horizon within a soil sample location
Characteristics of the horizon and soil sample location
Field observations

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Plot replicate ID	Stratum-soil replicate ID	Horizon symbol	Horizon depth	Horizon sequence number	User pedon ID and horizon sequence number	Soil moisture status D/M/W	Soil crust class	Ring diam eter	Total ring length	ring ht 1	ring ht 2	ring ht 3	ring ht 4
2	IN3	G1	A	0-2	1	S05UT037001-1	D	PDB	57	14.9	12.5	12.2	12.6	12.2
3	IN3	G1	A	2-8	2	S05UT037001-2	D	PDB	57	14.9	8.5	8.8	8.6	8.2
4	IN3	G1	Bw	8-25	3	S05UT037001-3	M	PDB	57	24.9	7.8	7.7	7.4	7.2
5	IN3	G4	A	0-2	1	S05UT037002-1	D	PDB	57	14.9	12.5	12	12	11.7
6	IN3	G4	A	2-7	2	S05UT037002-2	D	PDB	57	14.9	9.8	9.8	9.9	9.6
7	IN3	G4	Bw	7-24	3	S05UT037002-3	M	PDB	57	24.5	6.8	7.2	6.5	7.4
8	IN3	G7	A	0-2	1	S05UT037003-1	D	PDB	57	14.9	12.6	12.7	12.5	12.3
9	IN3	G7	A	2-7	2	S05UT037003-2	D	PDB	57	14.9	9.6	9.5	9.3	9.4
10	IN3	G7	Bw	7-24	3	S05UT037003-3	M	PDB	57	24.5	7.4	7.8	7.4	7.4
11	IN4	G1	A	0-2	1	S05UT019046-1	D	PDB	57	14.4	12.8	12.8	12.8	12.7
12	IN4	G1	A	2-11	2	S05UT019046-2	M	PDB	57	14.4	5.1	5.7	5.7	5.5
13	IN4	G1	Bw	11-28	3	S05UT019046-3	M	PDB	57	24.7	7.8	7.4	7.4	7.8
14	IN4	G3	A	0-2	1	S05UT019047-1	D	PDB	57	14.9	13.1	12.3	12.7	12.9
15	IN4	G3	A	2-7	2	S05UT019047-2	M	PDB	57	14.9	9.6	9.5	9.7	9.8
16	IN4	G3	Bw1	7-24	3	S05UT019047-3	M	PDB	57	24.5	7.4	7.2	7.4	7.3
17	IN4	G7	A	0-2	1	S05UT019048-1	D	PDB	57	14.9	12.6	12.7	12.9	12.6
18	IN4	G7	A	2-4	2	S05UT019048-2	M	PDB	57	14.9	12.8	12.5	12.6	12.7

Figure 4.5-2. Example of Sample Data Acquired from the National Soil Survey Laboratory. Each row corresponds to a sampled depth. Columns A and B uniquely identify the sample. Columns F through M are laboratory-measured values for specific properties. In this example, the columns include the following properties: F, air dry-oven dry gravimetric water ratio; G, total carbon %; H, total nitrogen %; I, total sulfur %; J, carbon (mg/kg) from $KMnO_4$ extract (active carbon); K, $CaCO_3$ %; L, pH in 1:2 soil-$CaCl_2$ solution; and M, pH in 1:1 soil-water suspension. Data dictionary codes are provided with NSSL data downloads http://ssldata.nrcs.usda.gov/advquery.asp. Use the project sequence number assigned by the laboratory to download data for multiple pedons at one time.



	A	B	C	D	E	F	G	H	I	J	K	L	M
1	natural_key	field_label1	horizon	depth to top	depth to bottom	adod	c_tot_ncs	n_tot_ncs	s_tot_ncs	CKMnO4	caco3	ph cacl2	ph h2o
2	06N00538	S05UT019009-1	A1	0	2	1.003	0.6	0.064	0	180	2	7.6	8.1
3	06N00539	S05UT019009-2	A2	2	8	1.003	0.48	0.07	0	108	3	7.8	8.5
4	06N00540	S05UT019009-3	Bw	8	25	1.003	0.59	0.014	0	72	4	7.9	8.5
5	06N00541	S05UT019010-1	A1	0	2	1.005	2.64	0.245	0.04	648	2	7.5	7.8
6	06N00542	S05UT019010-2	A2	2	9	1.002	0.5	0.051	0	180	2	7.9	8.5
7	06N00543	S05UT019010-3	Bw	9	26	1.002	0.48	0.039	0	108	3	7.9	8.6
8	06N00544	S05UT019011-1	A1	0	2	1.003	0.78	0.058	0	396	2	7.5	7.9
9	06N00545	S05UT019011-2	A2	2	8	1.002	0.53	0.034	0	216	3	7.8	8.4
10	06N00546	S05UT019011-3	Bw	8	25	1.003	0.61	0.038	0	36	4	7.9	8.5
11	06N00547	S05UT019012-1	A1	0	2	1.003	1.11	0.103	0.01	576	2	7.4	7.8
12	06N00548	S05UT019012-2	A2	2	6	1.002	0.7	0.065	0	252	2	7.8	8.3
13	06N00549	S05UT019012-3	Bw	6	25	1.003	0.6	0.018	0	72	4	7.9	8.5
14	06N00550	S05UT019013-1	A1	0	2	1.003	0.93	0.092	0.01	540	2	7.3	7.7
15	06N00551	S05UT019013-2	A2	2	5	1.002	0.61	0.04	0	396	2	7.6	8.1
16	06N00552	S05UT019013-3	Bw	5	22	1.003	0.59	0.048	0.02	144	3	7.8	8.4
17	06N00554	S05UT019014-1	A1	0	2	1.002	0.9	0.065	0	324	2	7.5	8
18	06N00553	S05UT019014-2	A2	2	5	1.002	0.47	0.039	0	144	3	7.7	8.4
19	06N00555	S05UT019014-3	Bw	5	22	1.003	0.58	0.031	0	108	4	7.9	8.5
20	06N00456	S06UT019015-1	A1	0	2	1.004	1.72	0.149	0.03	684	2	7.3	7.7
21	06N00457	S06UT019015-2	A2	2	5	1.003	0.89	0.032	0.01	252	5	7.8	8.5
22	06N00458	S06UT019015-3	Bw	5	22	1.003	0.84	0.034	0.02	216	5	8.1	8.7

Identify comparable layers

A method of pooling data for samples from equivalent horizons is needed to compute soil property means and facilitate comparisons among state phases or management systems. Soil horizons collected at the various soil sample locations, however, may have different horizons or horizon sequences. One pedon on a plot may have A-Bw-Bk horizons and another may have A-BA-Bk horizons. In this example, the Bw and BA horizons may be considered "equivalent" and pooled together with a "comparable layer ID" number. After all samples for a project have been collected, assign a comparable layer ID to the equivalent horizons (Figure 4.5-3) Consider the information needs related to soil function when determining which horizons are comparable. Horizons can be grouped on the basis of similar lithology or common pedogenic processes, such as accumulation, illuviation, eluviation, or concentration. It may be desirable for the equivalent horizons to roughly correspond to specific portions of the root zone.

In some situations, a horizon is “missing.” For example, soil pedons under the forest plant community have an E horizon. Because of cultivation, the pedons for the same kind of soil in a pasture do not have an E horizon. Because the E horizon does not occur under both land cover types, it is necessary to pool samples for this horizon with other similar horizons in order to make comparisons among state phases or management systems. It may be desirable to combine the E horizon with the A horizon in some projects and with the B horizon in others. In still others, it may be desirable to compute values for both the A plus E horizons and the E plus B horizons.

Figure 4.5-3. Example of Comparable Layer Assignments. The process of assigning comparable layer IDs is completed after all examples have been collected. These data represent seven pedons from one plot within a project. Horizons are grouped into comparable layers (column H) as follows: 1 is assigned to all O horizons; 2 is assigned to all A and Ab horizons; 3 is assigned to all Bw and Bwb horizons (see box outline in the figure); and 4 is assigned to all 2BE, 2EB, and 2EBt horizons. Horizons for all pedons within a project should be grouped in the same manner. A number of variations will almost always occur. For example, soil sample location CP1-F7 (row 28) does not have an O horizon or a comparable layer ID of 1. Horizon sequence (column G) and comparable layer ID numbers for a given pedon are not always the same. In this project, the only pedon having identical numbers for horizon sequence and comparable layer ID is at soil sample location CP1-F6. Also note that 40 cm of mineral soil was sampled in each pedon according to standard methods. This procedure resulted in a number of different lower soil depths.

	A	B	C	D	E	F	G	H
1	User pedon ID and horizon sequence number	Plot replicat ID	Stratum-soil replicate ID	Soil sample location ID	Horizon symbol	Layer depth_top to bottom	Horizon sequence number	Comparable layer ID
2	S07IXX009001-1	CP1	F1	CP1-F1	O	0-0.7	1	1
3	S07XX009001-2	CP1	F1	CP1-F1	A	0.7-8.2	2	2
4	S07XX009001-3	CP1	F1	CP1-F1	Bw1	8.2-23	3	3
5	S07XX009001-4	CP1	F1	CP1-F1	Bw2	23-30	4	3
6	S07XX009001-5	CP1	F1	CP1-F1	2BE	30-40.7	5	4
7	S07XX009002-1	CP1	F2	CP1-F2	O	0-4	1	1
8	S07XX009002-2	CP1	F2	CP1-F2	A	4-16	2	2
9	S07XX009002-3	CP1	F2	CP1-F2	Ab	16-19	3	2
10	S07IXX009002-4	CP1	F2	CP1-F2	Bw1b	19-35	4	3
11	S07XX009002-5	CP1	F2	CP1-F2	Bw2b	35-44	5	3
12	S07XX009003-1	CP1	F3	CP1-F3	O	0-3.1	1	1
13	S07XX009003-2	CP1	F3	CP1-F3	A	3.1-13	2	2
14	S07XX009003-3	CP1	F3	CP1-F3	Bw1	13-31	3	3
15	S07XX009003-4	CP1	F3	CP1-F3	Bw2	31-43.1	4	3
16	S07XX009004-1	CP1	F4	CP1-F4	O	0-2.3	1	1
17	S07XX009004-2	CP1	F4	CP1-F4	A	2.3-11	2	2
18	S07XX009004-3	CP1	F4	CP1-F4	Bw1	11-33	3	3
19	S07XX009004-4	CP1	F4	CP1-F4	Bw2	33-43	4	3
20	S07XX009005-1	CP1	F5	CP1-F5	O	0-2.4	1	1
21	S07XX009005-2	CP1	F5	CP1-F5	A	2.4-13	2	2
22	S07XX009005-3	CP1	F5	CP1-F5	Bw	13-33	3	3
23	S07XX009005-4	CP1	F5	CP1-F5	2BE	33-43	4	4
24	S07XX009006-1	CP1	F6	CP1-F6	O	0-2	1	1
25	S07XX009006-2	CP1	F6	CP1-F6	A	2-11	2	2
26	S07XX009006-3	CP1	F6	CP1-F6	Bw	11-30	3	3
27	S07XX009006-4	CP1	F6	CP1-F6	2EB	30-42	4	4
28		CP1	F7	CP1-F7				
29	S07XX009007-1	CP1	F7	CP1-F7	A	0-7	1	2
30	S07XX009007-2	CP1	F7	CP1-F7	Bw1	7-22	2	3
31	S07XX009007-3	CP1	F7	CP1-F7	Bw2	22-35	3	3
32	S07XX009007-4	CP1	F7	CP1-F7	2EBt	35-40	4	4

4.5.2 Make Necessary Calculations

Compute variables

Many of the soil properties of interest (project variables) are derived by combining field and laboratory data and/or making calculations on the raw data. After horizons are grouped into comparable layers, use weighted averages based on the thickness of each layer to compute a single value that represents the pooled horizons and layers. Use spreadsheet templates provided with this **Guide** (Appendix 3) for these calculations. It is also helpful to convert horizon data to a per cm basis. Computations using weighted averages can then be made for arbitrary layers in the soil, such as the 0-10 or 10-25 cm layer. This information is necessary for some interpretations. For example, carbon pools on an acre basis can be compared among different land uses only if the values used to compute total carbon are all for a layer of the same thickness. On the other hand, if the objective is to compare A horizons in terms of percent carbon, the thickness of the horizon does not matter.

For a description of the calculations for soil and vegetation properties, see Appendix 3. *Note: Once developed, a standardized information system that includes "built-in" algorithms for the calculations will automate this step.* Another tool for computing vegetation properties is the Rangeland Database and Field Data Entry System available at http://usda-ars.nmsu.edu/monit_assess/monitoring.php.

Chapter 4 Planning and Conducting a Comparison Study

Step 6 Data Analysis and Reports

Figures

Tables

Exhibits

Step 6 Data Analysis and Reports

4.6.1 Review Data Analysis Steps

Multiple steps for data analysis
Multiple steps are involved in data analysis and interpretation. The data must first be summarized and evaluated before statistical tests are completed and before standard reports or interpretations can be prepared. The steps are include the following:

- Summarize the data
- Evaluate the data
- Evaluate the sampling sufficiency
- Test for differences using statistics
- Look for differences using other techniques
- Develop reports

Request assistance from a specialist as needed. Summarizing the data requires at least a familiarity with basic statistics. For more information on basic statistics, consult an introductory textbook. Direct assistance from a specialist may be required to complete the data evaluation and statistical tests.

4.6.2 Summarize the Data

Multiple levels for the data summary
The data from a project are presented for multiple levels. Most commonly, they will be summarized for each comparable layer or depth increment by plot and by state phase or management system. They also can be summarized by stratum within a plot. For most projects, multiple observations or soil samples within a plot are collected. The values for these individual soil samples are combined, typically by averaging, to calculate the plot-level value of the property. The plot-level value of the property is then used in the statistical summary to calculate the central tendency and range of variation of the property within the state phase or management system. Variability within the plot also can be determined.

Compute summary statistics
A summary statistic condenses the information about the properties that are measured in a project. Statistical measures (Table 4.6-1) that describe the data for a state phase or management system can be generated using statistical software or an information system that includes the algorithms to compute these measures. For most purposes, the mean (measure of central tendency) and the standard deviation (measure of variation) are the fundamental summary statistics. When sample replication is low, median values are a

more reliable measure of central tendency and the range of variation can be expressed in terms of quantities. Quartiles (75% and 25%) are most commonly used. In addition, information about the certainty of the mean (standard error and confidence intervals) should be computed. Confidence intervals (discussed below) should not be computed using standard methods for a set of observations that is either 1) small or 2) not normally distributed (see Chapter 4, Step 6.3). **Report 1. Summary of Data and Statistical Measures for State Phases: As Sampled** (Table 4.6-2) is a summary report that can be produced for a project after the data evaluation is complete *(computations to be automated in the information system)*.

Table 4.6-1. Commonly Used Statistical Measures to Summarize the Data. Summary statistics should be calculated from plot means. Most summary statistics are expressed in units that are the same as those of the variable. These measures include mean, median, quantile, standard deviation, standard error, and confidence intervals. Variance has no units. Coefficient of variation is expressed as a percent and has no other units attached to it. It can be used to compare the amount of variation in different properties, including those that have different units (e.g., bulk density and organic carbon).

General class	Measure	Description
Sample size		
	Sample size	Number of samples collected
Measures of central tendency		
	Mean	Average value of the samples
	Median	Middle value of the samples, may be a better measure of central tendency if extreme outliers on one end of the distribution exist
Measures of variation		
	Variance	Average squared difference between individual samples and the mean
	Standard deviation (SD)	The square root of the average squared difference between individual samples and the mean
	Coefficient of variation (CV)	Standard deviation divided by mean, expressed as percent. Allows for easier comparison of the variation between properties on scales that differ by orders of magnitude
Measures of central range		
	25% Quantile	Value at which 25% of the samples when ordered consecutively are below and 75% of the samples are above
	75% Quantile	Value at which 75% of the samples when ordered consecutively are below and 25% of the samples are above
	Mean – 1 SD	Average value minus 1 standard deviation
	Mean + 1 SD	Average value plus 1 standard deviation
Measures of certainty or confidence about the mean		
	Standard error of the mean (SE)	SD divided by the square root of n (the number of samples); sampling variability of the mean
	Lower and upper 95%* confidence interval of the mean (CI)	Interval in which we are 95%* confident that the true population mean falls * (e.g. 95, 90%)

4.6.3 Evaluate the Data

Techniques for data evaluation
After the summary statistics have been computed, consult a specialist to evaluate the data. The data should be evaluated before tests for differences and reports are prepared. Histograms, box-plots, or other useful techniques can be used to evaluate the distribution of sample values within plots (fine scale) and the distribution of plot means (regional scale) for each state phase. Data that approximate a normal distribution are assumed to be normally distributed for the purposes of these soil survey procedures. Therefore, standard summary statistics are valid.

When evaluating data within and among plots, first examine the sample distribution and then evaluate the certainty of the sampling mean. Confidence intervals and standard error are used to evaluate the certainty of the sampling mean. The sampling mean is the average value of the sampling units (plots). Anomalies in the data also should be investigated for sample labeling, data entry, or soil analysis mistakes.

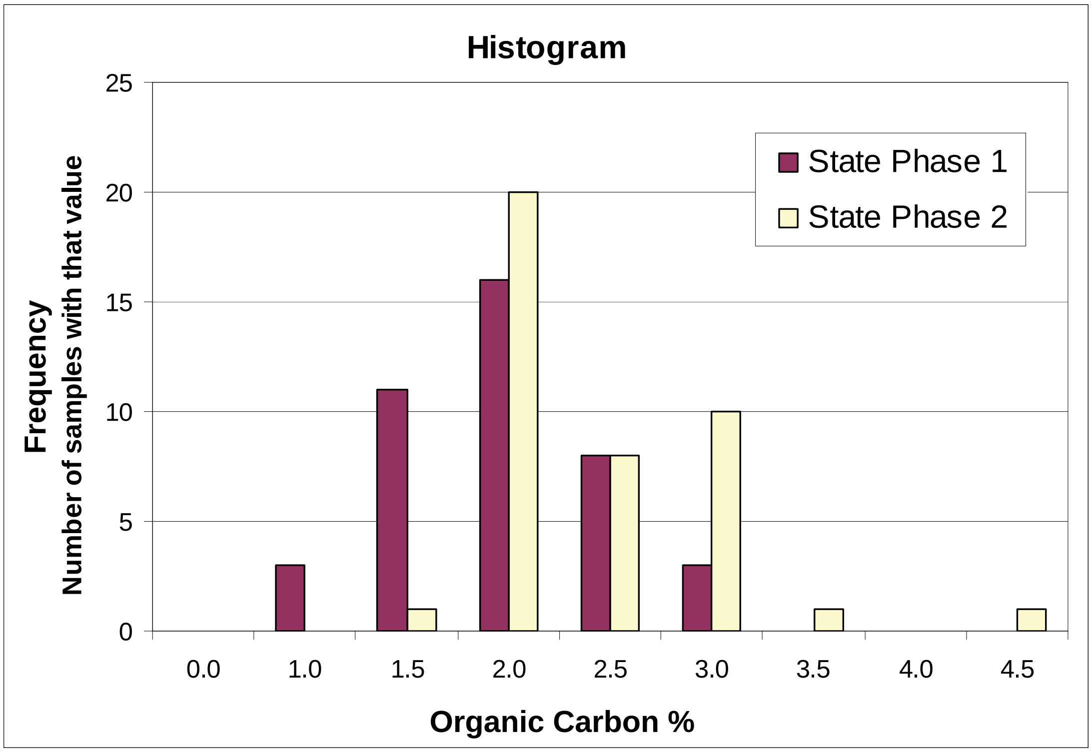
Examine the sample distribution
Use histograms, box-plots, or other useful techniques in order to examine and explore

1. the distribution of sample values within plots and
2. the distribution of plot means for each state phase.

Look at the shape of the histogram curve and the spread of the values for each state phase. In a normal distribution, the histogram forms a single characteristic symmetrical bell-shaped curve. Instructions for a distribution that is not normal are givenin number 3 below.

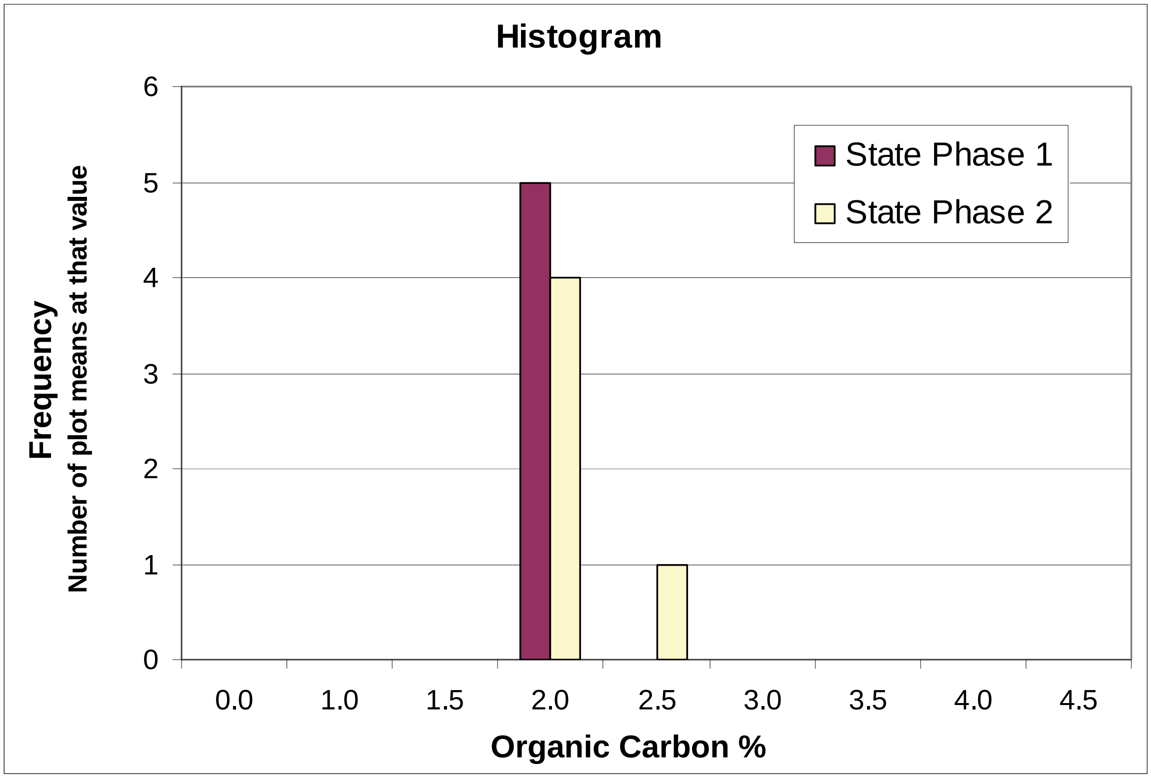
1. Sample values within plots. Display individual samples by state phase to visualize the distribution of all sample values within plots (Figure 4.6-1). If each state phase has dissimilar and histogram shapes (indicating differences in within the plot, e.g., fine-scale variability), more sophisticated techniques may be needed to statistically differentiate state phases. The need for these techniques should be considered when statistical tests for differences are applied. If useful, histograms can be prepared for each plot. For instance, a state phase with a wide range of values within a plot may have significant patterns or two distinct strata within plots that are functionally important and may need to be separated for analysis.

Figure 4.6-1. Example Histogram of All Samples Collected in Each State Phase. State phase 1 has a normal distribution, while state phase 2 is skewed to the right.



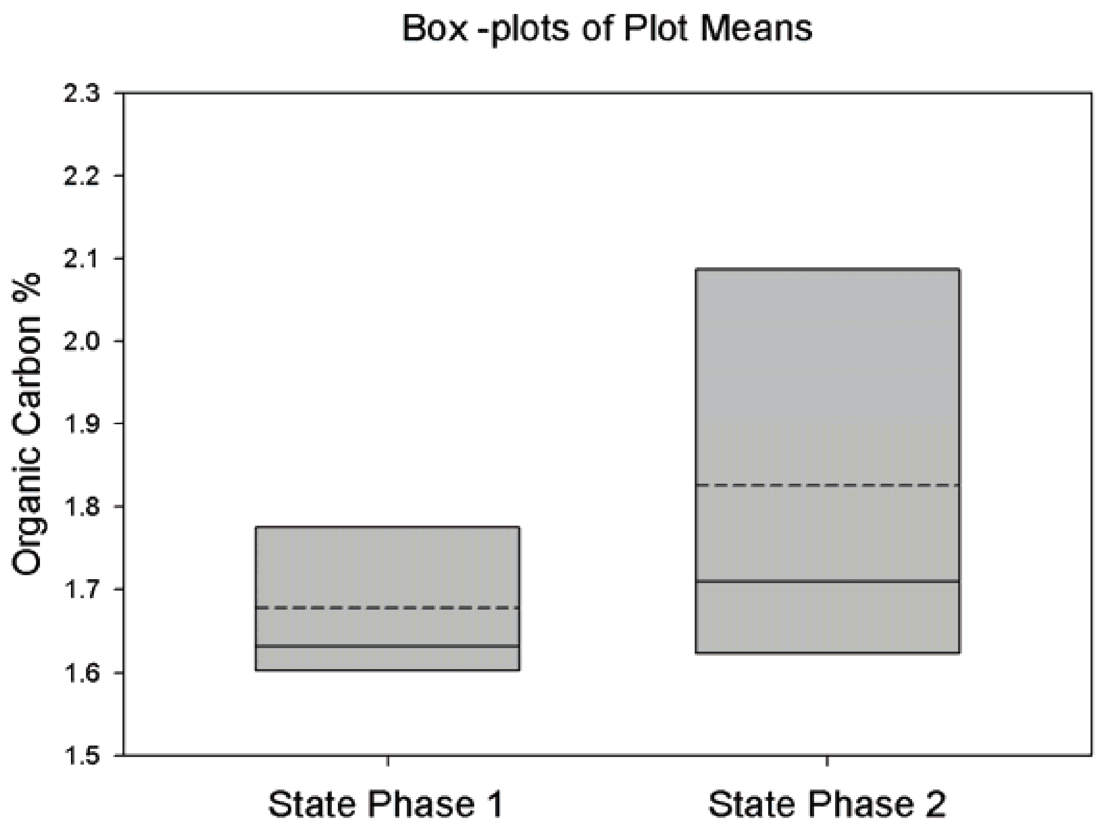
2. Plot means. Plot means for each property and layer or depth increment are displayed by state phase to gauge the normality of their distribution (Figure 4.6-2). If only a few plots were sampled, the distribution will not be an ideal bell-shaped curve even when the data are normally distributed. Data that approximate a normal distribution will be assumed to be normally distributed. Box-plots (Figure 4.6-3) can be used to display quantiles along with the median and mean of plot means. Interquartile ranges are a good measure of the central range of the property and are appropriate for both normal and nonnormal distributions.

Figure 4.6-2. Example Histogram of Plot Means in Each State Phase. Only five plots were sampled, and neither state phase appears to have an ideal normal distribution at this scale.



3. Distributions that are not normal. Most statistical tests are based on assumptions about the type of distribution. Consequently, it is important to know the distribution in order to properly apply the tests. This **Guide** uses plot means for comparisons between state phases. If plot mean values are widely dispersed or the bulk of the values occur at one end or the other, either too few plots were sampled or the distribution is not normal. If post-sampling stratification does not produce a data set that is normally distributed, either sample more plots or describe the central tendency using the median value, rather than the mean. With assistance from someone who can perform the proper calculations, data sets that differ from a normal distribution can be transformed into log values, square roots, or other values that can be used in statistical tests of difference.

Figure 4.6-3. Example Box-Plots of Plot Means. The central range of a property is represented by a box whose top and bottom represent upper and lower quantiles. Thus, the box covers the interquantile range. The 75th and 25th quantiles (i.e., quartiles) are used in this example. Means are indicated with dashed lines and medians with solid lines.



Evaluate the certainty of the sampling mean
Evaluate the certainty of the sampling mean to learn about the spread and precision of the data. The certainty of the sampling mean is partially described using the confidence interval of the mean. The text below describes the confidence interval and other factors that can influence the sampling mean.

1. **Confidence interval.** The sampling mean is the average value of the sampling units (plots). The confidence interval of the mean is the interval in which we would expect the true population mean for the state phase sampled to occur. The level of confidence (e.g., 95, 90, or 80%) indicates the probability that the interval includes the true value. The confidence interval takes into account the sample size and the variance of the state phase. The confidence interval, e.g., 0.48 to 0.70 percent organic carbon, and the confidence level, e.g., 95%, are reported together. A confidence interval provides information about the dispersion of the mean and an estimate of the precision around the mean. A narrow interval at a specified confidence level suggests high sampling precision compared to wider intervals at the same confidence level. Confidence intervals are never reliable with more than minimal deviations from normality.

2. Confidence intervals are derived from the standard error of the mean. Larger sample sizes result in increasing certainty that the state phase is being sampled adequately to characterize the mean. See Chapter 2, Figure 2.5, for an example of the effect of additional sampling on the standard error and the precision of the sampling. State phases with greater spatial variability at the regional scale require a larger sample size to obtain a specific level of certainty of the mean compared to more spatially homogenous state phases.

3. **Other factors influencing the certainty of the sampling mean.** Other aspects that affect the certainty of the sampling mean will not necessarily be captured by the sampling process. This information should be provided as descriptive information about the state phase in the summary report. An example of a description is as follows: “By chance, all of the plot locations occurred on slopes within the high end of the slope range for the target population.”

4.6.4 Evaluate the Sampling Sufficiency

Determine sampling sufficiency
Evaluating sampling sufficiency answers the following question: Did sampling include enough samples and plots to detect a difference in the property? For most soil survey projects, it is not important to detect minute differences among state phases. Knowledge of functionally important differences is needed, however, for resource management. Ideally, sufficient samples should be collected to detect the size of difference that is functionally important. Use the Multi-Scale Sample Sufficiency Requirement Evaluation Tool (MSSRET) as described in Appendix 2 to determine the size of difference that can

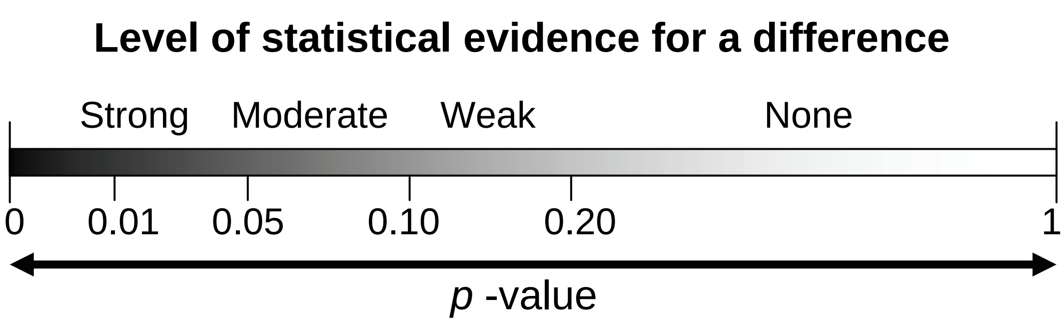
be detected with the project data. The MSSRET program reports this as the actual minimum detectable difference. Compute the actual minimum detectable difference for selected properties and depths in each state phase. For each property, compare the actual detectable difference to the "desired" minimum detectable difference (i.e., functionally important difference).

Sampling sufficiency and the minimum detectable difference
The evaluation of sampling sufficiency can provide three outcomes. First, it can indicate that additional plots need to be sampled during the ongoing study to detect the desired minimum detectable difference, that is, sampling may not be complete. Second, if additional sampling is not possible, the evaluation can guide adjustment of the desired minimum detectable difference to a larger magnitude. Third, if the actual minimum detectable difference as computed for the project data is smaller than the desired minimum detectable difference, it can be concluded that more samples were collected than needed. In this case, no further sampling is needed, and the data should be adequate for interpreting differences.

4.6.5 Test for Differences Using Statistics

Causes of differences in the sampling mean
Differences between the sampling mean of state phases may result from 1) true differences between the state phases or 2) differences caused by chance alone. Differences caused by chance are merely the result of how the sampling process encountered the property variability within the state phases. Statistical tests can help to distinguish between these two possibilities by assigning a likelihood that the difference observed results from the sampling process. Typically, if this likelihood (or probability), described by a *p*-value, is low enough, we conclude that the differences observed likely reflect true differences between state phases.

Figure 4.6-4. Level of Statistical Evidence and *p*-Value. The *p*-value is an indicator of statistical significance. It indicates the probability that the difference observed results from chance alone. It is used to determine the level of statistical evidence for a difference. Smaller *p*-values indicate greater levels of significance.



Run tests for differences between state phases

Run simple tests that compare selected properties of one state phase to those of another. Use the comparable layer ID to group horizons for the comparison tests, or make comparisons based on prescribed depths (e.g., 0-10, 10-25, or 25-50 cm). Both the *t*-test and ANOVA (analysis of variance) can be performed using standard statistical software, although they can be computed using Excel. If only two state phases are to be compared, use a *t*-test. ANOVA tests can be run for two or more state phases and are more readily performed in advanced software packages. All assumptions of the test should be met before the data are tested. Request assistance from a specialist to complete either of these tests and before preparing a report (Table 4.6-4). Additional background information about statistical tests is included in Exhibit 4.6-1.

Statistical significance vs. functional importance

Statistical significance should not be confused with functional importance. A significant statistical difference indicates that the means of two populations (e.g., two state phases) are reliably different. The measure of that significance, the *p*-value, does not necessarily indicate that the difference is functionally important. Two state phases may have slightly but reliably different means. The difference may not, however, have a practical effect on differences in functionality. In the reverse situation, the means are functionally different but not statistically significant. Care should be taken to determine if sampling was sufficient (adequate sample size) to detect that difference.

4.6.6 Look for Differences Using Other Techniques

Visually evaluate the differences

When the data are not normally distributed, the mean may not be a good measure of the central tendency. In these cases, the median value and interquartile range are nonbiased methods of assessing the data. These may be presented as graphs or charts that are used to make a simple visual evaluation of the differences in state phases. Look for similarities and differences in the central range (interquartile range) for each layer.

Box-plots and the control chart concept (Larson and Pierce, 1994) have been adapted in this **Guide** to illustrate state phase conditions with respect to a reference condition. These control charts include the mean, median, and interquartile range of plot means for properties sampled for each state phase. They also include the high (maximum) and low (minimum) plot means of the reference state phase. Multiple states and state phases can be included on the chart. Prepare control charts for selected soil properties and layers, as in Figure 4.6-5 (see Chapter 4, Step 6.7). Control charts can be created in Microsoft Excel by following the instructions to create a box plot at http://support.microsoft.com/kb/155130. Lines representing the maximum and minimum plot means can then be drawn across the plot to complete the control chart. *(NOTE: This process is to be automated in an information system.)*

Differences in pattern at the fine scale

There may be changes in functionally important patterns at the fine scale that are overlooked by averages and broad comparisons, such as tests for differences in plot means. Variability at the fine scale (within plots) may be more indicative of changes in properties and the effects of management on function than they are of plot means. Fine-scale variability that may need further investigation in the following situations: 1) distributions observed in histograms for individual plots have two or more clusters of data or an exceedingly broad spread in the data, 2) there is visual evidence in the field that within plot variability is an important indicator of function, or 3) within plot variability is markedly different among state phases. In these situations, a more complicated statistical analysis may be warranted. Statistical tests that take into account the nested or clustered nature of individual samples within plots may be appropriate.

4.6.7 Develop Reports

Using the data to make inferences beyond the project area

It is important to understand how data obtained from a project can be applied to other areas. From a statistical sampling perspective, the central tendency and range of variation provided in a data summary apply only to the project area. Specifically, the conclusions drawn apply to the area and conditions from which random samples were drawn. Expert opinion, however, can be used to ascribe general relationships to similar soil systems. It may also be possible to model for the intermediate conditions that were not sampled.

Develop reports

A number of reports can be developed for each project. Summary reports include data, statistical measures, and charts. Reports on sampling sufficiency and the results of statistical tests can also be developed. Each report is described below. When used together, **Reports 1, 3,** and **4** provide statistically based summaries for evaluating the project data, making conclusions about differences, and inferring changes in properties or their vertical distribution among state phases. **Reports 2** and **5** are recommended when general information is required.

Report 1. Summary of Data and Statistical Measures: As Sampled. This summary report (Table 4.6-2) includes soil and vegetation properties for each plant community or management system sampled. Data and statistical measures are computed from plot averages. The table is generated for layers that correspond to the "as sampled" comparable layers. The layers are either individual horizons or a grouping of similar horizons specified by the comparable layer ID (see Chapter 4, Step 5.1). Sample size is equal to the number of plots listed under the column "Plot level means." The table also includes the following:

1. Measures of central tendency: Mean and median
2. Measures of variation: Standard deviation (SD), variance, and coefficient of variation (CV)
3. Measures of central range: Quantiles and mean +/- 1 standard deviation (SD)

4. Measures of certainty or confidence about the mean: Standard error and lower and upper 95% confidence interval.

Report 2. General Summary of Dynamic Soil Properties for State Phases. This summary report (Table 4.6-3) includes selected dynamic soil and vegetation properties for each plant community or management system sampled. The table can be generated in two versions: 1) for layers that correspond to the “As Sampled” comparable layers or 2) for “Prescribed Depth Increments,” such as 0-10, 10-20, and 20-50 cm. The report includes information about the range, central tendency (mean and median), and variation (coefficient of variation) in properties. The full range of values for each property represents the low and high sample values among all samples from all plots for each state phase. All other measures are computed from plot means. The central range is typically reported as the interquartile range (75^{th} to 25^{th} quantile).

Report 3. Sampling Sufficiency at the Regional Scale for State Phases. This report (see Appendix 2) provides information about property variance and minimum detectable differences. The information is used to evaluate the numbers of samples collected in a project.

Report 4. Test for Differences Between Means of State Phases. This report (Table 4.6-4) provides the results of statistical tests of differences between state phases or management systems. Information is provided for each property and depth or layer of interest. Standard *t*-tests assuming unequal variances (Welch’s *t*-test) are used when two state phases are compared. When more than two state phases are compared, ANOVA is used. This report includes the variable or property, the depth or layer, the degrees of freedom, the test statistic (i.e., *t* from the *t*-test or F from the ANOVA) and the *p*-value. The *p*-values of less than 0.10 are considered significantly different between state phases.

Report 5. Control Charts of Dynamic Soil Properties for State Phases. This report (Figure 4.6-5) presents control charts that illustrate the central tendency (mean, median) and central range (inter-quartile range) of the reference state and other state phases sampled. The level of statistical evidence for difference (*p*-value) is included if the data are normally distributed. It is commonly prepared for the same properties and layers as those included in **Report 2. General Summary of Dynamic Soil Properties for State Phases.**

Report 6. Variation at the Fine Scale. The variation of sample values within plots can be an important indicator of the level of soil function at the fine scale. This variation can be compared between state phases. If there is interest in this kind of comparison, consult a statistical expert to prepare a report.

Other project deliverables

Vegetation data can be used to describe plant community characteristics in ecological site descriptions. Information provided in the reports can be used to develop function-based soil interpretations, ecological site descriptions, and other information for local resource issues. Function-based interpretations are described in Chapter 5.4.

Table 4.6-2. Report 1. Summary of Data and Statistical Measures for State Phases: As Sampled. Example of two state phases and three properties for layers as sampled.

Summary of Data and Statistical Measures for State Phases for Begay fine sandy loam, 0-6% slopes: As Sampled. Perennial Grass-Shrub (PGS) and Annual Grass (AG) State Phases

			Plot level means				**Measures of central tendency**		**Measures of variation**			**Measures of central range**				**Measures of sampling confidence**		
State phase	**Variable**	**Layer**	Plot 1	Plot 2	Plot 3	Plot 4	Mean	Median	SD	Variance	CV %	25% Quantile	75% Quantile	Mean -1 SD	Mean + 1 SD	SE	Lower 95% CI	Upper 95% CI
PGS	Bulk density, <2mm (g/cm^3)	0-2 cm	1.52	1.54	1.54	1.45	1.51	1.53	0.04	0.00	2.7	1.47	1.54	1.47	1.56	0.02	1.45	1.58
		A horizon without 0-2 cm	1.56	1.52	1.54	1.41	1.51	1.53	0.07	0.00	4.5	1.44	1.56	1.44	1.58	0.03	1.40	1.61
		B horizon to 25 cm	1.59	1.53	1.56	1.52	1.55	1.55	0.03	0.00	2.0	1.52	1.58	1.52	1.58	0.02	1.50	1.60
AG	Bulk density, <2mm (g/cm^3)	0-2 cm	1.27	1.46	1.46	1.48	1.42	1.46	0.10	0.01	6.9	1.32	1.47	1.32	1.51	0.05	1.26	1.57
		A horizon without 0-2 cm	1.38	1.49	1.44	1.37	1.42	1.41	0.06	0.00	3.9	1.38	1.48	1.37	1.48	0.03	1.33	1.51
		B horizon to 25 cm	1.47	1.54	1.51	1.51	1.51	1.51	0.03	0.00	2.0	1.48	1.54	1.48	1.54	0.01	1.46	1.56
PGS	Organic carbon (%)	0-2 cm	0.65	0.65	0.53	0.52	0.59	0.59	0.07	0.00	11.7	0.53	0.65	0.52	0.66	0.03	0.48	0.70
		A horizon without 0-2 cm	0.25	0.30	0.26	0.26	0.27	0.26	0.02	0.00	9.1	0.25	0.29	0.24	0.29	0.01	0.23	0.31
		B horizon to 25 cm	0.14	0.23	0.18	0.18	0.18	0.18	0.04	0.00	21.8	0.15	0.22	0.14	0.22	0.02	0.12	0.24
AG	Organic carbon (%)	0-2 cm	0.77	0.78	0.53	0.62	0.67	0.69	0.12	0.01	17.8	0.55	0.77	0.55	0.79	0.06	0.48	0.86
		A horizon without 0-2 cm	0.38	0.41	0.27	0.40	0.36	0.39	0.06	0.00	17.2	0.30	0.41	0.30	0.43	0.03	0.26	0.46
		B horizon to 25 cm	0.26	0.18	0.16	0.12	0.18	0.17	0.06	0.00	32.7	0.13	0.24	0.12	0.24	0.03	0.09	0.27
PGS	Horizon thickness (cm)	A horizon	7.2	6.5	7.0	7.5	7.0	7.1	0.4	0.2	2.5	6.9	7.3	7.5	6.6	0.2	6.1	7.9
AG	Horizon thickness (cm)	A horizon	4.5	6.5	10.0	10.3	7.8	8.3	2.8	7.8	99.9	6.0	10.1	10.6	5.0	1.4	6.9	13.8

Table 4.6-3. Report 2. General Summary of Dynamic Soil Properties for State Phases: Prescribed Depth Increments. Example includes two state phases and two properties. Values for each prescribed depth are determined from the as-sampled horizon data on a per cm basis and then calculated as a weighted average.

General Summary of Dynamic Soil Properties for State Phases for Begay fine sandy loam, 0-6% slopes: Prescribed Depth Increments.
Perennial Grass-Shrub (PGS) and Annual Grass (AG) State Phases

			Bulk density, <2mm (g/cm^3)					Organic carbon (%)				
			All samples within plots	Central tendency of plot means		Central range of plot means	Variation of plot means	All samples within plots	Central tendency of plot means		Central range of plot means	Variation
Soil map unit component phase	**State phase**	**Depth (cm)**	Range	Mean	Median	Interquartile range	CV %	Range	Mean	Median	Interquartile range	CV %
Begay fine sandy loam, 0 - 6% slopes	PGS	0 - 2	1.27 - 1.91	1.51	1.53	1.47 - 1.54	2.7	0.27 - 0.91	0.59	0.59	0.53 - 0.65	11.7
		0 - 10	1.34 - 1.59	1.52	1.53	1.46 - 1.56	3.50	0.22 - 0.39	0.30	0.29	0.29 - 0.34	10.90
		2 - 10	1.33 - 1.62	1.52	1.53	1.46 - 1.56	2.70	0.15 - 0.34	0.23	0.23	0.21 - 0.27	14.50
		10 - 25	1.46 - 1.62	1.55	1.55	1.52 - 1.58	3.80	0.13 - 0.27	0.18	0.18	0.15 - 0.22	21.80
		0 - 25	1.45 - 1.61	1.54	1.54	1.50 - 1.57	2.00	0.16 - 0.32	0.23	0.22	0.20 -0.27	15.40
	AG	0 - 2	1.01 - 1.67	1.42	1.46	1.32 - 1.47	6.9	0.26 - 1.48	0.67	0.69	0.55 - 0.77	17.8
		0 - 10	1.34 - 1.55	1.44	1.43	1.39 - 1.49	3.60	0.15 -0.66	0.40	0.42	0.34 - 0.43	13.50
		2 - 10	1.34 - 1.55	1.44	1.43	1.40 - 1.50	3.70	0.13 -0.57	0.33	0.33	0.28 - 0.37	15.50
		10 - 25	1.42 - 1.59	1.50	1.50	1.48 - 1.53	2.00	0.07 - 0.32	0.19	0.17	0.37 - 0.24	25.60
		0 - 25	1.40 - 1.57	1.48	1.47	1.44 - 1.52	2.60	0.11 - 0.41	0.27	0.27	0.15 - 0.24	14.20

Table 4.6-4. Report 4. Test for Differences Between Means of State Phases. Example of statistical comparisons between state phases. The *p*-values equal to or less than 0.10 are considered to be statistically significant for soil survey purposes. The *p*-values indicate that organic carbon (%) and bulk density are significantly different between state phases for the layer "A horizon without 0-2cm." Organic carbon (kg/m^2) is different for the 2-10 cm layer. Organic carbon and bulk density for other layers as well as A horizon thickness were not significantly different between state phases. Welch's *t*-test, which assumes unequal variances, was used to test for a significant difference. Basic t-test software will estimate degrees of freedom for each test.

Test for Differences between Means of State Phases for Begay fine sandy loam, 0 - 6% slopes.
Perennial Grass-Shrub (PGS) and Annual Grass (AG) State Phases

		State phase mean		**Difference in means**	**Degrees of freedom**	***t*‡**	**F‡**	***p*-value**
Variable	**Layer**	PGS	AG					
Bulk density, <2mm (g/cm^3)	0-2 cm	1.51	1.42	0.09	4.1	-1.84	-	0.138
Bulk density, <2mm (g/cm^3)	A horizon without 0-2 cm	1.51	1.42	0.09	5.8	-1.97	-	0.099
Bulk density, <2mm (g/cm$^{3)}$	B horizon to 25 cm	1.55	1.51	0.04	6.0	-1.90	-	0.106
Organic carbon (%)	0-2 cm	0.59	0.67	0.08	4.8	1.22	-	0.281
Organic carbon (%)	A horizon without 0-2 cm	0.27	0.36	0.09	3.9	2.87	-	0.047
Organic carbon (%)	B horizon to 25 cm	0.18	0.18	0.00	5.3	-0.11	-	0.919
Organic carbon (kg/m^2)	0 - 2 cm	0.18	0.19	0.01	5.5	0.58	-	0.584
Organic carbon (kg/m^2)	2 - 10 cm	0.28	0.38	0.10	5.5	2.75	-	0.037
Organic carbon (kg/m^2)	10 - 25 cm	0.42	0.42	0.00	5.9	-0.06	-	0.958
Horizon thickness (cm)	A horizon	7.04	7.81	0.77	3.0	-0.06	-	0.623

‡ The test statistic "*t*" is provided for *t*-tests and "F" for ANOVA tests

Figure 4.6-5. Report 5. Control Charts of Dynamic Soil Properties for State Phases for Begay fine sandy loam, 0-6% slopes. Example includes two state phases and three properties. These charts illustrate the central tendency and range of variability in properties for each state phase. This is a graphical method of depicting property means, medians, and their range. The box plot at the left side of each chart is the reference state phase. Horizontal lines across each chart (marked by a bracket and arrow) represent high (maximum) and low (minimum) plot means of the reference state phase. These horizontal lines are equivalent to the whiskers shown on basic box and whisker plots only if the whiskers represent the maximum and minimum plot observations. The upper and lower values of the shaded box represent the central range of values for the property as determined by the 75th and 25th quartiles, respectively. Use *p*-values to determine the level of statistical evidence for a difference. For soil survey inventory work, *p*-values of less than 0.10 or even 0.20 can be considered significant. Values of less than 0.05 are commonly used in controlled plot research. In this example, the reference state is represented by the perennial grass-shrub (PGS) plant community (state phase).

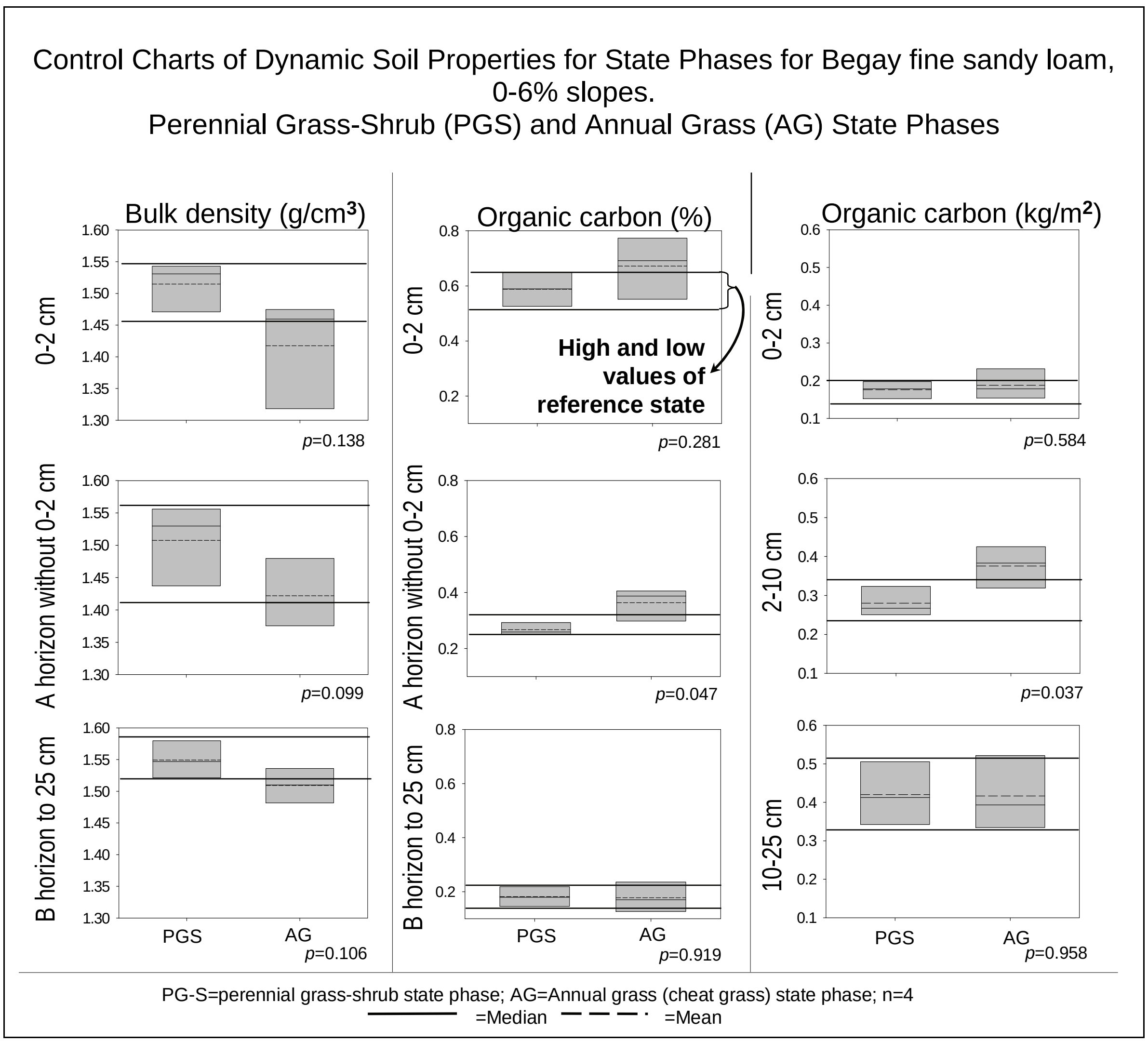


Exhibit 4.6-1. More Than You Really Wanted To Know About Statistical Tests

Statistical tests are used to validate hypotheses about the relationships of groups or treatments. A test is used to validate the null hypothesis, in this case, that there is no difference between state phases on a given soil map unit component phase. The test can be used to assign a statistical likelihood that the differences observed between state phases are caused by chance alone.

Statistical tests come in a variety of forms. The statistical test used is determined primarily by the type and number of variables and the number of state phases being compared. Certain tests are used for continuous variables, such as organic matter content. Other tests are used for discrete variables that have a limited number of possible values, such as soil surface stability classes. Standard statistical software handles a great variety of these statistical tests.

Each statistical test has its own set of assumptions about the data underlying its output. For instance, ANOVA (analysis of variance) assumes independence of samples, normality of sample distribution, and homogeneity of variances (the variances of the state phases are not significantly different). The random and independent selection of plot locations helps to ensure that the first assumption is met. Normality and homogeneity need to be visually or statistically verified. Welch's *t*-test (or *t*-test with unequal variances) assumes normality and independence of samples, but not homogeneity of variance. Deviations from these assumptions will require advanced methodology to assess and may require consultation with a statistician.

The output from these tests typically (at a minimum) will include the test statistic, the degrees of freedom, and the *p*-value. The test statistic (i.e., t in a *t*-test and F in an ANOVA) describes the position of the observed difference in a distribution characteristic of the statistical test and the degrees of freedom. The degrees of freedom are the number of statistically independent (or independent pieces of information) that go into a statistical measure. The *p*-value is an indication of the evidence for or against the null hypothesis.

The *p*-value is often used as an indicator of statistical significance. It answers the following question: If the null hypothesis (no difference between state phases) is true, what is the probability that random sampling would lead to a difference between sample means as large as or larger than the one that was actually observed? Typically if this likelihood (or probability), described by a *p*-value, is low enough, the differences observed likely reflect true differences between the state phases and thus we reject the null hypothesis and conclude that the state phases are truly different.

Chapter 5 Interpreting Soil Change and Soil Function

Figures

Tables

Exhibits

Chapter 5 Interpreting Soil Change and Soil Function

5.1 Introduction

Importance of information about the effects of management
Information about how soils change and human impacts on soil function is crucial to sustainable soil management on agricultural and nonagricultural lands. Of particular interest are changes that occur within the human time scale. Knowledge of attainable soil conditions under specific land uses and management systems in combination with the procedures that predict management responses will help policy makers, land managers, producers, and others who make decisions that protect soil function.

Dynamic soil property data will improve our ability to explain and quantify changes in soil function. For example, soil aggregate stability and infiltration rate often decrease where the content of organic matter has decreased. Changes in these dynamic soil properties may affect water availability, resistance to erosion, and ultimately, production. The effects of these changes are predictable, although not always quantifiable. Furthermore, where these changes cause a decrease in productivity, organic matter inputs decrease and organic matter levels can decline even more. The downward trend of the content of organic matter content in this situation illustrates the importance of providing information to land managers about the effects of management on dynamic soil properties.

This chapter describes the fundamental concepts currently developed for soil survey and resource inventory. As knowledge gaps are filled, the material in this chapter will likely be improved. Three major topics are discussed:

- Soil function
- Understanding soil change
- Interpreting soil change and soil function

5.2 Soil Function

Emerging needs
During the last few decades of the twentieth century, the focus of user's needs for soil surveys expanded from erosion control, productivity, land use planning, and infrastructure development to include soil, water and environmental quality, sustainability, climate change, food-security, bio-terrorism, and biofuel issues. Information about how the soil's capacity to function has and can change is critical to the

management of these issues. Function-based interpretations can help land managers and policy makers to:

- Plan for long-term productivity and sustainability,
- Protect, maintain, and restore ecosystem functions and services provided by soil,
- Design and interpret monitoring and assessments for resource condition,
- Predict the effects of management on soil, and
- Adjust management practices for changes in near-surface soil behavior.

Defining soil function

Soil function describes what the soil does. Soil sustains, regulates, and controls biotic and abiotic processes through its interactions with the biosphere, hydrosphere, atmosphere, and lithosphere (Yaalon, 2000). Soil function, ecological function, soil ecosystem function, and ecosystem services are similar concepts. They represent services provided by natural and agricultural systems. Soil functions are described in a number of different ways, and a particular function is often expressed with slightly different terms by a variety of authors. These are summarized in Exhibit 5-1. For the purposes of this **Guide**, the primary functions of interest are those that will ensure the possibility that soil can perform all other functions, such as providing goods, services, and cultural benefits and filtering and buffering environmental pollutants. These functions are:

- Provide a stable medium for plant growth and human structures,
- Buffer and moderate the hydrologic cycle, and
- Maintain carbon, nutrient, and element cycling.

Measuring soil function

Soil function cannot be measured directly, but certain soil properties that reflect complex processes and functions can be measured (Karlen and Stott, 1994). For example, a high bulk density value can indicate limited root penetration or poor aeration. Various methods of detecting change in soil function are summarized in Chapter 2, Exhibit 2-1. According to the procedures described in this **Guide**, change is inferred by substituting space for time and comparing measurements of dynamic soil properties for different management systems or ecological states.

Functionally important differences

In the context of this **Guide**, a functionally important difference in dynamic soil or vegetation properties is a difference sufficiently large to reflect or cause an important difference in soil or ecosystem function. Minor differences in dynamic soil properties among management systems may correspond to minor but not “important” differences in the functional capacity of the soil and are expected to occur.

5.3 Understanding Soil Change

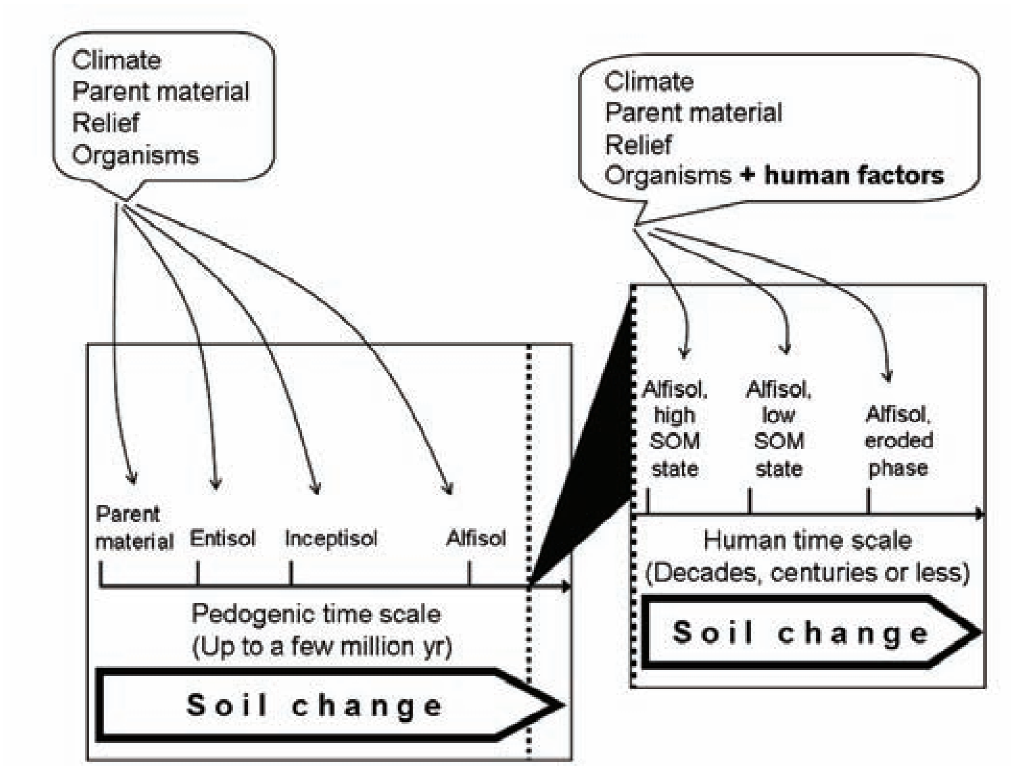
What is soil change?

Simply stated, soil change is variation in soil properties at a specific location over time. Soil properties emerge as a result of pedogenesis, are affected by historical land use, and are subject to change in modern agricultural systems and all other ecosystems (Richter and Markewitz, 2001). Soil scientists often make such statements as, "The soil changes across a soil boundary line" or "Soil properties change through the continuum of an ecotone." These statements convey information about spatial variability, not temporal variability. Rather than using the word "change" to represent differences in properties across the land, more appropriate terms include "spatial variability," "variation," "vary," and "differ."

Pedology and soil change

The study of pedology encompasses human influences on soil. Jenny's (1941) model of the five soil-forming factors and the pedologic processes described by Simonson (1959) apply to the study of soil change. Just as the soil-forming factors act through time, changes to a system require time but are not caused by time (Figure 5-1). Change results from variation in physical force or energy, whether the force is climate change on a geologic time scale, absence of fire on a centurial time scale, or use of a plow on a seasonal time scale. A special term for the study of human-altered pedogenesis is metapedogenesis (Yaalon and Yaron, 1966; Richter, 2007). Providing instructions on how to study metapedogenesis is not the objective of this **Guide**, although some of the procedures may be applicable.

Figure 5-1. Soil-Forming Factors and the Human Time Scale.
(Tugel et al., 2005; permission to reprint). The human time scale is a subset of the pedogenic time scale.



Importance of soil change

Soil change is important primarily because of the effects of change on soil function. In one context, the ultimate consequences of soil change depend on its reversibility (Arnold et al., 1990). For others, success in enhancing the soil functional capacity of soil to produce goods and services while minimizing effects on the environment is paramount. Minimizing the consequences of change so that all future goals for soil function can be attained is an overarching goal for long-term soil conservation and resource management.

Concepts intrinsic to understanding soil change

Knowledge of soil change and soil function is somewhat limited and not fully synthesized. Furthermore, property-process relationships are quantified for only a few processes (Palm et al., 2007). With information about the relationships between properties, processes, and human impacts on soil and soil function, soil scientists working together with other discipline specialists can begin to quantify and predict changes in function (Homann and Grigal, 1996). The concepts intrinsic to understanding soil change are included in the following: human time scale, dynamic soil properties, attributes of soil change, ecological processes, stressors and disturbances, degradation processes, resistance and resilience, spatial scale and variability in space and time, and the effects of management on property-process-pattern relationships as well as the soil functions described previously in this document. Attributes of soil change, also called soil change metrics, are described in Exhibit 5-2.

The human time scale

The relevant temporal scale for studying human impacts on soil is the human time scale, which spans centuries, decades, and less (Tugel et al., 2005). Change-related soil survey procedures emphasize the decadal and centurial scales. A land manager's lifetime, i.e. the scale of decades, is relevant for the implementation of new management practices. The time scales that relate to the time frame of recovery, however, include decades and, particularly in arid and semiarid environments, even centuries (Stringham et al., 2003).

Numerous factors can be used to define the time zero for the human time scale. These include climate, geomorphology, ancient civilizations, and termination of disturbances. The current climate governs the geomorphic processes that are shaping or preserving the landscape today. Even though direct human impacts on soil can be dramatic, the combination of climate and geomorphic processes transcend these impacts over the long term. Consequently, a climatic-geomorphic rationale is recommended in this **Guide.** Thus, time zero of the human time scale is no earlier than the beginning of the most recent episode of climatically controlled landscape development, even though human impacts may have occurred prior to that time.

Dynamic soil properties

Almost all soil properties change eventually. Dynamic soil properties are those that change within the human time scale in response to management and natural and anthropogenic disturbances and stressors. Dynamic soil properties that can reveal the most about changes in soil function are included in the minimum data set for comparison studies (see Chapter 4, Step 2.5). Dynamic soil properties include use-dependent properties (Grossman et al., 2001). Dynamic soil properties are also called state variables.

Attributes of soil change

Quantifying change and its effect on processes and function requires data for attributes of soil change (Tugel et al., 2005). These attributes include state variables (dynamic soil properties), fluctuation, trend, rate, feedback, pathway of change, threshold, reversibility, and characteristic response time. Information about these attributes can help land managers predict the effects of management and evaluate alternatives. Values for dynamic soil properties and trend can be determined from studies conducted in accordance with this **Guide**. Short-term fluctuations can be measured with short-interval monitoring. Quantifying rates, pathways of change, and thresholds generally requires long-term studies. See Exhibit 5-2 for a more detailed discussion of some of these attributes.

Ecological processes

Changes in soil properties result from and produce variation in processes. The primary ecological processes are energy flow, the hydrologic cycle, and nutrient cycling. These ecological processes describe the movement of ecological currency (i.e., energy, water, and nutrients) through a system. These processes occur because of interactions among soil and the other components of an ecosystem. Changes that can be measured by comparing temporally variable or "dynamic soil properties" among management systems actually reflect the change in process. For example, a loss of soil organic matter results in decreased nutrient cycling.

Stressors and disturbances

Stressors and disturbances cause significant changes in ecological processes as well as the components (including dynamic soil properties) and patterns of the components in ecological systems (Barrett et al., 1976; White, 1979). Stressors and disturbances can be either natural or anthropogenic. Stressors are prolonged or continuous factors and include climate change, prolonged drought, farming, heavy continuous grazing, fire suppression, and invasive species. The term "disturbance," as used in this **Guide**, represents relatively discrete events in time. Each occurrence of the following is an example: plowing, fertilization, irrigation, brush removal, fire, flooding, short-term drought, high-intensity storms, and high winds. Many disturbances are an integral feature of natural systems and necessary operations in managed systems. Disturbance regimes, such as recurring fire in natural systems, are characteristic of many systems.

It may take decades or longer for the cumulative effects of stressors to cause a functionally important change in dynamic soil properties. Discrete disturbance events, however, can precipitate almost immediate change. Episodic events, such as hurricanes and drought, are often the events that trigger a detrimental shift in systems that have experienced gradual change resulting from long-term management impacts (Scheffer et al., 2001).

Degradation processes

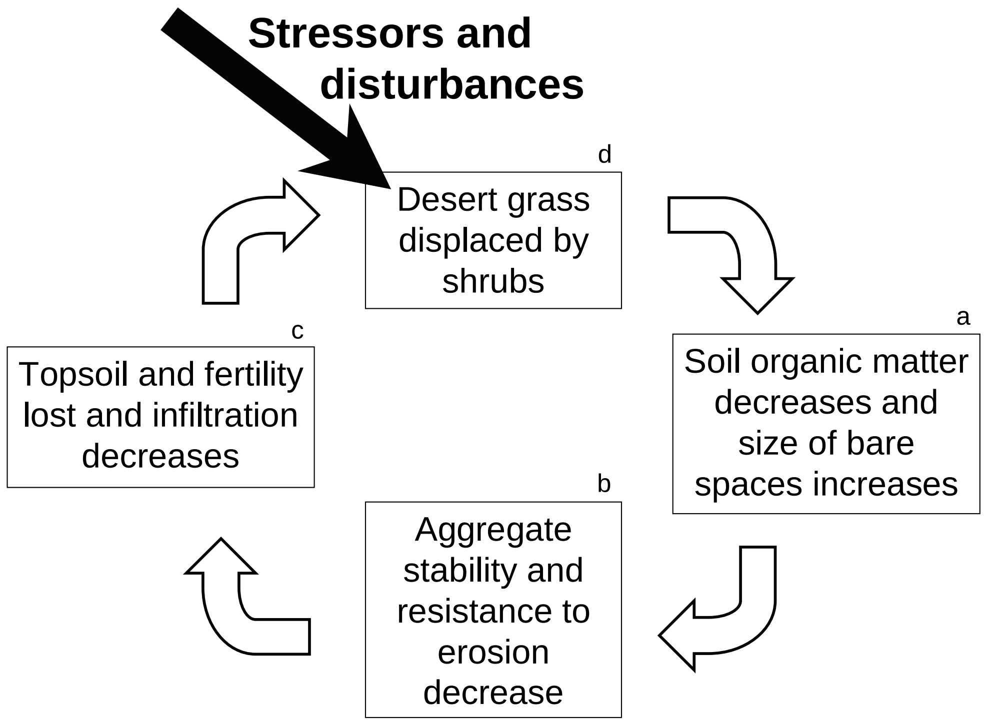
Soil degradation can be defined as changes in soil properties and processes leading to a reduction in ecosystem services and soil function (Palm et al., 2007). The soil degradation processes identified in Table 5-1 are associated with many land cover types. The physical, chemical, biological, and mineralogical processes are listed separately for simplicity. These processes interact, however, in most situations. The functional capacity of soil is impacted by soil degradation processes (Herrick and Whitford, 1999) and positive or negative feedbacks among soils, plants, animals, climate, and management (Figure 5-2). When developing and updating state-and-transition models (see Chapter 2.2; Chapter 4, Step 1.4), include specific degradation processes (mechanisms) involved in transitions.

Table 5-1. Causes, Degradation Processes, and Impacts of Four Types of Soil Degradation. (Modified from Palm et al., 2007). The relationships of degradation processes and impacts to causes are likely to be many to one.

<table>
<tr><th>Causes</th><th>Degradation process
(not one to one along row)</th><th>Impact on:</th></tr>
<tr><td colspan="3">PHYSICAL SOIL DEGRADATION</td></tr>
<tr><td>Deforestation</td><td rowspan="6">– Degradation of soil structure, aggregates, and porosity; including breakdown and reduction in proportion and strength/stability of aggregates, leading to reduction in porosity.
– Crusting and surface sealing.
– Soil heating
– Fire-induced water repellancy
– Compaction of surface and subsoil
– Accelerated erosion by water and wind.
– Deposition
– Litter removal</td><td rowspan="6">– Soil water relations
– Leaching and runoff of nutrients and water
– Energy exchange
– Water quantity
– Hydrologic response to rain events
– Susceptibility to water and wind erosion</td></tr>
<tr><td>Biomass burning, catastrophic wild fire</td></tr>
<tr><td>Tillage up and down slope</td></tr>
<tr><td>Excessive animal, human, and machine traffic; improper heavy equipment use; overgrazing</td></tr>
<tr><td>Road and trail construction</td></tr>
<tr><td>Altered surface hydrology</td></tr>
<tr><td colspan="3">CHEMICAL SOIL DEGRADATION</td></tr>
<tr><td>Irrigation with poor quality water, inadequate drainage</td><td rowspan="4">– Salinization
– Alkalinization
– Water logging and oxygen depletion
– Nutrient depletion
– Nutrient enrichment
– Acidification
– Toxification (contamination with heavy metals, pollution)
– Accumulation of pathogens and pharmaceuticals</td><td rowspan="4">– Plant species suitability and composition
– Infiltration and water movement related to alkalinization
– Nutrient availability and toxicity
– Heavy metal toxicity
– Water quality and eutrophication of water bodies
– Human and animal health</td></tr>
<tr><td>Little to no use of fertilizers</td></tr>
<tr><td>Excess use of fertilizers</td></tr>
<tr><td>Application of industrial, urban wastes</td></tr>
</table>

BIOLOGICAL SOIL DEGRADATION		
Burning or excess removal of residues	– Changes in litter accumulation (reorganized, transported, increased, decreased) – Depletion of soil organic carbon (decomposition) – Reduced organic matter accumulation – Decline in diversity and abundance of soil biota – Loss of soil structure – Soil heating	– Reduction in N mineralization – Shift in species composition and diversity of soil organisms – Reduction in soil aggregation, porosity and infiltration, – Habitat for soil biota – Soil doughtiness
Little or no use of organic inputs		
Monoculture, excessive tillage		
Conversion of land use, plant community, or plant functional groups		
Invasive species		
Improper use of pesticides		
Loss of topsoil		
Artificial drainage		
MINERALOGICAL SOIL DEGRADATION		
Artificial drainage, seepage	– Drainage and oxidation of sulfidic soil materials (iron pyprite, FeS_2) – Loss of mineral CEC	– Soil and water acidity (pH< 5) – Water quality – Nutrient holding capacity
Excess use of acidifying fertilizers		

Figure 5-2. The Effects of Management on the Interactions Between Plants and Soils. In this example, heavy continuous grazing followed by drought produces positive feedbacks between vegetation and soil properties that enhance physical, chemical, and biological degradation processes. These feedbacks lead to the following: a) a decrease in soil organic matter and an increase in size of bare spaces, b) a decrease in soil aggregate stability and resistance to erosion, c) a loss of topsoil and a decrease in infiltration, and d) an additional loss of grass and increase in shrubs, which cause the feedback loop to continue. Curved arrows represent physical, chemical, and biological degradation processes. (Figure modified from Bird et al., 2001.)



Resistance and resilience

The resistance and resilience of soil are the capacity of a particular soil to respond to stressors, disturbances, and management (Blum, 1997; Seybold et al., 1999). Resistance is the capacity of a soil to maintain functional capacity through disturbances. Resilience is the capacity of the soil to recover the functional and structural integrity lost after a disturbance or prolonged stress. Some concepts of resilience incorporate resistance to change as well as the capacity to recover (Holling, 1973; Szabolcs, 1994; Gunderson, 2000; Tenwya et al., 2006). Soil resilience differs somewhat from ecological resilience. Ecological resilience involves multiple subsystems of the ecosystem (Walker et al., 2004). Thus, soil resilience as used in this **Guide** is considered a component of ecological resilience.

Spatial scale and variability in space and time

The spatial variability of dynamic soil properties depends upon the type of soil, the plant community, the scale of disturbance, and the management history as well as the scale of measurement (Wilding et al., 1994). For the purposes of this **Guide**, spatial variability at the fine, local, and regional scales is considered (see Chapter 4, Step 2.4). Changes in spatial variability through time can occur as a result of stressors, disturbances, and management and are sometimes produced at one scale but not another or are expressed differently at various scales.

Legacies from past land use and management can persist in modern systems (Foster et al., 2003). For example, tillage-related decreases in soil organic matter can persist for many years, especially in limiting climates (McLauchlan, 2006). Understanding legacies and historic ranges of anthropogenic and nonanthropogenic variability is essential in interpreting modern changes in soil, although this knowledge does not include all of the information necessary for predicting future change (Millar and Woolfenden, 1999; Parsons et al., 1999).

The effects of management on property-process-pattern relationships

The spatial variability of dynamic soil properties is often associated with spatial patterns of vegetation or surface morphology, such as coppiced shrubs and concave intershrub spaces. Because dynamic soil properties reflect processes, a property-process-pattern relationship can be established. Furthermore, patterns can shift and reorganize through time in response to stressors, disturbances, and vegetation dynamics (Bestelmeyer et al., 2006). Information about these patterns and their relationship to function is important in many systems. An example in a cropland system includes row and furrow components of a field and their effect on 1) salt redistribution within the soil after irrigation and 2) toxic salt damage to the crop (Ashraf and Saeed, 2006; Miyamoto and Cruz, 1987; Wadleigh and Fireman, 1949).

5.4 Interpreting Soil Change and Soil Function

Traditional and function-based interpretations

In the traditional soil survey perspective, soil interpretations summarize predicted responses and behavior for similar soils. They are commonly used to evaluate the suitability of one soil relative to another and to identify limitations that need to be overcome for the intended use. Function-based interpretations provide information about a variety of land use and management conditions for similar soils. The information can be used to:

- Evaluate actual conditions with respect to inherent and attainable conditions,
- Predict the effects of changes in the conditions, and
- Set goals to improve a particular type of management system on a particular kind of soil.

The key concepts and techniques used to summarize, synthesize, and extend information about soil function and changes in function are described in this section.

Inherent, attainable, and actual functional levels

Soil interpretations should support management needs. Furthermore, management with respect to soil function and soil change requires information about the condition of the soil as it could be (natural potential, managed potential) and the condition that actually exists. Some authors describe these conditions as potential, attainable, and actual (Ingram and Fernandes, 2001; Dick and Gregorich, 2004). The terms used in this **Guide** are inherent, attainable, and actual (Figure 5-3).

The inherent and attainable concepts incorporate steady-state conditions. That is, soil properties that change in response to land use and management will, over time, reach a new steady-state condition. When land use is modified or a new management system is initiated, many soil properties will begin to change. The rate of change of the various properties may differ, but all will eventually reach a new level that is considered to be the steady-state condition for that land use, management, and soil combination. Though important, the comparison study procedures in this **Guide** do not provide information that can be used to quantify rates of change.

- The inherent level is the innate capacity of a given soil to function. The inherent capacity is determined by environmental factors, called capacity factors (climate, parent material, relief, and organisms over time). Inherent soil conditions occur under nondegraded native plant communities where past management has not degraded the soil. Under the comparison study procedures in this **Guide**, inherent soil conditions are documented for mature or late succession plant communities at steady-state. The term “steady-state” is used broadly here to refer to a condition in which there is minimal directional change (trend) of dynamic soil properties. The steady-state concept has fallen out of favor in the ecological literature as, strictly interpreted, it implies no change. We apply it here to include natural variation (fluctuation) in response to short-term climate variation (weather), and we understand that there is no true steady-state.

- The attainable level is the functional level that is possible for a given soil under a given management system. In combination with the inherent capacity factors, many other factors determine what is attainable. These determining factors include management inputs (e.g., fertilization, irrigation, and weed and pest management), plant characteristics (e.g., kind of plant functional group or crop, plant variety, and shoot-root ratio), and long-term climate fluctuations. Attainable soil conditions occur under a management system or plant community at steady-state. The attainable condition can be lower or higher than inherent levels.

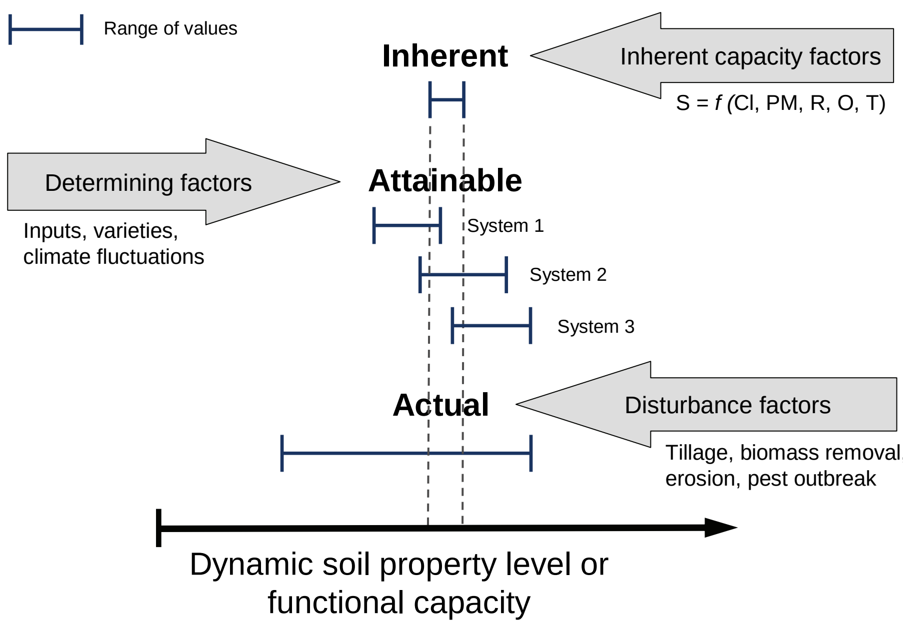
- The actual level is the functional level of a given soil and management system at a given point in time. The factors that determine the actual functional level include those that determine the inherent and attainable levels as well as disturbance factors that constrain the system. Improper or poorly applied practices (e.g., excessive tillage, excessive biomass removal, and poor nutrient management) and other stressors and disturbances (e.g., short-term drought, pest outbreaks, and excessive rainfall) can reduce the attainable level to an actual condition. Actual condition can also reflect proper management that has not had sufficient time to reach the attainable condition. All other factors that affect the day-to-day decisions of the land manager, including economics, environmental considerations, and beliefs about successful management practices, can influence the actual condition. Actual soil conditions are associated with any management system or plant community in any condition, including steady-state.

Inherent and attainable steady-state conditions are quantified through soil survey work. Where needed, actual conditions are measured by the land manager. Function-based interpretations facilitate the evaluation of inherent, attainable, and actual conditions. Although all situations that could be documented are, in reality, actual conditions, many of them do not reflect inherent conditions or have not achieved attainable levels.

Inherent and attainable conditions and the reference state

Inherent and attainable conditions can be used as targets or yardsticks in soil assessment and management. Depending on the situation, either inherent or attainable conditions serve as the reference condition for resource assessments. For range and forest-land management, the reference state includes the plant community in inherent condition, if it still exists. Where inherent conditions no longer exist, one of the multiple alternative stable states depicted in a state- and -transition model is designated the reference state. The relationship between reference state and attainable is not one to one. All states can have an attainable condition, but only one state is designated the reference state for range and forest-land management. Inherent or attainable conditions defined by a plant community are useful for describing how cropland soils have changed, but have little value as a target, yardstick, or reference state when cropland management is evaluated with respect to a cropland potential. For this purpose, a cropland system in attainable condition is a useful "yardstick."

Figure 5-3. Factors Influencing Dynamic Soil Property Values and Functional Levels as Related to Three Conditions: Inherent, Attainable, and Actual. The factors influencing the functional capacity and condition of a specific soil include capacity factors, determining factors, and disturbance factors (broad arrows). "Inherent" applies to a nondegraded native plant community at steady-state. "Attainable" applies to a particular management system at steady-state. Dynamic soil property or functional capacity levels are presented for three different attainable management systems in this example. Values lower and higher than the inherent range of values signify departure from the inherent condition. In this figure, the range of values for "actual" represents the combined range of many different management systems. If "actual" is higher than "attainable," it represents a specific management system not included in the soil inventory data. Vertical dashed lines represent the inherent range of values at steady-state.



Techniques for developing function-based and soil change interpretations
A number of techniques are involved in the development of function-based soil survey interpretations for land use and management. When interpreting soil change and its effect on function, apply one or more of the following techniques: 1) identification of characteristic values for inherent and attainable conditions, including the reference state, 2) qualitative or quantitative estimation of functional capacity, 3) synthesis of cause-and-effect relationships using state-based models, 4) space-for-time substitution to describe

change, 5) application of long-term study and monitoring data to quantify rates and thresholds of change, and 6) identification of similar soils to extend interpretations.

1. **Identifying characteristic values.** Characteristic values for soil and vegetation properties are provided for inherent and attainable steady-state conditions. They can be reported for conditions that represent the reference state and for alternative states or management systems. The characteristic values for a state phase can include any of the following: 1) measures of central tendency (mean, median), 2) a measure of variation (standard deviation), and 3) measures of the range of variation for the state phases (25^{th} and 75^{th} quartile; mean +/- SD, minimum and maximum plot level means or medians).

2. **Estimating functional capacity**. Procedures to quantify functional capacity for many key soil functions across the majority of soils are not readily available. Until these procedures, which may include simulation models, are fully developed, dynamic soil properties will be used to reflect processes and functional levels.

3. **Synthesizing soil change data**. Soil scientists use conceptual landscape models to map soils. In a similar manner, a conceptual management model of cause-and-effect relationships is used to predict soil change and the effects of management on soil function. State-based models are described in Chapter 2.2. The models provide a framework to organize and display information about cause-and-affect relationships among states (specific management systems or plant communities), inherent and attainable conditions, management practices and disturbances, and dynamic soil properties for soils having the same initial conditions.

4. **Substituting space for time.** The space-for-time substitution technique (see Chapter 2.1) is used to make statements about how soils have changed, particularly where insufficient long-term monitoring data are insufficient. It is applied to data collected for management systems identified within the conceptual model.

5. **Applying long-term study and monitoring data.** Additional interpretations are possible where long-term study data are combined with comparison study data. Long-term studies can provide data to describe rates, thresholds, and pathways of change. This information is important in interpreting human impacts and ecological processes related to soil change and soil function.

6. **Extending relationships to similar soils.** Conceptual management models commonly apply to groups of similar soils, such as those soils correlated to an ecological site. Consequently, descriptions of the effects of management on soil and soil function for one soil can be applied to other soils represented by the model.

5.5 Interpretations and Reports for Sustainable Soil Management

Products for planning, assessment, and monitoring
Project data can be used to develop a number of interpretations for sustainable soil management. These interpretations include characteristic values, indicators, and ratings for resistance and resilience. These soil survey products can be used for planning, resource assessment, and monitoring. See Chapter 4, Step 6.7, for **Reports 2** through **5** described below.

Report of characteristic values
Characteristic values can be provided for any plant community or management system sampled at or near steady-state conditions. In special cases, the management systems that are sampled may not have achieved steady-state. These situations are likely where change is gradual and requires many decades to level off. In these situations, clearly describe the length of time that a system has been in place. Two reports are available to present characteristic values. **Report 2. General Summary of Dynamic Soil Properties for State Phases** is a tabular option and **Report 5. Control Charts of Dynamic Soil Properties for State Phases** is a graphical display of characteristic values for each state phase or management system. Prepare these reports for properties and layers for which the sampling was sufficient to detect the desired minimum detectable difference as presented in **Report 3. Sampling Sufficiency at the Regional Scale for State Phases**. Control charts present the same statistical measures that are included in **Report 2.** These charts effectively illustrate the central range of variation of the property, which can be useful for interpreting soil quality and other assessments.

Characteristic values can be used in the evaluation of resource assessments and monitoring data with respect to inherent and attainable conditions or the reference state. They can also be used to improve practice designs.

Report of indicators for assessment and monitoring
Identifying indicators for resource assessment and monitoring is one example of a function-based interpretation. An indicator is a property that reflects functions and processes that cannot be readily measured. Dynamic soil properties can reflect changes in many important soil functions and are commonly used as indicators. Furthermore, comparison studies can be used to identify properties that are different among states. Because state phases are measured at steady-state, it is important to understand that those properties that change after a disturbance and then recover to the level of the reference condition will not be revealed as properties that change in a comparison study. Those that do differ among states can reflect either desirable or undesirable changes. Those properties that exhibit undesirable changes and that are difficult to reverse can be very important indicators to assess sustainability. These properties should be included in a report of indicators suitable for detecting changes that persist at steady-state conditions.

Conducting assessments and monitoring for reversible changes also are objectives for many land managers. Other dynamic soil properties not included on the list of properties that persist may also be valid indicators for detecting change directly following a disturbance or a recently applied management practice.

The interpretation report should include a list of suitable indicators (dynamic soil properties) that can be used to document persistent changes. Before using a data set to identify indicators, evaluate “how good” the data is by looking at the sampling sufficiency in **Report 3. Sampling Sufficiency at the Regional Scale for State Phases**. The data are adequate for this interpretation if the actual sample size was sufficient to detect a functional difference. The actual minimum detectable difference should be great enough to be considered functionally important. The next step is to evaluate the difference in state-phase means. The differences should be reflected with a strong level of statistical evidence (review results of *t*-test or ANOVA in **Report 4. Test for Differences between Means of State Phases)**. Properties for which a functionally important difference was detected but for which the level of statistical significance in the difference is weak may require additional sampling to make the interpretation. Refer to Appendix 2 to determine new sampling requirements.

Suitable indicators can be incorporated into assessment and monitoring programs for soil quality, rangeland health, forest health, and environmental health. The indicators can be used to evaluate the status of current conditions with respect to characteristic values for inherent or attainable conditions (e.g., the reference state).

Interpretations of resistance and resilience

Information about changes in soil function can be used to develop soil resistance and resilience ratings. Simple computations for resistance and resilience have been developed using dynamic soil properties data (Seybold et al., 1999; Tugel et al., 2005). More complex approaches are available (Szabolcs, 1994). Also refer to Exhibit 5-2 for a discussion of reversibility. Standardized qualitative and quantitative methods for estimating and computing resistance and resilience have not yet been developed for soil survey.

Soil resistance and resilience ratings provide important information for sustainable soil management, restoration planning, and risk assessments. The interpretations can be used by land managers and decision makers to:

- Promote positive changes in the soil resource and the environment,
- Identify land at risk of degradation, and
- Avoid further degradation.

Conceptual models for information delivery

State and transition models in ecological site descriptions and other conceptual models depicting soil, management, and vegetation dynamics serve as communication tools and decision aids. The models and pertinent ecological site descriptions should be updated at the completion of each project. These models convey information to help producers and land managers understand the effects of management on soil function. With knowledge of the effects of management on functionally important soil properties, land managers can choose practices and policy makers can establish programs that meet their individual goals.

Exhibit 5-1. A Review of Soil Functions Described in the Literature

Soil functions relating to agricultural production, human and animal health, and environmental concerns are presented in the soil quality literature (Larson and Pierce, 1991; Parr et al., 1992; Doran and Parkin, 1994; Karlen and Stott, 1994; Acton and Gregorich, 1995; Seybold et al., 1997; Andrews et al., 2004). These functions focus on 1) sustaining biological activity, diversity, and productivity; 2) regulating and partitioning water and solute flow; 3) cycling, storing, releasing, regulating, transforming, filtering, or buffering water, nutrients, and environmental pollutants; 4) storing and cycling nutrients and other elements within the Earth's biosphere; 5) providing a medium for root growth; 6) maintaining soil biological habitat; and 7) resisting structural degradation. Harris et al., (1996) list nutrient relations, water relations, toxicant relations, pathogen relations, rooting relations, esthetic relations, and physical stability. In a description of the role of soil in ecosystems, Warkentin (1995) includes an additional function, the partitioning of energy.

One author, Daily (1997), defines ecosystem services as the processes through which natural ecosystems sustain and fulfill human life and includes the following services: 1) maintaining biodiversity and the production of ecosystem goods; 2) life-support functions, such as cleansing, recycling, and renewal; and 3) intangible asthetic values. Daily specifically describes ecosystem services supplied by soil as follows: 1) buffering and moderation of the hydrologic cycle, 2) physical support of plants, 3) retention and delivery of nutrients to plants, 4) disposal of wastes and dead matter, 5) renewal of soil fertility, and 6) regulation of major element cycles.

The Millennium Ecosystem Assessment (Hassan et al., 2005) provides the following definition: "Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food and water (products), regulating services such as regulation of floods, drought, land degradation, and disease, supporting services such as soil formation and nutrient cycling, and cultural services such as recreational, spiritual, religious, and other nonmaterial benefits." Supporting services are essential for the production of provisioning, regulating, and cultural services.

Soil functions identified by Blum and Santelises (1994) include 1) ecological functions similar to those described above and 2) the following cultural functions: a base for structures, a source of raw materials, and a cultural heritage having paleontological and archaeological treasures. Carter et al., (2003) discuss the relationships between soil quality functions and ecological theory. At the global scale, Arnold et al., (1990) and Yaalon (2000) describe the unique boundary position of the pedosphere and its role in sustaining, regulating, and controlling biotic and abiotic processes through its interactions with the biosphere, hydrosphere, atmosphere, and lithosphere.

In rangeland assessments, Tongway and Ludwig (1997) apply the term “functional” to describe how a landscape captures, retains, and uses water and nutrients. In the procedures described in “Interpreting Indicators of Rangeland Health,” functional status, or capacity, is evaluated for three ecological attributes: soil and site stability, hydrologic function, and biotic integrity (Pellant et al., 2005; Pyke et al., 2002).

Exhibit 5-2. Attributes of Soil Change

The following descriptions of attributes of soil change are summarized from Arnold et al. (1990), except where noted.

Fluctuation. Fluctuation is temporal variation in soil properties and includes nonsystematic, random variation and regular periodic, cyclic variation. Random variation does not have a cyclic pattern or trend and is difficult or impossible to model or predict. The frequency of measurements determines the magnitude of variation and rate of recurrence that can be detected. This is an important consideration for short-interval monitoring. Daily moisture content and hydrologic features that depend on rainfall distribution can appear random at the time scale of days but seasonally cyclic when evaluated over a period of many years. Nonsystematic variation also includes most of the human-induced changes.

Regular periodic variation is mostly related to seasonal climatic factors, such as variation in temperature, light, and precipitation, or to regular application of management practices. The periodicities are short to long and include diurnal, seasonal, and multiple years, such as prolonged periods of drought. Many properties that exhibit regular periodic variation can be forecasted or modeled with high or acceptable accuracy. Management can cause changes in the fluctuation pattern, such as increased magnitude of variation or rate of recurrence.

Trend. Trend is the general direction of change and can be increasing, decreasing, or steady-state equilibrium. The time it takes to reach steady-state or equilibrium varies with the property, the kind of soil, the type of management, and any continuing stressors or disturbances (see Chapter 4, Step 2, Figure 4.2-1).

Trend is commonly detected through monitoring or long-term studies. Also, past trend can be predicted by simulation models (Powlson, 1996) and can be inferred from the comparison of two management systems that had the same initial conditions (i.e., comparison studies). Trend can be accompanied by regular, cyclic, or random fluctuations. Both cyclic and random fluctuations can be of greater magnitude than the general trend change. Distinguishing between trends and long-term cyclic fluctuations can be difficult and unreliable using monitoring data and possibly more reliable using comparison techniques. For example, where the conventionallytilled field has less organic matter than the intact grassland on the same kind of soil after prolonged drought, it can be inferred that the organic matter trend after cultivation is downward for this comparison of systems.

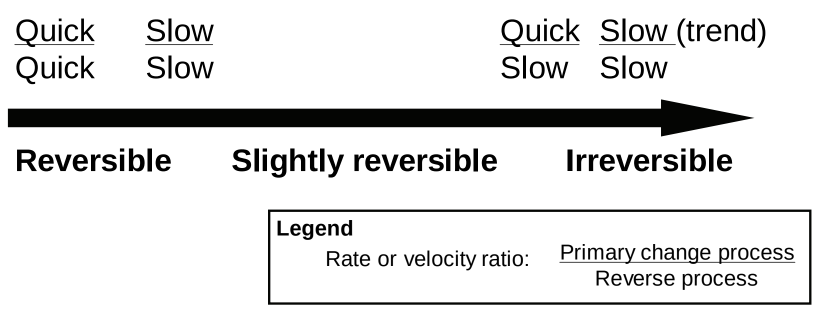
Rate, feedback, and pathways of change. Changes in dynamic soil properties reflect changes in process. The rate of change is commonly not constant. The change can follow several types of pathways (see Chapter 4, Step 2, Figure 4.2-1). For example, the magnitude of change can be high at first and diminish over time, or it can be the reverse in other cases. Feedback mechanisms are involved when the rate changes (Figure 5-2). Positive feedbacks intensify the process rate, and negative feedbacks diminish or restrict the rate. Plant-soil feedbacks appear to be strongest for plants growing in extreme environments (Ehrenfeld et al., 2005).

Threshold. The concept of threshold implies that a functionally important change in process rate has occurred (Bestelmeyer 2006). This change gives rise to different alternative states that differ in some manner, such as plant successional patterns, soil quality, and ecosystem services. In ecosystem management, an ecological threshold represents the conditions at a point in time after which future management options become limited. The same concept can be applied to agricultural systems. Once a threshold is crossed, processes may no longer function at the same level. The post-threshold system may support, for example, modified hydrologic processes, different levels of production, or different kinds of plant communities or crops when compared to a field in a pre-threshold condition (Stringham et al., 2003). The management actions used to restore a post-threshold state may be different and more costly than those used to keep a system from crossing a threshold (Bestelmeyer, 2006). Once a threshold has been crossed, the limited reversibility of altered conditions is an important management consideration.

Changes in process rates, feedbacks, and thresholds are involved in pattern reorganization within plant communities (Bestelmeyer, et al., 2006). For example, energy and matter are redistributed through such processes as microbial decomposition of organic matter and erosion. Following redistribution, feedback among the plant community, soil organisms, and soil affects the rates and amount of nutrient capture in the system (Lawrence et al., 2007). Where feedback accelerates process rates, such as erosion rates over time, the feedback is said to be positive, even though the result may have a negative effect on soil function. The feedback in the system contributes to a change in the pattern of vegetation. Eventually, the system crosses a threshold to an alternative state in which the changes in properties, processes, and patterns persist.

Reversibility. Few soil changes are truly irreversible. Even the loss of topsoil can be reversed with adequate time and inputs of organic matter and water, although the reversal is unlikely to be economical. From a land management perspective, the length of time required to reverse a change can have a significant influence on the perception of the ease of reversibility and its cost. Reversibility is characterized using rate or velocity of change and is classified on the basis of the ratio of the primary change process to the reverse process (Figure 5-4). In contrast to a simple two-class system of reversible and irreversible thresholds, the recognition of various classes of reversibility provides a more realistic representation of management alternatives once a threshold has been crossed. Furthermore, the reverse process is often different from the primary change process. Examples of irreversible changes include severe erosion, loss of mineral cation-exchange capacity, salinization without a suitable outlet for drainage water or salts, drainage (and oxidation) of sulfidic soil materials (iron pyrite, FeS_2), and heavy metal contamination.

Figure 5-4. Reversibility Classes (Reversible, Slightly Reversible, and Irreversible) Are Based on Rate or Velocity of Recovery in Relation to Rate or Velocity of Primary Change. These classes incorporate biophysical process information and human perceptions about the duration of time (quick, slow) required for change to take place. Illustration developed from concepts in Arnold et al. (1990).



Characteristic response time. Many soil properties are affected by environmental trend changes (e.g., a warming climate) and fluctuations (e.g., daily and seasonal fluctuation in temperature or moisture). Properties respond at different rates and require different time periods to reach a steady-state status after the environmental change. Soil respond in this general sequence:

- gaseous phase
- liquid phase
- biotic phase
- solid phase

In other words, the gaseous phase reaches steady-state before the solid phase. The time period of response in the absence of disturbances or stressors is the characteristic response time (CRT).

The CRT under natural conditions ranges from seconds to thousands of years or more. Soil properties can be assigned to six CRT classes (Table 5-2). The CRT identified in the table is generally applicable to most undisturbed environments. In extremely harsh environments, such as Antarctica, it may be necessary to establish more broadly defined CRTs for the classes.

The CRT should be considered when dynamic soil properties are selected for inclusion in a project (Sparling, 2006). The ideal dynamic soil properties for detecting change in the condition of the soil are those in Classes 3 and 4. These properties are not likely to be affected by short-term environmental fluctuations but are changeable over the human time scale. For example, indicators used for assessment and monitoring should have CRTs of more than 5 years under natural conditions. This CRT helps to minimize the confounding of inherent temporal variability with management-induced changes over time.

The CRT should also be considered when the data are analyzed. Many properties are sensitive to fluctuations in environmental conditions of moisture, temperature, and light. Properties in Class 1 or 2 with CRTs of less than 1 year can fluctuate hourly, daily, or seasonally. In order to interpret measurements of these properties that are made at one point in time, the fluctuations should be well understood and quantitative techniques to predict the fluctuations over time must be available.

The CRT should not be confused with immediate changes that occur after a disturbance, such as a decrease in soil bulk density after plowing. Furthermore, continued disturbances or anthropogenic stressors can interfere with the ability of a soil to achieve steady-state after environmental changes have occurred.

Table 5-2. Classes of Characteristic Response Time (CRT) in the Absence of Disturbances and Stressors for Selected Soil Properties. Selected properties from Arnold et al., (1990).

Class	Characteristic response time (years)	Property‡
1	$< 10^{-1}$	Bulk density, total porosity, moisture content, water storage capacity (2), infiltration rate, hydraulic conductivity (2), composition of soil air, available nutrients (2), electrical conductivity
2	10^{-1} - 10^{0}	Aggregate stability (3), pH
3	10^{0} - 10^{1}	Total cation exchange capacity (4), exchangeable acidity, cations, soil organic matter (4)
4	10^{1} - 10^{2}	Specific surface (5), clay mineral associations
5	10^{2} - 10^{3}	Primary mineral composition, horizons
6	$> 10^{3}$	Texture, particle density

‡ Numbers in parentheses indicate alternate class placement for the property.

Appendix 1 Planning Documents

Tables

Appendix 1 Planning Documents

1.1 Introduction

About this appendix
This appendix includes the Project Outline and the Workplan Worksheet described in Chapter 3.3. Together, the Project Outline and the Workplan Worksheet form the workplan.

1.2 Project Outline

Project outline
Use this outline to propose a project and request technical and laboratory assistance from the NRCS National Soil Survey Center. Refer to information in Chapter 4, Step 1, for related information.

Project Outline Worksheet -- Field/Laboratory – FY _____

Project name: (The project name should be descriptive: ex: Infiltration rates under different management practices.)

Project contact person: (Include telephone number and email address.)

Project objective(s): (Be specific about the objective without detailing methods or giving a justification. Those are separate topics.)

Project deliverables: (What will be learned and why the project is important to soil survey or soil interpretations?)

Background information and justification: (Is there project or site history of importance? Is this project related to a previous or existing project?)

Soil series affected. Is this a benchmark soil?

Ecological site to be included:

Project location: (Be specific as to state and county. Define ownership and current land use.)

Key soil properties relevant to project sampling/interpretation:

Proposed methodology: (How do you suggest/propose that the project should be conducted? What expertise is needed?)

Project personnel: (Identify staff and cooperators who will or should be involved. Identify each person's role. An NSSL liaison should be identified for each project prior to project initiation.)

Estimate of time required/Dates and person from NSSC requested:

Equipment required: (Other than State, MO or MLRA equipment)

Support materials to be used: (Maps, GIS data, existing research publications, etc.)

1.3 Workplan Worksheet

Workplan Worksheet (includes minimum data set)
Use this worksheet to document planning decisions for each project. These decisions are related to the questions of Where, What, When, How, and How many to sample. The Workplan Worksheet is divided into four sections, one for each of the following project steps:

Step 1 Project Scope
Step 2 Project Design
Step 3 Project Requirements
Step 4 Field Work

Individual items are numbered under each step. Follow instructions in the appropriate step of Chapter 4 in order to complete these items. Within the chapter text, look for the term Workplan Worksheet: Item x to locate the relevant instructions. For example, the phrase "Workplan Worksheet: Item 8" in Chapter 4, Step 2.2, indicates the location of additional instructions on selecting ecological states and state phases.

Note to Readers: *This worksheet is intended to simplify the development of the sampling design and workplan for a project. In its current format, the worksheet seems a bit cumbersome. Any suggestions to help simplify this process are welcome. The information on the Workplan Worksheet should ultimately be stored for each project in an information system. This information may be needed in the future for additional data analysis.*

Workplan Worksheet (Version. 1.1)

Instructions: Use this worksheet to record information required in Project Steps 1 through 4.

Step 1 Project Scope
Items 1-7

1. About the project

Project name		
Prepared by		**Date:**
SS update?	**Benchmark soil study?**	**Ecological site inventory?**
Project outline attached?		
Collaborators (see also Item 28)		
Sampling dates (mm/dd/yyyy to **mm/dd/yyyy)**		

2. Project objectives

Describe objectives.

3. Deliverables

Refer to Chapter 4, Step 6, for descriptions of each standard report listed below.

Report 1. Summary of Data and Statistical Measures for State Phases: As Sampled.
A report of the dynamic soil and vegetation properties for each plant community or management system sampled. The following are reported for layers as sampled:

a. Central tendency: Mean and median
b. Measures of variation: Standard deviation (SD), variance, and coefficient of variation (CV)
c. Measures of central range: Quantiles and mean +/- standard deviation (SD)
d. Measures of certainty or confidence about the mean: Standard error (SE) and lower and upper 95% confidence intervals (CI).

Report 2. General Summary of Dynamic Soil Properties for State Phases.
This summary report contains mean, median, range of values, and coefficient of variation (CV%) for selected dynamic soil and vegetation properties for each plant community or management system sampled.

Report 3. Sampling Sufficiency at the Regional Scale for State Phases.
From the final project data, this table provides information about variance, the number of samples collected, the actual minimum detectable difference that can be detected with the samples collected in the project and the number of samples required to detect the desired minimum detectable difference. These sampling requirements will be developed using the default error rates and correlation values for comparison studies: alpha = 0.20, power = 0.80, and rho = 0.00.

Report 4. Test for Differences Between Means of State Phases.
This report provides the results of the statistical test of differences between state phases or management systems for properties and layers or depths of interest.

Report 5. Control Charts of Dynamic Soil Properties for State Phases
This report includes control charts that illustrate the central tendency and range of selected soil and vegetation properties of the reference state and other state phases sampled. Can be used to visually compare the reference state to other state phases.

Other deliverables (describe):

4. Selected soils.

If sampling a catena, list all soils to be sampled

Selected soil (series)	
Soil name	**Classification**
Similar soils that may be sampled in place of the selected soil	
Similar soil name	**Classification**
Properties of the similar soil that differ from the selected soil:	

5. Ecological site (where appropriate).

Ecological site name	**Site ID**

6. Selected habitat type for forest land (optional)

Selected habitat types	**Code**	**Target habitat type phase**	**Source**

7. Location of project area

MLRA number	Common Resource Area (CRA)
Crop management zone	
Other designation name	**Other designation number**

State	County	FIPS county code	Soil survey area symbol	Soil survey area name	Update in progress	Update completed

Step 2 Sampling Design
Items 8-18

8. Selected state phases or management systems

Enter the selected plant community or management system for the reference state and for the other state phase(s) to be sampled. Refer to the Ecological Site Description, state and transition model, or other management system model for information about states, state phases, the reference state, and management.

For each state phase to be sampled, describe repeating patterns within the plant community phase or management system that should be stratified for sampling. Patterns commonly occur at the plot scale and include, among other features: intermingled patches of vegetation, such as shrub or intershrub patches; row and furrow; and periglacial patterned ground.

Reference state	Selected plant community or management system (state phase) to sample	Land use
Name	**Name**	
ID No.	**ID No.**	
Describe repeating patterns.		
Describe historic management that may have impacted the plant community or management system.		
Describe current management and practices associated with this state phase. (Use to help locate plots to sample.)		

Other state phase	Selected plant community or management system (state phase) to sample		Land use
Name	**Name**		
ID No.	**ID No.**		
Describe repeating patterns.			
Describe historic management that may have impacted the plant community or management system.			
Describe current management and practices associated with this state phase. (Use to help locate plots to sample.)			
Describe reasons for selecting this plant community or management system.			

Other state phase	Selected plant community or management system (state phase) to sample	Land use
Name	Name	
ID No.	ID No.	
Describe repeating patterns.		
Describe historic management that may have impacted the plant community or management system.		
Describe current management and practices associated with this state phase. (Use to help locate plots to sample.)		
Describe reasons for selecting this plant community or management system.		

Insert diagram of the state and transition model or other simple conceptual model for cropland or pastureland.

9. Target phase properties

Surface texture (s)	Slope percent (range)	Aspect(s)	Elevation (range)
Landform			
Will rock fragments interfere with sampling soil cores?		At what depths?	
Instructions about what to exclude (e.g., a certain landforms, aspects)			
Insert block diagram illustrating landforms to be sampled or excluded (optional).			

10. Selected soil map units in the project area are those that contain the target soil map unit component phase.

On grassland, shrubland, savanna, and forest land ecosystems, the target soil phases must be correlated to the selected ecological site.

Map unit ID	Map unit name	Acres of MU	Percent target soil phase in MU	Acres of target soil phase
Acres of target soil map unit component phase within study area (also size of target area)				

11. Estimated sources of spatial variability

For each of three scales (regional, local, and fine) complete the following: (A) Describe features that are likely sources of variability; (B) describe the degree to which each feature is presumed to affect soil property variability; (C) state conclusions about the need to address these sources in the sampling design; and (D) identify any special instructions for sampling design or sampling procedures.

Regional-scale sources of variability		
(A) **Environmental features**	**(A)** **Range** **(across all polygons in a project area)**	**(B)** **Describe effect**
Elevation		
Temperature		
Precipitation		
Wind		
Other		
(C) Conclusions	The following features may be sources of variability within the target population of soil: ________________________________.	
(D) Special sampling instructions	1. Plots will be distributed throughout the target area to capture this variation. 2. OR, the study area will be restricted as follows (e.g., exclude high-elevation polygons): ________________________________ ________________________________	

Local-scale sources of variability		
(A) **Local physiographic features**	**(A)** **Range** **(within individual polygons)**	**(B)** **Describe effect**
Landform component		
Aspect		
Slope percent		
Slope shape		
Other		
(C) Conclusions	The following features may be sources of variability within individual polygons: ____.	
(D) Special sampling instructions	1. Plots will not include atypical features (e.g., north aspect) ____________ ____. 2. Sampling design **will / will not** (circle one) include extra sample in stratification stratified sampling to more precisely capture the variability at this scale. If stratified sampling is used, establish separate plots on each of the following strata (e.g., shoulder, backslope): ________ ____.	

Fine-scale (on-plot) sources of variability	
(A) **Pattern feature** **(within individual plots)**	**(B)** **Kind and degree of effect**
Shrub and intershrub patches	
Grass patches	
Compaction in trails or wheel tracks	
Variable stand vigor or plant density	
Gopher activity	
Plant species/functional group effects	
Planted or natural regeneration	
Slash piles	
Microtopography	
Row and furrow	
Terraces, waterways	
Other	
(C) Conclusions	The following fine scale patterns or features can be detected without digging a hole and may be sources of soil property variability on plots: ____________________.
(D) Special sampling instructions	1. Sampling design **will / will not** (circle one) include stratified sampling to more precisely capture the variability at this scale. If stratified sampling is used, stratify soil sample collection within the plot according to (e.g., shrub and intershrub): ____________________ ____________________ patches. 2. If other features are encountered during sampling, notations will be made on field datasheets. 3. Relocate unsuitable soil sample locations. These locations include creeks, rock outcrop, soil inclusions, and ____________________. If a soil sample location falls on one of these unsuitable locations, move 2 m in a random direction until a suitable location is found.

12. Dynamic soil properties to measure: Minimum soil data set for a project

This is a list of all soil properties that will be included in all projects, except as noted below. The minimum data set includes dynamic soil properties as well as properties that may be relatively stable and are important for interpreting the dynamic soil properties. Some of the properties important for interpretation may be affected by management.

Consider sensitivity to environmentally-induced or irrigation-induced fluctuations in moisture when determining time of year to sample. Also consider sensitivity to tillage and those properties that fluctuate in response to biological activity on a seasonal basis (i.e., in response to moisture and temperature).

Enter "Y" (yes) or "N" (no) in the table to indicate properties selected for the project. Include properties in lieu of particle size where needed (e.g., organic soils, mineral soils with andic soil properties). Follow guidelines for horizons to analyze.

Minimum Data Set (March 15, 2008)

Property	Land cover type	Horizons to analyze	Sensitive to cyclic or noncyclic seasonal fluctuation in:	Selected for project?
Dynamic soil properties				
Organic C (Total C – $CaCO_3$-C)	All	All		Y
pH	All	All	Biological activity	Y
EC	All	All	Moisture	Y
Bulk density/soil porosity	All	All	Tillage, moisture	Y
Soil structure (grade, size, type) and macropores (kind for connectivity)	All	All	Tillage, moisture	Y
Aggregate stability (wet) (If aggregates are likely to be disrupted during sampling or shipping, omit this property.)	All	Include 3 upper mineral layers or more if needed to reach a depth of 25 cm	Tillage, moisture, biological activity	Y
Total N	All	All	Tillage, biological activity	Y
Soil stability kit (field)	Rangeland; others as needed	At surface and 2.5 cm	Tillage, moisture, biological activity	
Properties for interpretation				
Soil horizon thickness	All	All	Tillage	Y
Field moisture content (%)	All	All	Moisture	Y
Particle-size distribution analysis	All	All		Y
Other properties in lieu of particl size for organic soil materials	As needed	As needed		
Other properties in lieu of particle size for ash-affected soil materials; acid oxalate Fe and Al, P retention, pH NaF, 15kpa water, glass count	As needed	As needed		
Rock fragment content	All	All		Y
CEC7	All	All		Y
Extractable bases (Ca, Mg, K, Na)	All	All		Y
Clay mineralogy (for fine and moderately fine textured samples)	As needed	As needed		
Other	As needed	As needed		
Additional notes on horizons to analyze.				

13. Dynamic soil properties to measure: Supplemental and experimental properties.

Some dynamic soil properties are functionally important for some, but not all, soils and land cover types. Supplemental and experimental properties can be included in a project if they meet the following criteria: 1) the property is functionally important for the land cover type, and 2) staff and funds are available to collect, analyze, and interpret the data.

Select soil horizon, soil hydrology, other field measured properties and forest floor properties for the appropriate land cover type (cropland, pastureland, rangeland, forest land, or all land). Consider sensitivity to environmentally induced or irrigation-induced fluctuations in moisture when determining time of year to sample. Also consider sensitivity to tillage and those properties that fluctuate in response to biological activity on a seasonal basis (i.e., in response to moisture and temperature).

Enter “Y” (yes) or “N” (no) in the table to indicate properties selected for the project. Follow guidelines for horizons to sample.

Provisional List: Supplemental and Experimental Soil Properties (March 15, 2008)

Property	Land cover type‡	Horizons to analyze		Sensitive to cyclic or non-cyclic seasonal fluctuation in:	Selected for project?
		Soil without forest floor	Soil with forest floor		
Soil horizon: chemical, carbon and biological measures					
eCEC, mineral CEC	As needed	All	All		
KCl-Al	As needed	All	All		
$CaCO_3$	As needed	All	All		
SAR	As needed	All	All		
C:N ratio (Organic C:Total N)	All	All layers to 25 cm	All layers within upper 25 cm of mineral soil	Tillage, biological activity	
Plant available P	All	All	All		
Total ions (Ion resin capsules)	As needed	As needed	As needed	Moisture, biological activity	
Potentially mineralizable N	All	All layers to 25 cm	All layers within upper 25 cm of mineral soil	Biological activity	
POM (Total, POM-C and POM-N)	All	All layers to 25 cm	All layers within upper 25 cm of mineral soil	Biological activity	
Active C	All	All layers to 25 cm	All layers within upper 25 cm of mineral soil	Tillage, biological activity	
Active C kit (field)	All	All layers to 25 cm	All layers within upper 25 cm of mineral soil	Tillage, biological activity	
Microbial biomass-C	All	All layers to 25 cm	All layers within upper 25 cm of mineral soil	Tillage, biological activity	
B-glucosidase	All	All layers to 25 cm	All layers within upper 25 cm of mineral soil		
Other					
Soil horizon: hydrology					
Saturated hydraulic conductivity (Ksat by horizon) Amoozemeter	All	As needed	As needed	Tillage	
Ponded infiltration, single ring infiltrometer	All	Soil surface	Mineral soil surface	Tillage, moisture; biological activity in some cases	
Water retention, 0.1, 0.33, and 15 bar (sieved soil)	All	All	All layers within upper 25 cm of mineral soil	Tillage	
Pore size distribution	All	All	All layers within upper 25 cm of mineral soil	Tillage, moisture, biological activity	
Other					

Other field measures					
Dry aggregate stability	As needed for wind erosion	Include 2 upper layers	None	Tillage	
Pocket penetrometer	P, R, F, as needed on C	See method	See method	Tillage, moisture	
Impact penetrometer	As needed	See method	See method	Tillage, moisture	
Modified singleton blade	All	Soil surface	Mineral soil surface	Tillage, moisture	
Torvane	All	Soil surface	Mineral soil surface	Tillage, moisture; biological activity in some cases	
Albedo, bare soil	All	Soil surface	Soil surface	Tillage, moisture	
Soil temperature	All	Soil surface	Mineral soil surface	Moisture, temperature	
Other					
Forest floor					
Forest floor (O horizon), mass	F	-	Above mineral soil surface	Biological activity	
Forest floor (O horizon), total C	F	-	Above mineral soil surface	Biological activity	
Forest floor (O horizon), total N	F	-	Above mineral soil surface	Biological activity	
Forest floor (O horizon), OM (loss on ignition)	F	-	Above mineral soil surface	Biological activity	
Downed wood, total mass	F	-	Forest floor		
Downed wood, total C	F	-	Forest floor		
Downed wood, total N	F	-	Forest floor		
Downed wood, OM (loss on ignition)	F	-	Forest floor		
Additional notes on horizons to analyze.					
Describe justification for selecting properties not in the minimum data set.					
NOTE: Samples for biological measures must be kept cool, and out of the light while in the field and prior to shipping. They are to be shipped in coolers at the end of each week.					

‡ C, cropland; P, pastureland; R, rangeland; F, forest land

14. Vegetation properties to measure

In addition to soil properties, vegetation characteristics will be measured where a plant community is present. Select the appropriate land cover type or ecosystem.

14.1. Methods and vegetation properties for a project: Grassland, shrubland, and savanna ecosystems. Relationships among methods, uses of data, and properties are presented for the minimum data set. Add supplemental or experimental properties as needed (requires approval).

Minimum data set (June, 2008)		
Field protocol or method	**Used for**	**Property**
Linepoint intercept	Soil-vegetation relationships, cover and extent estimates, properties affecting air-soil interface functions (resistance to erosion, infiltration, etc.)	Total canopy (foliar) cover (%) Canopy (foliar) cover by plant functional group (%) Canopy cover by functional group (%) (not foliar) Bare ground (%) (no canopy over no soil cover) Litter cover (%) Biological crust cover by functional group (%) (moss, lichen, dark cyanobacteria, light cyanobacteria) Rock fragment cover
Canopy and basal gap intercept (transect)	Wind erosion and exotic plant invasion (canopy); water erosion risk and; infiltration (gap)	Canopy gaps by size (%) Basal gaps by size (%) (Gap sizes: 25-50, 51-100, 101-200, 201-500, 500-1000, >1000)
Plant production-herbaceous. Double sampling method	Annual production, soil-vegetation relationships	Annual herbaceous production
Plant production-woody	Annual production, soil-vegetation relationships	Annual woody production
Resource retention class	Resource retention, soil-plant interactions, grass fragmentation, shrub encroachment	Resource retention class
Erosion pattern class	Current or past erosion, resource redistribution	Erosion pattern class
Pedoderm/ Soil crust class	Resistance to erosion, biological crust development	Pedoderm/crust class

Supplemental or experimental properties		
Field protocol or method	**Used for**	**Property**

14.2. Methods and vegetation properties for a project: Forest land ecosystems. Relationships among methods, uses of data, and properties are presented for the minimum data set. Add supplemental or experimental properties as needed (requires approval).

Minimum data set (June, 2008)		
Field protocol or method	**Used for**	**Property**
Site index	Site productivity	Site index
Overstory vegetation	Species composition, soil-vegetation relationships, canopy cover and extent estimates, wildlife values	Tally of species Canopy cover
Understory vegetation (high)	Species composition, soil-vegetation relationships, plant invasions, wildlife values	Tally of species Understory canopy cover and height
Understory vegetation (low)	Species composition, ground cover, total and annual production, soil-vegetation relationships, plant invasions, wildlife values	Cover (%) by species. Total biomass Annual ground cover production
Woody debris transect	Nutrient cycling status of forest floor	
Visual disturbance classes transect	Soil surface displacement, compaction, litter thickness, soil surface cover, rock fragment cover, biological crust cover	

Supplemental or experimental properties		
Field protocol or method	**Used for**	**Property**

14.3. Methods and vegetation properties for a project: Pastureland.

Not yet developed.

14.4. Methods and vegetation properties for a project: Cropland.

Not yet developed.

15. Desired environmental conditions at time of sampling

Desired conditions			
Soil moisture	**Soil temperature**	**Plant growth stage**	**Crop stage**
Recommended time of year to sample			

16. Laboratory services

Describe analyses to be performed by labs other than the National Soil Survey Laboratory and list laboratory names.

17. Soil descriptions, horizons, layers, and depth to sample (soil sample locations within a plot)

Describe and georeference one soil profile (1.5-2 m or to bedrock) for each plot. For each soil sample location on each plot, develop a brief soil profile description for each horizon sampled. Collect samples for the same lower depth or mineral soil thickness at each location. Follow instructions (Appendix 3.5) for sampling O horizons and mineral soil material. If any horizon is greater than 25 cm total thickness, divide horizon into 2 layers and collect samples for each. Divide the two increments morphologically if apparent; otherwise, split approximately in half.

Identify amount, layers and horizons to sample as well as the lower sampling depth.

18. Comprehensive characterization pedons

Describe and sample at least one pedon per plant community or management phase (not per plot) to bedrock or a depth of 1.5 – 2 m for comprehensive characterization unless suitable data are already available.

Report the estimated number of horizons for comprehensive characterization to the NSSL.

Existing pedon data				
Soil name	**Pedon ID**	**Lab name**	**Classification**	**Land cover type**

Comprehensive characterization pedons to sample in this project			
State phase	**Estimated number of horizons**	**Lab name**	**Special analyses requested**

Step 3 Sampling Requirements
Items 19-25

19. Plot type and dimensions (primary sampling unit)

Select the plot type (square, circle, or transect) based on standard protocols for land cover type. Plot size should encompass fine-scale variability. Refer to Appendix 3 for guidance. The plot will be the primary sampling unit.

State phase or management system	Plot type	Plot area		Width, diameter or length		Number of strata to be sampled per plot
		h	ac	m	f	no.

20. Plot elements and sampling requirements

Select the appropriate land cover type or ecosystem. Enter the sampling requirements for each plot element. Refer to standard vegetation methods and ecological site inventory procedures for minimum sampling requirements or modify as needed.

Grassland, shrubland and savanna ecosystems									
Field protocol or method	Plot element (secondary sampling unit)	Sampling requirements per plot: Area		Width or radius		Length		Transects or subplots per plot	Points per transect (tertiary sampling unit)
		h	ac	m	ft	m	ft	no.	no.
Linepoint transect	transect								
Canopy and basal gap intercept	transect								
Plant production-herbaceous. Double sampling method	subplot								
Plant production-woody	subplot								

Forest land ecosystems									
Field protocol or method	**Plot element** (secondary sampling unit)	**Sampling requirements per plot**							
		Area		**Width or radius**		**Length**		**Transects or subplots per plot**	**Points per transect** (tertiary sampling unit)
		h	**ac**	**m**	**ft**	**m**	**ft**	**no.**	**no.**
Site index	variable radius plot							1	
Overstory vegetation	fixed radius plot (same as variable radius plot)							1	
Understory vegetation (high)	fixed radius subplot							1	
Understory vegetation (low)	subplot								
Woody debris transect	transect								
Visual disturbance classes	transect								

21. Obtain or compute appropriate variances (for sampling requirements)

Describe option that will be used to derive variance values that will be used to determine number of replicates needed. Refer to Appendix 2 for more information.

Calculate variance based on existing data set.	**Yes /No**	**Collect new or preliminary data and calculate variance.**	**Yes/No**
Describe source article (author and title) or project data:			

22. Sample distribution at multiple scales: Numbers of plot replicates and soil sample locations

If suitable estimate of regional- or local-scale variance is not available, sample a minimum of five plot replicates per plant community phase or management system and a minimum of five soil sample locations per plot.

When determining numbers of plots and samples to include in a project, consider the time available to and magnitude of difference that you wish to detect. Detecting a smaller difference requires more samples and more time to collect them. If the staff and resources are not available to detect a small difference, increase the amount of difference to be detected. Use the sampling requirements tools in Appendix 2 to evaluate alternatives and then record your decision below. If the local scale is to be stratified using different plots, either include the same number of plots for each stratum or use a number proportional to the area of the stratum as it occurs throughout the extent of the soil map unit component phase.

State phase, or management system	Kind of local-scale stratum to be sampled using different plots	Number of plot replicates	Number of soil sample locations per plot
EXAMPLE: Conventional tillage	shoulder	5	4
Conventional tillage	backslope	5	4

23. Number of dynamic soil property laboratory samples

Compute total number of samples (e.g., 2 *plant community phases x 6 plots x 8 soil sample locations x 3 soil horizons per sample location = 288 total samples for laboratory analysis*). If unequal numbers of soil sample locations are collected for each state phase, compute separately and then combine subtotals.

Get prior approval from NSSL for more than 300 samples per project.

	Number plots	x	Soil sample locations	x	Soil horizons per sample location	=	Number samples for laboratory analysis
Reference state:		x		x		=	
Other state phase:		x		x		=	
Other state phase:		x		x		=	
TOTAL:							

24. Sampling summary

Provide a narrative summary of sampling design.

25. Sample identification system

Create plot identification symbols for each state phase, management system, or local-scale stratum. Also create identification symbols for strata within a plot. Some state phases or management systems have one stratum, and some have more than one. Create a symbol for each kind of stratum to be sampled, even if there is only one stratum. See sample identification examples for other projects in Table 4.3-1 (reproduced here from Chapter 4, Step 3).

State phase, management system, or stratum at the local scale		**Stratum within a plot (fine scale)**	
Name	**ID**	**Kind**	**ID**

Table 4.3-1. Sample Identification System for a Project. Examples illustrate the system of combining ID codes for a plot and its plot elements in order to uniquely identify soil sample locations (column I) within a project. A unique code is assigned to the state phases, management systems, and local-scale strata within a project (column B). Only those selected for sampling need an identification code. This code, when appended with a consecutive number, becomes the identifier, i.e., "Plot replicate ID" (column D) for each plot replicate. Then a unique code is assigned to each stratum that will be sampled (column E), even if there is only one stratum (Chapter 4, Step 2.4). This code, when numbered consecutively, becomes the identifier, i.e., "Stratum-soil replicate ID" (column H), for each soil sample location. When combined, the "Plot replicate ID" and the "Stratum-soil replicate ID" become the "Soil sample location ID" (column I) for an individual soil sample location, e.g., PGS1-G1 (column I). This symbol is also used as the "User Site ID" (column I) in NASIS and PC PEDON programs. Horizon sequence numbers are added to the pedon identifier codes (not shown in the table) and then used as labels on sample bags collected in the field.

Plot identifier				Plot element identifier				Unique pedon identifier	
Plot within a project				Soil sample location within a plot				Plot replicate + stratum within plot + soil sample location replicate no.	
Plant community phase (state phase), management system, or stratum at the local scale				Stratum within a plot (fine scale)		Soil sample location within a stratum			
(A) Name	(B) ID	(C) Plot replicate no.	(D) Plot replicate ID	(E) Kind	(F) ID	(G) Soil sample location replicate no.	(H) Stratum-soil replicate ID	(I) Soil sample location ID (User Site ID)	(J) User Pedon ID
EXAMPLE 1; Single fine-scale stratum within a plot									
Invasive grass	IN	1	IN1	Grass	G	1	G1	IN1-G1	S05UT019-001
Invasive grass	IN	1	IN1	Grass	G	2	G2	IN1-G2	S05UT019-006
Invasive grass	IN	4	IN4	Grass	G	1	G1	IN4-G1	S05UT019-047
EXAMPLE 2; Multiple fine-scale strata (grass; shrub) within a plot									
Perennial grass-shrub	PGS	1	PGS1	Grass	G	1	G1	PGS1-G1	S05UT019-009
Perennial grass-shrub	PGS	1	PGS1	Shrub	S	1	S1	PGS1-S1	S05UT019-010
Conventional tillage	CT	1	CT1	Shoulder	S	1	S1	CT1-S1	S07XX123-001
Conventional tillage	CT	1	CT1	Backslope	B	1	B1	CT1-B1	S07XX123-002
EXAMPLE 3; Multiple local-scale strata (shoulder; backslope) not on the same plot									
Conventional tillage, shoulder	CTS	1	CTS1	None	N	1	N1	CTS1-N1	S07XX456-001
Conventional tillage, backslope	CTB	1	CTB1	None	N	1	N1	CTB1-N1	S07XX456-002

Step 4 Field Work and Appendix 3
Items 26-29

26. Plot acceptance criteria

List criteria to be used to evaluate plot suitability. Modify the criteria listed in Chapter 4, Step 4, for local conditions.

Criteria

27. Plot Master and field forms

Refer to Appendix 3.2, 3.3, or 3.4 to acquire the appropriate Plot Master field form for this project. Attach to this Worksheet. Use the Plot Master in the field to keep track of work completed on each plot. The Plot Master is the primary record for 1) geospatial information, 2) plot and sample identification, and 3) completed field forms.

List all datasheets to be used in the project. Be sure all forms are included on the sampling checklist of the Plot Master.

Field form name	Used in project?

28. Roles of project collaborators and individual project personnel

29. Plan modifications and field notes

Describe any modifications to this plan that were made during field data collection.

Appendix 2 Sampling Requirements

Figures

Tables

Appendix 2 Sampling Requirements

2.1 Introduction

About this appendix

This appendix presents background information and tools for determining sampling requirements. Instructions for three simple tools make it easy to complete the necessary calculations for a project. These tools can help ensure that enough samples are collected and that time is not wasted collecting unnecessary samples. They can also minimize the number of samples needed by helping to most efficiently distribute samples across the landscape. The process of determining sampling requirements is outlined in Figure A2-1. We have tried to present all the information needed to address a wide variety of situations. Some background in statistics will help you understand some of the text. In most cases, however, all that is really needed is a bit of patience and the ability to complete simple spreadsheet functions. The calculations are automated!

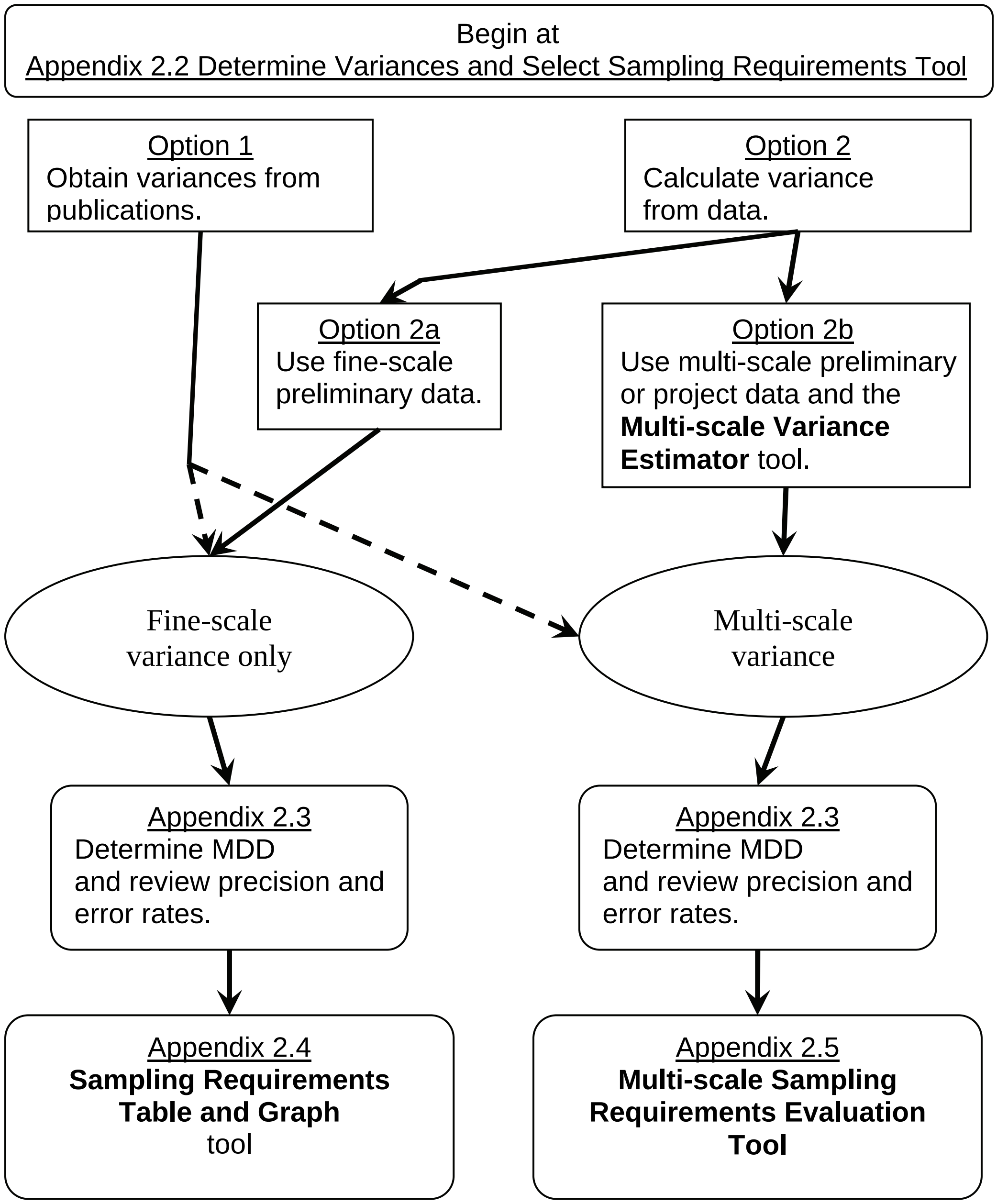
The three tools were designed to help determine and evaluate sampling requirements. The **Sampling Requirements Table and Graph** tool and **Multi-scale Sampling Requirements Evaluation Tool (MSSRET)** are used to estimate sampling requirements for project planning. **MSSRET** is a Microsoft Excel spreadsheet file that can also be used to determine whether a sufficient number of samples has been collected. The **Multi-scale Variance Estimator** is another Excel file tool that calculates multi-scale variances for use in **MSSRET**.

All three of these tools were developed specifically for multi-scale sampling of dynamic soil properties as described in this **Guide**. The **Multi-scale Variance Estimator** and **MSSRET** can also be used for virtually any other field sampling project, including sampling of ground water and vegetation that is collected in a multi-scale fashion. "Multi-scale" refers to the arrangement and spacing of samples. For example, samples within a plot are relatively close together (fine or within-plot scale), whereas plots are relatively spread out across the project area (regional scale). The term "state phase" is defined in this **Guide** as "a component of a state, such as a plant community phase or cropland management system." For the purposes of this appendix, it can also be interpreted more broadly to include any individual vegetative condition, management system, or other treatment being studied in a project.

Introduction to sampling requirements

Sampling objectives are established in order to ensure that sampling is sufficient to meet project objectives (Elzinga et al., 1998). In a comparison study, the project objective is to detect functionally important differences between state phases. The sampling objective is to collect samples in a way that those differences, if there are any, are detected. The numbers of samples and plots needed to meet the sampling objective are called sampling requirements. Sampling requirements are calculated from the variability of the property (measured as variance), the magnitude of the difference to be detected (minimum detectable difference, MDD), correlation between measurements (rho) and the desired level of precision, and acceptable error rates (α and power).

Figure A2-1. Flowchart of Process Used to Determine Sampling Requirements. Sections from the text are underlined. Tools (provided as a figures or Excel files with the **Guide**) are in bold.



2.2 Determine Variances and Select Sampling Requirements Tool

Variance
The first step in determining sampling requirements is to determine variances. Variance is a statistical measure of the variability of individual values around the mean. Variance is related to the variability of a property. As variability increases, variance increases. The spatial variability of a property may vary at multiple scales within a map unit component phase. Soils and state phases with high fine-scale variability (between samples within a plot) and high regional-scale variability (between plots within a state phase) have much greater sampling requirements to estimate parameters and detect differences than those that exhibit more spatially uniform values. Variances can be obtained from existing data sets or from collected data (preliminary samples or a partially or fully completed project).

Sampling requirements that are established for a project should be adequate for all properties measured in that project. That is, the sampling requirements should be adequate for the most variable property of the most variable state phase in a project. Because each property, depth, and state phase is likely to have a different variance, the property used for determining sampling requirements must meet the needs of all properties. Organic carbon is often one of the most variable properties (see Chapter 4, Step 2, Table 4.2-1). Therefore, its variance should be used for deriving sampling requirements that will be sufficiently large for most other soil properties. For simplicity, use organic carbon in the A horizon or the upper 10 cm of the mineral soil surface. This is a conservative approach. Note that for some situations another dynamic soil property that is highly variable and correlated with other dynamic soil properties could be used. Furthermore, measurement costs can be reduced by randomly selecting a subset of the collected samples for analysis of less variable properties.

Variance is modified by the spacing and timing of sample collection. The more closely the spatial location and sampling conditions are repeated, the greater the correlation between samples. Rho is a measure of that correlation (0 - not correlated, 1 - perfect correlation). It modifies variance in sample requirement formulas. Rho is the square root of r^2 in a regression of the two sample times. The more closely the spatial location and sampling conditions are repeated, the greater the value of rho. For comparison studies, samples are independent of one another and rho equals 0. In monitoring projects, samples taken repeatedly on the same plot will be correlated and rho can range from 0 to 1.

There are two primary options for finding variances: 1) obtain them from publications and 2) compute them from preliminary or project samples.

Option 1. Obtain variances from publications
Variances for soils that are the same as the similar to those in a project may be found in scientific journal articles, academic theses, or even unpublished data sets. The variance of organic carbon (%) in the A horizon is recommended for use in determining sampling requirements. Work with collaborators to identify sources that may contain these values. Take note of the sample configuration from which variances are derived. Use only those

that have sample spacing comparable to the distribution of sample locations and/or plots in your project.

Option 2. Compute variances using preliminary or project data
Option 2a. Fine-scale preliminary samples. Preliminary sample collection allows calculation of variances for the exact conditions of your project. Use the following or similar procedure to obtain fine-scale variance.

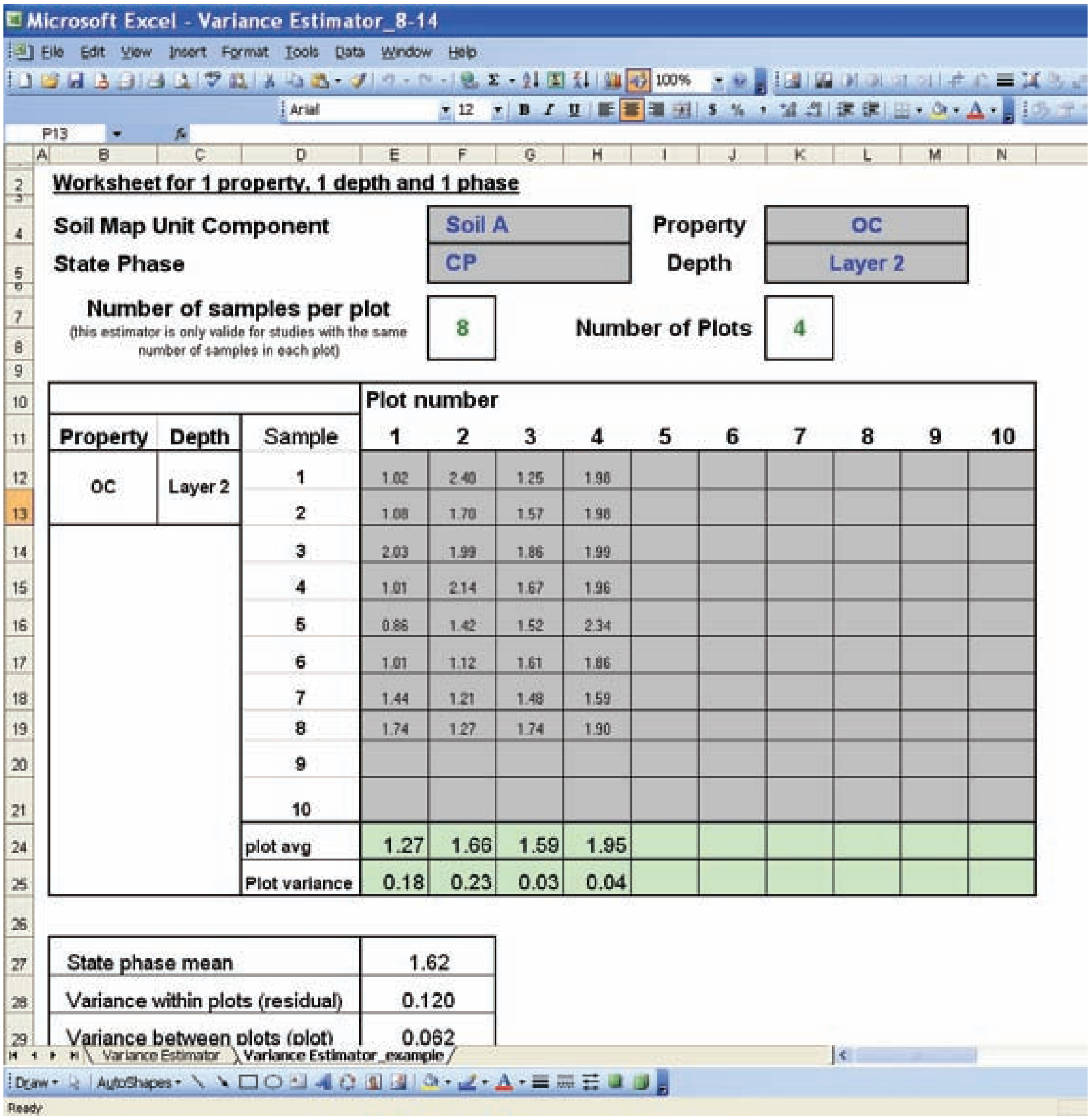
1. Locate one plot for each state phase or management system to be included in the project.
2. Randomly select 10 sample locations on each plot.
3. At each location, collect a core sample of the upper 10 cm of the mineral soil (no grab samples; collect the entire volume of soil for the 10 cm layer). Note the thickness of the A horizon for each sample.
4. Analyze these samples for organic carbon (%).
5. Compute the variance for samples collected on each plot using any common statistical software.
6. Compare the variance estimates for each state phase sampled and select the highest estimate.
7. Proceed to Appendix 2.4 and use the variance in the **Sampling Requirements Table and Graph**.

Option 2b. Multi-scale preliminary or project samples. Multi-scale variances can be derived at any time during a project. Data from preliminary sampling of more than one plot on the same state phase or management system, from a portion of the project, or from the completed project can be used to derive variances. When multiple samples are collected on multiple plots (according to the **Guide**), there are two variance pools: residual (within plot) and plot (between plots). The variances for each state phase should be computed separately. For preliminary and mid-project analysis, the variances can be estimated with the Excel worksheet **Multi-scale Variance Estimator** (Figure A2-2) or they can be derived with a mixed model in a commercial software package (Figure A2-3).

The **Multi-scale Variance Estimator** tool is valid when there is equal replication (the same number of samples within every plot). If there is unequal replication, see directions in Figure A2-3. To use the **Multi-scale Variance Estimator** worksheet**:**

1. Enter soil map unit component phase, state phase, property and depth for record keeping purposes.
2. Enter sample values by plot in the grey area. Samples should be arranged in columns under the appropriate plot number
3. The variance estimator will report the state phase means, variance within plots, and variance between plots. These estimates can then be used in **MSSRET (Appendix 2.5)**.

Figure A2-2. Example of Data Entry and Output of the Multi-scale Variance Estimator. This example is for one state phase with four plots and eight samples per plot.



Worksheet for 1 property, 1 depth and 1 phase

Soil Map Unit Component	Soil A	Property	OC
State Phase	CP	Depth	Layer 2
Number of samples per plot (this estimator is only valide for studies with the same number of samples in each plot)	8	Number of Plots	4

			Plot number									
Property	Depth	Sample	1	2	3	4	5	6	7	8	9	10
OC	Layer 2	1	1.02	2.40	1.25	1.98						
		2	1.08	1.70	1.57	1.98						
		3	2.03	1.99	1.86	1.99						
		4	1.01	2.14	1.67	1.96						
		5	0.86	1.42	1.52	2.34						
		6	1.01	1.12	1.61	1.86						
		7	1.44	1.21	1.48	1.59						
		8	1.74	1.27	1.74	1.90						
		9										
		10										
		plot avg	1.27	1.66	1.59	1.95						
		Plot variance	0.18	0.23	0.03	0.04						

State phase mean	1.62
Variance within plots (residual)	0.120
Variance between plots (plot)	0.062

Figure A2-3. Example of Mixed Model SAS Code and Output for Variance. If there are an unequal number of samples per plot, ask an expert to generate variances from the data with a mixed model estimator using a sophisticated software package, such as SAS, R, or SPSS. The recommended SAS (SAS Inc. Cary, NC) code is provided here. This SAS code requires that the data have plot identification codes (plotid). "Data" refers to any property that is measured at multiple locations on a plot. The plot and residual variance values will be used in the **MSSRET** tool (Appendix 2.5).

The SAS code is as follows:

```
proc mixed;
        class plotid;
        model data =/solution;
        random plotid;
        run;
```

The output for this code includes:

```
Covariance Parameter
   Estimates

Cov Parm    Estimate

Plot         0.06207
Residual     0.1197
```

Sampling requirements tool selection based on variance source

Use Figure A2-1 and Table A2-1 as guides to select the appropriate sampling requirements tool. Instructions for the tool are provided in Appendix 2.4 and 2.5. Choose a tool based on the scale of variances available:

1. Fine scale only: Use the **Sampling Requirements Table and Graph** to estimate samples needed per plot with existing data or a preliminary sample. Go to Appendix 2.4.
2. Multiple scales: Use the **Multi-scale Sampling Requirements Evaluation Tool (MSSRET)** to estimate both samples per plot and plots needed for the project with existing, mid-project, or post-project data. Go to Appendix 2.5.

Table A2-1. Appropriate Use of Sampling Requirements and Evaluation Tools Based on Variance Sources.

Variance scale	Variance source	Select tool: Pre-project	Select tool: Post-project
Fine-scale: within plot variance	Existing data set	**SRTG**	
	Preliminary sample	**SRTG**	
Multi-scale: within and between plot variance	Existing data set	**MSSRET**	
	Collected data	**MSSRET**	**MSSRET**

SRTG - Sampling Requirements Table and Graph
MSSRET - Multi-scale Sampling Requirements Evaluation Tool

2.3 Review of Components of Sampling Requirements Calculations

Components of sampling requirements calculations
Calculation of sampling requirements requires variance and rho (Appendix 2.2) in addition to minimum detectable difference (MDD) and error rates. Minimum detectable difference and error rates are briefly discussed in the following paragraphs. To use the sampling requirements tools, users should be aware of the desired MDD for specific dynamic soil properties. Default values are provided for error rates.

Minimum detectable difference
The minimum detectable difference (MDD) is the smallest difference that can be detected with a given number and variability of samples. The desired MDD is the difference that one would like to detect between state phases. It should be based upon differences that are known to be functionally important. Specific, functionally important differences are not well established for most systems. To overcome this knowledge gap, a % MDD of the grand or overall mean can be used. The grand mean is the average of all state phase means for that property and depth. The % MDD is a percentage of that overall mean.

Precision and error rates
To detect a difference between state phases, where they occur, sufficient samples are needed to reduce the probability of false-change errors and missed-change errors (Table A2-2). A probability of a false-change error (Type I error) of 0.20 and a probability of a missed-change error (Type II error = 1 – power) of 0.20 are the recommended sampling objectives for inventory. In the **Sampling Requirements Table and Graph** and

MSSRET tools, these default values appear as alpha = 0.2 and power = 0.8. These values were also selected by members of the range community for rangeland monitoring (Herrick et al., 2005) and have been applied to characterization of tidal marsh soils (Hussein and Rabenhorst, 1999).

Table A2-2. Explanation of False-change and Missed-change Errors. Small values for Type I (alpha) and Type II (beta) errors mean that there is a low probability of making an incorrect conclusion. Power is the complement of Type II (missed changed error) because high power occurs when the Type II error is low. High power (close to 1) corresponds to a high ability to detect a difference or a low risk of making a missed-change error.

Type of sampling error	False conclusion that:	Probability set by:
False-change (Type I)	There is a difference in the property when there actually is not.	alpha (α)
Missed-change (Type II = 1- Power)	There is not a difference in the property when there actually is.	beta (β)

2.4 Sampling Requirements Table and Graph Tool

Project planning with fine-scale data

The **Sampling Requirements Table and Graph** (Figure A2-4) is intended for project planning purposes when only fine-scale variances are available. This tool can be used to determine the number of samples needed per plot. Use the highest likely within-plot variance (samples within one plot) to determine the number of samples needed per plot. In Figure A2-4, the graph allows for estimation of sample sizes for variances intermediate to those in the table. Then determine the desired minimum detectable difference (MDD). Consider actual differences between preliminary plots, differences found in the literature, and important functional differences to determine this level. Use the graph to find samples needed per plot for variances and MDDs that are not in the table. For practical reasons, between 5 and 10 samples per plot are recommended.

Figure A2-4. Sampling Requirements Table and Graph for Percent Organic Carbon. Use the table (1) to lookup per plot sampling requirements for a given variance and minimum detectable difference (MDD). Use the graph (2) to determine the estimated number of samples needed per plot for a given within-plot variance and minimum detectable difference (MDD). Scale of variance and MDD are based on organic carbon (%). A minimum number of 5 samples per plot is recommended for each plot. Sample numbers greater than 15 are shaded out because they are considered impractical.

1. Sampling Requirements Table

Variance within plot	Minimum detectable difference Organic carbon (%) 0.25	0.50	1.00	2.00
0.010	5	5	5	5
0.100	15	5	5	5
0.250	37	10	5	5
0.500	73	19	5	5
1.000	145	37	10	5
2.500	361	91	23	6
5.000	722	181	46	12

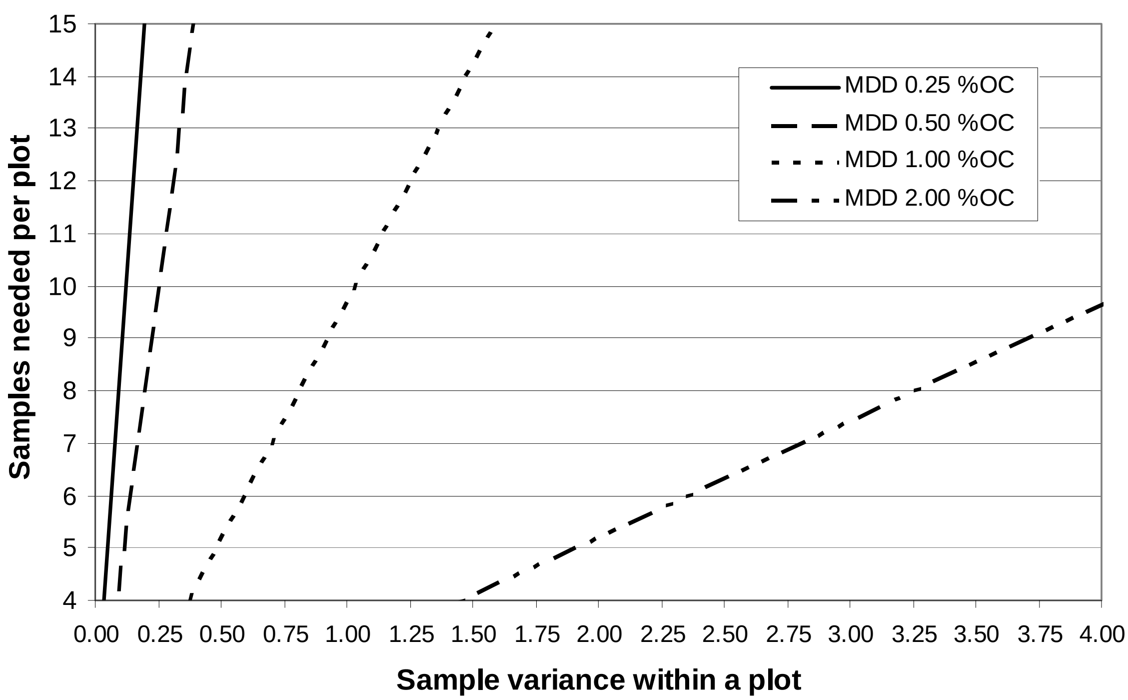
2. Sampling Requirements Graph

Instructions for using Sampling Requirements Graph:

a. Find the within-plot variance along the horizontal-axis (Sample variance within a plot).

b. From this value, trace a line straight up until you intercept the line of the desired MDD level.

c. From this point, trace a line straight left to the vertical axis (Samples needed per plot). Round up to the nearest whole number. This value is the number of samples needed per plot

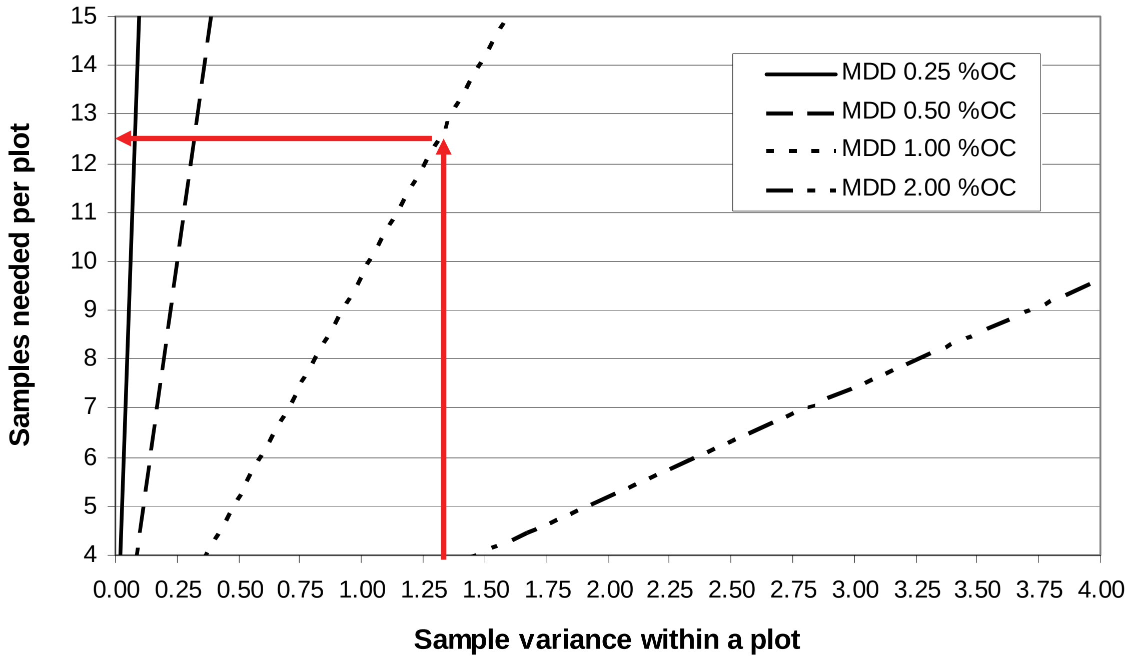


Note: It is possible that the variance and/or MDD will not fit on this graph. Possible problems and solutions are as follows:

- If the variance is less than those found on the desired MDD line, consider reducing the MDD or collect the minimum of 5 samples per plot.
- If the desired MDD level is not intercepted because the variance is too high, either select a higher MDD or reevaluate the range of conditions included in the project. If the variance is greater than those found on the graph, expert assistance may be required.
- If the values do not have a normal distribution (Chapter 4, Step 6.3), consult a statistics textbook or expert to identify an appropriate transformation. It is also possible that there are two or more strata on one plot. Evaluate the patterns and distributions present and consider stratification or refining the conditions of the project. Consult with an expert to determine how to proceed. It may be too costly to collect sufficient data. A different soil, conditions, or properties with lower variance should be considered.

Figure A2-5. Example: Using the Sampling Requirements Graph. Preliminary samples are collected on plots of two different state phases occurring on one soil map unit component phase. After the values of organic carbon (%) for each sample are entered in a spreadsheet, mean and variance values are computed as shown below. In this example, the difference between state phase means is approximately 1.0. The greatest variance is in state phase 1. On the graph, find the variance "1.32" on the horizontal axis (sample variance within a plot) and trace straight up to the MDD 1.00 line. Follow left to the vertical axis (samples needed per plot); the vertical axis is intercepted between 12 and 13, and thus 13 samples per plot are needed.

	Sample: organic carbon (%)						
	1	**2**	**3**	**4**	**5**	**Mean**	**Variance**
State phase 1	2.31	1.76	2.10	4.29	1.30	2.35	1.32
State phase 2	1.70	1.60	1.47	1.28	1.01	1.41	0.08



2.5 Multi-scale Sampling Requirements Evaluation Tool (MSSRET)

About MSSRET

The **MSSRET** tool is available with this **Guide** as a Microsoft Excel file. There are four worksheets in this file. The first two are intended to help determine the number of samples that should be collected in a project: “**Pre-project Sampling”** and “**Pre-project Multi-property**.” The final two worksheets are intended for use in sampling sufficiency evaluation: “**Post-project Sample Suff”** and “**Post-project Report.**”

The **Pre-project Sampling** and **Post-project Sample Suff** worksheets are designed to evaluate one state phase property and depth per sheet. The **Pre-project Multi-property** and **Post-project Report** worksheets expand on the single state phase-property worksheets to allow the entry of multiple state phases, properties, and depth in one worksheet. Instructions for all four worksheet are provided here.

MSSRET for project planning with multi-scale data

In the **Pre-project Sampling** worksheet, variances can be used from other sources or preliminary multi-scale sampling to explore the relationship between the number of samples collected per plot, the number of plots, and the minimum detectable difference (MDD). This worksheet is intended for one property, depth, and state phase. Once again, organic carbon (%) in the A horizon is recommended for use in determining sampling requirements. Use the state phase with the greatest requirements to determine the sampling distribution for the entire project. The worksheet is designed to be interactive and iterative. Enter data into the grey cells on the **Pre-project Sampling** worksheet and evaluate the output as follows:

1. Enter acceptable error rates and correlations or accept the default values. (The default values for the guide's sampling protocols are alpha = 0.2, power = 0.8, and rho = 0.0.)
2. Enter the grand property mean (the overall property mean for all state phases) for the property and depth increment and residual (within plot) and plot (between plot) variances for the individual state phase.
3. Use Table 1 to evaluate the number of samples needed per plot for a range of MDDs. This table uses the residual variances given to show the relationship between MDD and samples needed to detect differences at the plot scale. Alter the % MDDs in the grey cells (D14 to D22) to evaluate specific MDDs of interest.
4. Use Table 2* to evaluate the number of plots needed in that state phase for a range of MDDs and samples per plot. Alter the % MDD (C27 to C35) or samples per plot (E26 to K26), in the grey cells, to evaluate specific combinations of interest.

   *__Note:__ Use Table 2 in the **Pre-project Sampling** worksheet to determine the most efficient distribution of samples. In some cases, the samples needed per plot as computed in Table 1 can be reduced if the number of plots is increased. In most cases, the most efficient distribution of plots and samples per plot is the one with the lowest number of total samples per project. It is important to balance the cost of analyzing samples with the costs of time and travel to reach plots.

In the **Pre-project Multi-property** worksheet, multiple state phases, properties, and depths can be evaluated for plot- and project- (regional) scale sampling requirements. Identifying information is entered at the top of the worksheet. Scroll down to find the corresponding sampling requirements. Enter data into the grey cells on the **Pre-project Multi-property** worksheet and evaluate the output as follows:

1. Enter acceptable error rates and correlation or accept the default values. (The default values for the guide's sampling protocols are alpha = 0.2, power = 0.8, and rho = 0.0.)
2. Enter the identifying information (state phase, property and depth) in rows 5 to 7.
3. Enter the grand property means (the overall property means at that depth increment for all state phases) in row 8.
4. Enter the residual and plot variances for the individual state phase under the appropriate columns in rows 9 and 10.

5. Use Table 1 to evaluate the number of samples needed per plot for a range of MDDs reported as a % of the mean. This table uses the residual variances given to show the relationship between MDD and samples needed to detect differences at the plot scale.
    a. Alter the % MDDs in the grey cells (C15 to C18) to evaluate specific % MDDs of interest.
6. Use Table 2 to evaluate the number of plots needed in that state phase for a range of MDDs and samples per plot.
    a. Alter the % MDDs in rows 23 to26 and/or
    b. Enter the samples per plot in D23 to D36.

MSSRET for post-project sampling sufficiency evaluation with multi-scale data
For mid-project assessment and post- project reporting of a single state phase-property-depth combination, use the **Post-project Sampling Suff** worksheet. This worksheet will report the actual MDD (absolute and % of mean) with current samples and plots, as well as the number of samples and plots needed to achieve a desired MDD. While organic carbon (%) in the A horizon is recommended for use in determining sampling requirements, other properties and depths may also be assessed with this tool. Once the residual and plot-plot variances have been determined, decide what MDD should be achieved. Consider actual differences between state phase means and important functional differences to determine this level. A lookup table is provided to give the absolute MDD as a percent of the mean. Follow these steps to generate a report for each soil map unit component phase, state phase, property, and depth individually:

1. Copy Excel worksheet "**Post-project Sampling Suff**" and save under a new name (this can be done as a new tab in the same file) for record-keeping purposes.
2. Enter Soil map unit component phase, State phase, Property, and Depth for record-keeping purposes in "Identifying information."
3. Enter acceptable error rates and correlations. The default values for the **Guide**'s sampling protocols are alpha = 0.2, power = 0.8, and rho = 0.0 (rho may be increased for monitoring studies where the same plots are repeatedly measured).
4. Enter grand mean (mean over all state phases sampled) and plot and residual variances for the individual state phase to be evaluated.
5. Enter the number of samples and plots as collected.
6. Enter the desired minimum detectable difference (MDD). If necessary, use the lookup table to find the absolute MDD from the % MDD of the overall property mean.

The **Post Project Sampling Suff** worksheet will generate the actual MDD with the current samples and plots as well as the number of samples/plots needed to detect the desired MDD. These values are reported on two scales: plot scale and regional (project) scale.

The **Post-project Report** worksheet can be used to generate the sampling sufficiency report for multiple dynamic soil properties and depths. **Report 3. Sampling Sufficiency at the Regional Scale for State Phases** (Table A2-3) provides information on projects described in this **Guide**. The regional scale is used to report project sampling sufficiency (see Chapter 4, Step 6.4). This report should include the number of plots and samples taken (sample size) and the actual MDD that can be detected with those samples. It should also include the desired MDD and the number of plots that would be required to detect that difference (assuming the number of samples per plot remains the same as the sample size). The desired MDD should be determined with the best available information about functionally significant differences. If no information is available, a percentage of the grand mean may be used. Include the source of this information on the report.

1. Enter acceptable error rates and correlation. The default values for the **Guide**'s sampling protocols and reporting are alpha = 0.2, power = 0.8, and rho = 0.0.
2. Enter the identifying information (property, depth, and state phase) in columns B, C, and D.
3. Enter the mean, residual and plot variances for that individual state phase, property and depth combination in columns E, F, and G.
4. Enter number of plots and samples per plot as collected in columns H and I.
5. Enter the desired MDD as a percentage of the individual mean in K2. (Individual desired absolute MDDs can be entered directly in column K and/or N.)
6. The actual minimum detectable difference (MDD) is reported in column J for the plot scale and M for the project scale. The number of samples needed to detect the desired MDD is given in column L. The number of plots needed to detect the desired MDD (assuming the number of samples per plot remains the same) is given in column O.

Guidance for unreasonable MSSRET sampling recommendations Both the pre- and post-project worksheets may generate recommendations of one sample per plot or one plot per project. In order to do any statistical analysis, at least two samples per plot and two plots per project should be collected. In most cases, increasing the number of samples and plots beyond that is advisable. Extra samples will allow analysis in the event that some samples are damaged or lost. This **Guide** recommends a minimum of five plots per state phase with five samples per plot.

The variance and desired MDD may also result in sampling recommendations that are unreasonably high. In that case, either select a higher MDD or re-evaluate the range of conditions included in the project. Check the distribution of the property for normality and within-plot stratification (Chapter 4, Step 6.3). Consult a statistical textbook or expert to determine how to proceed. While it may be too costly to collect sufficient data in one season or year, consider collecting samples from additional plots over multiple years in order to obtain sufficient samples.

Table A2-3. Report 3. Sampling Sufficiency at the Regional Scale for State Phases. Example report of sampling sufficiency for dynamic soil properties of two state phases sampled in a project.

Sampling Sufficiency at the Regional Scale for State Phases for Begay fine sandy loam, 0-6% slopes.
Perennial Grass-Shrub (PGS) and Annual Grass (AG) State Phases

Property	Layer	State phase	State phase mean	Overall mean	Variance: Residual (within plots)	Variance: Plot-to-plot (between plots)	Sample size*: Plots	Sample size*: Samples per plot	Actual MDD** (regional scale)	Desired MDD†	Plots required††
Bulk density, <2mm (g/cm^3)	0-2 cm	PGS	1.51	1.47	0.039	0.002	4	6	0.14	0.15	4
		AG	1.42		0.024	0.009	4	4	0.18	0.15	7
	A horizon without 0-2 cm	PGS	1.51	1.47	0.009	0.005	4	6	0.12	0.15	3
		AG	1.42		0.004	0.003	4	4	0.09	0.15	2
	B horizon to 25 cm	PGS	1.55	1.53	0.001	0.001	4	6	0.05	0.15	1
		AG	1.51		0.001	0.001	4	4	0.05	0.15	1
Organic carbon (%)	0-2 cm	PGS	0.59	0.63	0.037	0.000	4	6	0.16	0.13	4
		AG	0.67		0.121	0.000	4	4	0.32	0.13	153
	A horizon without 0-2 cm	PGS	0.27	0.32	0.007	0.000	4	6	0.07	0.06	3
		AG	0.36		0.016	0.000	4	4	0.13	0.06	8
	B horizon to 25 cm	PGS	0.18	0.18	0.003	0.001	4	6	0.08	0.04	9
		AG	0.18		0.004	0.003	4	4	0.09	0.04	23
Organic carbon (kg/m^2)	0-2 cm	PGS	0.18	0.19	0.001	0.000	4	6	0.01	0.04	1
		AG	0.19		0.001	0.000	4	4	0.02	0.04	2
	2 - 10 cm	PGS	0.28	0.33	0.002	0.000	4	6	0.02	0.07	1
		AG	0.38		0.003	0.000	4	4	0.04	0.07	2
	10 - 25 cm	PGS	0.42	0.41	0.008	0.000	4	6	0.06	0.08	2
		AG	0.39		0.010	0.000	4	4	0.08	0.08	4

* Number of plots and samples that were actually collected.
** Alpha = 0.2, power = 0.8, and rho = 0.0.
† Reported in same units as the mean. Desired MDDs for this project are based on arbitrary values: 10 % and 20% of the overall mean for that property and depth increment are used for bulk density and organic carbon, respectively.
†† Assumes that the number of samples per plot is the same as the number actually collected.

Appendix 3 Methods, Field Forms, and Data Entry Sheets

Figures

Tables

Appendix 3 Methods, Field Forms, and Data Entry Sheets

3.1 Introduction

About this appendix
This appendix describes methods, field forms, and equipment for field data collection, including standard rules for sampling layers and horizons. It also describes data entry sheets for interim storage. Standard methods are indicated for three primary land cover types in the sections below, as follows: 3.2) grassland, shrubland, and savanna ecosystems; 3.3) forest land ecosystems; and 3.4) cropland agroecosystems. For pastureland, select the standard methods that are most applicable to each situation. In some cases, pastureland is managed intensively in a manner similar to the way cropland is managed; in others it is managed primarily as grazing land in a manner similar to a natural system. Instructions for some of the field methods are available online in other field guides and sampling manuals. Web site addresses are provided for these methods.

Integrated soil and vegetation data collection
In each project, appropriate soil horizon, pedoderm, and plant community properties (where present) and their patterns will be characterized. Many of the data collection methods will be determined by the information requirements associated with each land cover type. The properties included in the minimum data set for soil (organic C, pH, EC, bulk density/soil porosity, soil structure, aggregate stability [wet and field kit], and total N) and plant community characteristics are listed on the Workplan Worksheet, Items 12 and 14. Projects may include additional properties as recorded on the Workplan Worksheet, Item 13.

Integrating data collection for soil and vegetation characteristics at the same field location places special requirements on the plot configuration. The plot designed for the primary sampling unit needs to be large enough to capture the variability in soil and vegetation properties, but not so large that it includes more than one kind of soil. The plot type generally is determined by the data collection methods for vegetation. Consequently, the recommended plot type is square or rectangular for grassland, shrubland, and savanna ecosystems and circular for forest land ecosystems. Plot types for cropland and pastureland can be square, rectangular, or circular or can consist of transects.

3.2 Standard Methods and Field Forms for Grassland, Shrubland, and Savanna Ecosystems

Summary

Standard methods include procedures that characterize soil horizons, the pedoderm (air-soil interface), and the plant community. Soil samples will be collected, and field measurements for soil and vegetation characteristics will be gathered. The standard methods are designed for a square or rectangular plot to accommodate 1) multiple vegetation transects extending across the entire plot and 2) classification of soil surface and vegetation patterns within a spatially defined area. Circular plots with transects radiating from a center point are not recommended. Transects placed in this manner tend to over-sample near the center of the plot and under-sample near the perimeter.

Plot layout

Typical plot elements of the primary sampling unit include transects for line-point and gap observations, woody and herbaceous production subplots, and replicate soil sample locations (Figure A3-1.). The same soil sample locations can be used on all plots in a project. Refer to Table A3-1 for meter mark coordinates that specify positions for 5, 6, 7, 8, or 9 soil sample locations. Review the primary sampling unit plot diagram and evaluate its suitability for each project. Modify as needed and record plot type, size, and information about plot elements on the Workplan Worksheet, Items 19 and 20. Instructions for laying out a plot and the plot elements are provided in the form "Plot Master_RANGE_square."

Figure A3-1. Standard Plot Layout for Grassland, Shrubland, and Savanna Ecosystems. Example is a primary sampling unit (plot) for sampling one stratum with five soil sample locations.

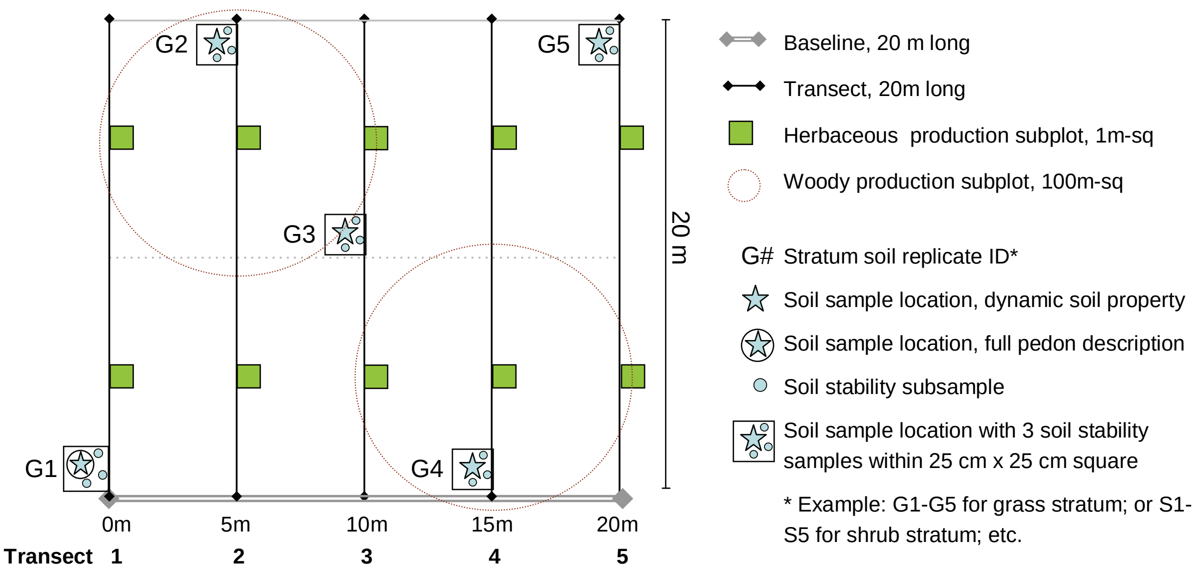


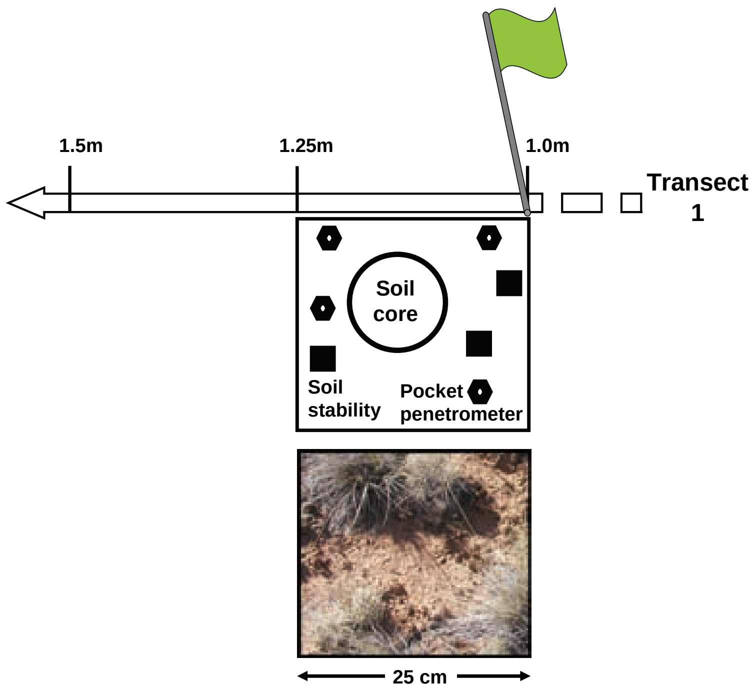
Table A3-1. Standard Location for Soil Samples Within a Standard Square Plot Layout. Plot size is 20 m x 20 m. Transect and meter mark of soil sample locations are provided for 5, 6, 7, 8, or 9 samples per plot.

Samples per plot	Soil sample location replicate no.	Transect	Meter mark	Samples per plot	Soil sample location replicate no.	Transect	Meter mark
5	1	1	1	8	1	1	1
	2	2	19		2	1	19
	3	3	10		3	2	10
	4	4	1		4	3	1
	5	5	19		5	3	19
6	1	1	1		6	4	10
	2	2	7.5		7	5	1
	3	2	19		8	5	19
	4	4	1	9	1	1	1
	5	4	12.5		2	1	12.5
	6	5	19		3	2	7.5
7	1	1	1		4	2	19
	2	1	19		5	3	12.5
	3	2	12.5		6	4	1
	4	3	7.5		7	4	17.5
	5	4	12.5		8	5	7.5
	6	5	1		9	5	19
	7	5	19				

Data collection at the soil sample location

Soil sample locations are indicated by a star on the diagram of the primary sampling unit. Instructions for placing a 25- by 25- cm plot at the soil sample location are provided on the form “Soil Sample, Db(field), Penetration Resistance, Pedoderm_RANGE.” Bulk density cores and soil samples will be collected for each horizon to the depth defined in the workplan. Measurements for soil surface stability and penetration resistance will be replicated within the 25- by 25- cm plot (Figure A3-2), and penetration resistance will also be replicated for each horizon. If bulk density cores cannot be collected because of soil conditions, such as a large amount of rock fragments, use an alternative method described in Appendix 3.5.

Figure A3-2. Example Layout for Soil Sample Locations: Square. The 25cm x 25 cm plot is placed adjacent to the point selected for the soil sample location (marked by flag). To avoid bias, always place a corner of the plot at the point and extend the rest of the plot along the tape in the increasing direction. In this example the flag and point corner are at 1m and the plot extends to 1.25m. Measurements are indicated by unique symbols for the soil core sample, soil aggregate stability, and penetration resistance). Collect soil samples for laboratory analysis according to the instructions on the field form (no grab samples from the center of the horizon!).



Field forms and equipment

For grassland, shrubland or savanna ecosystems within a project, use the field forms listed in Table A3-2. List forms that will be used for each project on the Workplan Worksheet: Item 27. On each form, record the required plot and sample identification codes for a comparison study. Refer to the field form for method instructions. Additional sources of instructions are provided in the table. Equipment needs are listed in Table A3-3.

Table A3-2. Standard Methods and Field Forms for Grassland, Shrubland, and Savanna Ecosystems. Unless otherwise stated all forms are provided with this **Guide**.

Form name	Description
Plot Master_RANGE_square	Primary record for geospatial information, plot and pedon identification codes, and list of completed field forms. Includes example of plot layout.
Photocard	Plot identification card for photographs. Photocard template to be prepared for each plot prior to field work.
Photo Record	Record for photograph identification and description.
Soils-232	Pedon description form or use PEDON PC, PEDON CE. Form at http://soils.usda.gov/technical/aids/investigations/
Soil Sample, Db(core), Penetration Resistance, Pedoderm_RANGE	Soil sample location and horizon ID codes. Field observations related to bulk density, penetration resistance; cover and pedoderm classes at the soil sample location. Includes instructions.
Soil Aggregate Stability Test (field)_RANGE	Soil aggregate stability measured with the field by slaking and dipping small soil ped (6 to 8 mm dia.). Use form modified for replicate sample collection at each soil sample location. For instructions, see Herrick et al., 2005. http://usda-ars.nmsu.edu/monit_assess/PDF_files/Quick_Start.pdf
Pedoderm, Pattern Classes (plot)	Includes class descriptions for soil surface properties (pedoderm), resource retention, and erosion pattern. Assign one class to a plot. Use form modified to include project ID information Other versions of form at http://usda-ars.nmsu.edu/esd/ESD_pedoderm.xls
Gap Intercept	Canopy and basal gap sizes along transects. Use form modified to include project ID information. For instructions, see: Herrick et al., 2005. http://usda-ars.nmsu.edu/monit_assess/PDF_files/Quick_Start.pdf
Linepoint Intercept 20m_0.5,1.0 interval	Canopy and soil surface features recorded along transects to estimate cover. Use form adapted for 20- x 20-m plot and project ID information. Soil surface codes added for soil survey. For instructions, see: Herrick et al., 2005. http://usda-ars.nmsu.edu/monit_assess/PDF_files/Quick_Start.pdf Other versions of form at http://usda-ars.nmsu.edu/esd/ESD_HighIntensity_plant.xls
Double Sampling for Production	Double sampling procedure for herbaceous and woody annual production. Use form modified to include project ID information. For instructions, see: Herrick et al., 2005. http://usda-ars.nmsu.edu/monit_assess/PDF_files/Volume_II.pdf

Herrick et al., 2005. Monitoring Manual for Grasslands, Shrublands and Savanna Ecosystems http://usda-ars.nmsu.edu/monit_assess/monitoring.php

Table A3-3. List of Sampling Equipment for Grassland, Shrubland, and Savanna Ecosystems. Includes equipment to sample one plot using two soil sampling crews and one vegetation crew. Where additional sampling crews are available, increase amount of equipment for items marked with an asterisk (*).

Method	Equipment	Number for two sampling crews
General	Clip boards	1 per person
	Pencils	1 per person
	Field forms	1 for each method per plot
	Field briefcase or file box for completed data sheets	1
	5 gal bucket for carrying equipment and samples	3 or 4*
Plot set-up and vegetation transects	Compass	1
	Transect tapes (20 m)	6
	Chain pins	12
	Pin flags, 3 colors	10 each
	GPS unit	1
Photopoint	Digital camera	1
	Extra camera batteries	4
	Photo point ID cards	1 per plot
	Clipboard	1
	4 ft tall stake and fastener to hang clipboard (optional)	1
	Felt pen (wide point)	1
Vegetation clipping	Grass clippers	1*
	Hand pruners, 8 – 9" total length (for shrubs)	1*
	Spring-loaded scale with clip (kg and gm)	1*
	Paper sacks	~12 per plot plus extra
	1 m square frame OR standard hoop	1*
Soil stability	Soil Stability Kit (3 boxes of sieves and one box for dipping	3 kits
	Deionized (distilled) water for stability kit	0.4 gal per plot
	Stop watch or watch with second hand	1
	Small mister bottle	1
Penetration resistance	Pocket penetrometer, regular point; with set of 4 springs	2*
	Pocket penetrometer, wide foot; with set of 4 springs	2*
	30 cm ruler, with mounting hole (wooden is best)	2*
	Golf tee	8*
Soil samples	Sharp shooter, shovel	2*
	Auger	1
	Hand pick or other small digging tool	2*
	Wood block (10" long 2x4)	6*
	Canvas tarp, 4'x6'	2*

	Metal hoop, 25 – 50 cm dia (for O horizon)	2*
	Metal surface soil sample scoop, 2 cm deep, flat bottom with handle	2*
	Metal sample ring, 15 cm long x 57 mm dia.	2*
	Metal sample ring, 25 cm long x 57 mm dia.	2*
	Wide spackle blade, square tip (wider than ring dia.)	2*
	Rubber bands (height marker for metal ring)	8 plus extra*
	Rubber mallet	2*
	Large soil cutting knife	2*
	Serrated edge knife (steak knife)	2*
	Clippers, grass	2*
	Hand pruners, 8 - 9” total length (for shrubs)	2*
	Tape measure, cm	2*
	School ruler, 30 cm	2*
	Paint brush, 2” wide	2*
	Mechanics rag	2*
	Soil sample pan, 15” x 7” x 3” (for mixing soil)	2*
	Gloves	2 pr*
	Soil sample bags-sealable for bulk density cores (1qt plastic ziplock, or equivalent with write-on label);	~5 bags per soil sample location
	Soil sample bags for laboratory analysis (1gal ziplock or equivalent with write-on label)	~5 bags per soil sample location
	Cloth sample bags for O horizon (2 gal with write-on label)	1 per soil sample location
	Soil sample bags- to carry other bags (2 kg bag);	1 per soil sample location
	Felt pen, fine to med point (to label bags); e.g., Sharpie	2*

Resource retention and erosion pattern classes

Classes of resource retention and erosion pattern are visual classification systems that can be applied rapidly in the field to describe vegetation and soil erosion patterns (Bestelmeyer et al., in press). They do not require skills for plant species identification. These two pattern class systems are designed to be used in combination. The purpose of these two class systems is to capture the relationships of pattern and processes and the consequences of each. Apply these classes (Table A3-4 and A3-5) to the primary sampling unit (20-m x 20-m plot).

Table A3-4. Resource Retention Class. Resource retention is a measure of patch structure that relates to the potential for erosion and resource redistribution as controlled by vegetation. It also provides a description of the grass fragmentation pattern. The classes can be applied to vegetation fragmentation in plant communities dominated by shrubs and trees, but plot size and bare ground sizes may need to be adjusted.

Class	***Resource retention class in __ x __ (e.g., 20 x 20m) plot***
1	Interconnected grass cover or dense bunchgrasses; and surrounding ellipsoid bare patches < 30 cm
2	Grass cover interconnected and surrounding ellipsoid bare ground patches from 30-__cm
3	Grass cover fragmented by elongate bare ground areas to __ cm wide but bounded in plot
4	Grass cover fragmented by elongate bare ground areas to __ cm wide that cross entire width of plot
5	Bare ground interconnected in several directions and isolated grass patches up to __ cm
6	Bare ground interconnected with scattered or no grass plants

Table A3-5. Erosion Pattern Class. These classes correspond to erosion patterns that indicate the consequences of erosion soils. Classes are distinguished on the basis of observable features, including waterflow patterns, rills, gullies, deflation, wind scour, pedestals, coppicing, deposition, and exposed subsoil horizons. This method does not designate unique classes for wind or water erosion because a particular location can be affected by both. In contrast to this method, the classes of accelerated erosion described in the *Soil Survey Manual* (Soil Survey Division Staff, 1993) pertain to the proportion of upper horizons that have been removed. Erosion pattern classes provide descriptive information most appropriate for lands that are not cultivated or for abandoned cropland. A simple crosswalk of the two systems is not readily apparent. In general, erosion pattern classes 0 through 3 and 5 are not represented by any accelerated erosion class. Erosion pattern class 3 corresponds to accelerated erosion class 1 or 2. Erosion pattern class 4 corresponds to accelerated erosion class 3 or 4.

Class	***Erosion pattern class in __ x __ (e.g., 20 x 20m) plot***
0	No evidence of erosion or deposition
1	Erosion limited to small (< 50 cm) patches (may see: minimal sheet erosion, wind scouring)
2	Erosion across large (> 50 cm) patches (may see: no to few small pedestals, terracettes, waterflow patterns, wind scouring)
3	Erosion across large areas (> 50 cm) with extensive loss of A horizon (may see: prominent pedestals, water flow patterns, rills, gullies, extensive wind scouring or deflation, coppicing)
4	Erosion across large areas with exposed subsoil (may see: scarplets, patchy remnant surface horizons, waterflow patterns, rills, gullies, extensive wind scouring, deflation, large coppices, prominant pedestals, exposed roots)
5	Deposition* across large areas (may see: waterflow patterns, rills, large coppices, small dunes, sand sheets)

*Confirm deposition by digging a hole and observing recent deposition. Recently deposited material is generally finely stratified with alternating thin layers of varying texture. It lacks structure.

Pedoderm features and soil surface crust classes for a spatially defined area
The classes for pedoderm features and soil surface crusts are a visual classification system that describes the dominant types of soil surface features covering an area (Table A3-6). Pedoderm features include properties that characterize the air-soil interface (Mills and Fey, 2004). This classification system accounts for the assemblage of surface features, such as physical, chemical, and biological, crusts, rock pavement, a duff layer of decomposing organic matter, and bare soil. It recognizes broad functional/structural groups of biological crust organisms, including moss, lichen, cyanobacteria, algae, and liverworts. It cannot be applied to point observations, such as those made on a line-point transect. It can be applied to plots of various sizes. The value of using these classes to characterize plots smaller than 25-cm x 25-cm is questionable.

Table A3-6. Pedoderm/Soil Crust Class. These classes are applied to an area only. They are not for line point observations. The area ranges from a few square centimeters to many square meters in size.

Pedoderm/Crust class in _____x______ (e.g., 20 x20m) plot

S =	Soil; pedoderm is characterized by bare mineral soil and none of the classes below
WP =	Weak physical or biological crust; can be disrupted by rainfall, none to few cyanobacterial sheaths dangling from ped, no darkening from cyanobacteria
SP =	Strong physical crust, usually platy or massive (structure not disrupted by rainfall), no substantial biological component
VC =	Vesicular crust; a layer of many unconnected spherical or ovoid pores; at the soil surface
CEM =	Cemented pan exposed at surface
SC =	Salt crust of fine to extremely coarse evaporite crystals or visible whitening on the soil surface; may include biological components
PDB =	Poorly developed biological crust assemblage, many cyanobacterial sheaths, may be slightly dark, can include other functional/structural groups (algae, lichen, moss)
SDB =	Strongly developed biological crust assemblage, obvious dark cyanobacteria, rubbery algal, moss or lichen crust
CB =	Cracking or curling, rubbery algal crusts, with or without lichen
EP =	Erosion pavement; a concentration of rock fragments at the soil surface caused by erosion and removal of finer soil material; individual fragments may be displaced during runoff events
DP =	Desert pavement; a concentration of closely packed and polished rock fragments at the soil surface, embedded in a vesicular crust
D =	Duff (partially to fully decomposed plant and organic matter; above the A horizon)
SA =	Well-formed or distinct structural aggregates at the soil surface and no other class above (well aggregated, stable soils)

3.3 Standard Methods and Field Forms for Forest Land Ecosystems

Summary

Standard methods include procedures that characterize soil horizons, the forest floor, and the plant community. Soil samples will be collected and field measurements for soil and vegetation characteristics will be gathered. The standard methods are designed for a circular plot to accommodate site index measurements. Plots for other vegetation measurements are nested within the primary sampling unit.

Plot layout

Typical plot elements of the primary sampling unit include smaller plots for understory and ground cover measurements, transects, and replicate soil sample locations (Figure A3-3). Soil sample locations are placed randomly within the circular plot. The same set of random points can be used for all plots in a project. Refer to instructions and an example of random point computations for a circular plot (Table A3-7). Transects for woody debris and Visual Disturbance Classes are placed in a random direction extending from the center of each soil sample location. Review the plot diagram of the primary sampling unit and evaluate its suitability for each project. Modify as needed and record plot type, size, and information about plot elements on the Workplan Worksheet, Items 19 and 20. Instructions for laying out a plot and the plot elements are provided in the form "Plot Master_FOREST_Circular"

Figure A3-3. Standard Plot Layout for Forest Land Ecosystems. Example is a primary sampling unit for a plot with a radius of 58.9 feet. This radius was selected to accommodate the variable radius plot required for site index in the western hemlock plant community in north-central Idaho. The site index sampling requirements of the plant communities included in a project dictate the radius for the plot. It may be necessary to vary the plot radius from project to project, but it is important to use the same plot radius for all plots within a single project.

¼ acre plot

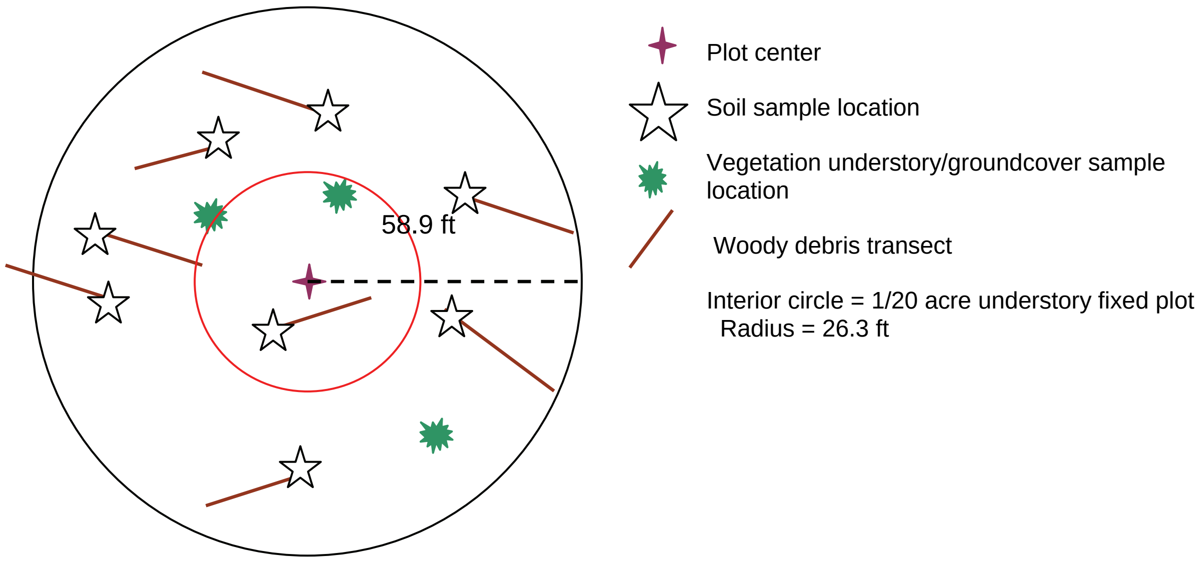


Table A3-7. Example of Randomly Selected Sample Locations for a Circular Plot With a Radius of 58.9 ft. On a circular plot, sample locations should be located by azimuth or direction and distance from the plot center. One set of sample locations can be generated and used on each plot in a project. Each set of sample locations should include twice as many potential locations as the required number of samples for a plot. This procedure allows some to be discarded if they are rejected during the plot layout phase. A special procedure is used to randomly distribute samples on a circular plot (Skalski, 1987). First, generate two random numbers (R1 and R2) for each potential sample location. Then use those numbers in the following equations to compute the azimuth and distance:

azimuth of sample location = 360^{o} x (R1)
distance from plot center = radius of plot * square root (R2)

Distances can be computed in feet or meters as in this example. A spreadsheet for completing this computation is included with the data entry sheets.

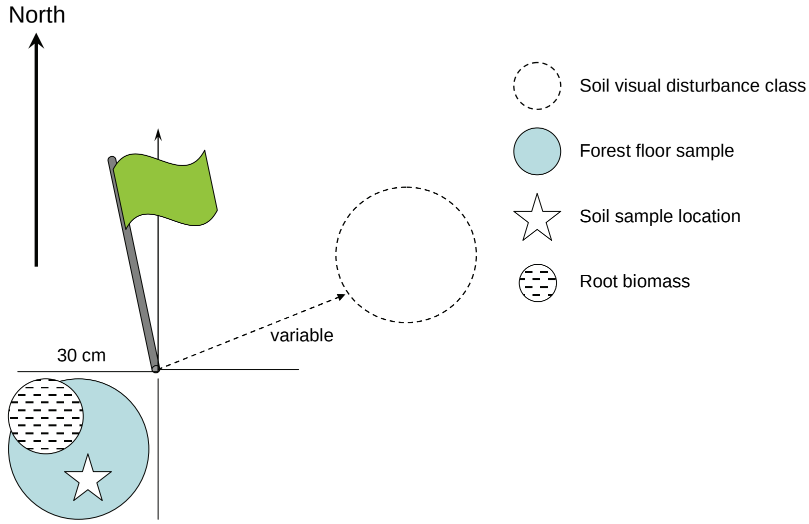
R1	R2	Azimuth	Distance(ft)	Distance(m)
0.63	0.83	226.77	53.80	16.35
0.91	0.21	326.70	26.93	8.19
0.13	0.93	47.91	56.78	17.26
0.99	0.37	356.28	35.94	10.92
0.41	0.40	148.43	37.40	11.37
0.34	0.94	123.97	57.14	17.37
0.68	0.93	244.46	56.68	17.23
0.22	0.35	77.50	34.97	10.63
0.60	0.83	214.96	53.50	16.26
0.07	0.41	26.59	37.61	11.43
0.92	0.91	332.99	56.27	17.10
0.90	0.24	323.76	28.87	8.77
0.09	0.96	33.29	57.73	17.55
0.85	0.86	306.25	54.51	16.57
0.73	0.06	262.04	14.32	4.35
0.47	0.79	169.63	52.19	15.86

Skalski, J.R. 1987. Selecting a Random Sample of Points in Circular Field Plots. Ecology. 68(3):749-749.

Data collection at the soil sample location

Soil sample locations are indicated by a star on the diagram of the primary sampling unit. Instructions for positioning the bulk density soil core and the forest floor (O horizon) sampling ring at each soil sample location (Figure A3-4.) are provided on the form “Soil Sample, Db(field), Penetration Resistance, Forest Floor_FOREST.” Bulk density cores and soil samples will be collected for each horizon to the depth defined in the workplan, and measurements for penetration resistance will be replicated for each horizon. If bulk density cores cannot be collected because of soil conditions, such as a large amount of rock fragments, use an alternative method described in Appendix 3.5.

Figure A3-4. Example Layout for Soil Sample Locations: Circular. Visualize two lines, one north-south and the other east-west intersecting at the sample point marked by the flag. To avoid bias, the 30 cm diameter plot is placed in the southwest quadrat formed by these two imaginary lines. Use the hoop for the forest floor method as a guide for the 30 cm diameter plot. Measurements are indicated by unique symbols for forest floor and soil samples, supplemental root biomass samples, and the visual disturbance class. Collect soil samples for laboratory analysis according to the instructions on the field form (no grab samples from the center of the horizon!).



Field forms and equipment

For forest land ecosystems within a project, use the field forms listed in Table A3-8. List forms that will be used for each project on the Workplan Worksheet: Item 27. On each form, record the required plot and sample identification codes for a comparison study. Refer to the field form for method instructions. Additional sources of instructions are provided in the table. Equipment needs are listed in Table A3-9.

Table A3-8. Standard Methods and Field Forms for Forest Land Ecosystems. Unless otherwise stated, all forms are provided with this **Guide.**

Form	Description
Plot Master_FOREST_circular	Primary record for geospatial information, plot and pedon identification codes, and list of completed field forms. Includes instructions for plot layout.
Photocard	Plot identification card for photographs. Photocard template to be prepared for each plot prior to field work.
Photo Record	Record for photograph identification and description.
Soils-232	Pedon description form or use PEDON PC, PEDON CE. Form at http://soils.usda.gov/technical/aids/investigations/
Soil Sample, Db(core), Penetration Resistance, Forest Floor_FOREST	Soil sample location and horizon ID codes. Field observations related to bulk density, penetration resistance, cover, and forest floor at the soil sample location. Includes instructions.
Plot Vegetation_FOREST	Overstory Veg (variable radius) Includes stand inventory observations, tree health status (NRCS) and tree condition codes (USFS), densitometer readings, and photo numbers. Understory Veg (high) Plot Includes tree and shrub inventory for small tress and tall shrubs (3 to 14 ft tall), health status (NRCS), understory canopy characteristics, and ocular cover estimates, by stratum. Understory Veg (low) Plot Includes height and cover by species for small shrubs (< 3 ft tall) and ground cover clip weights.

Table A3-9. List of Sampling Equipment for Forest Land Ecosystems. Includes equipment to sample one plot using two soil sampling crews and one vegetation crew. Where additional sampling crews are available, increase amount of equipment for items marked with an asterisk (*).

Method	**Equipment**	**Number for two sampling crews**
General	Clip boards	1 per person
	Pencils	1 per person
	Field forms	1 for each method per plot
	Field briefcase or file box for completed data sheets	1
	5 gal. bucket for carrying equipment and samples	3 or 4*
Plot set-up	Compass	1
	Transect tapes (20 m)	2
	Chain pins	2
	Pin flags, 1 color	10 each
	GPS unit	1
Photopoint	Digital camera	1
	Extra camera batteries	4
	Photo point ID cards	1 per plot
	Clipboard	1
	4 ft. tall stake and fastener to hang clipboard (optional)	1
	Felt pen (wide point)	1
Soil stability	Soil Stability Kit (three boxes of sieves and one box for dipping	3 kits
	Deionized (distilled) water for stability kit	0.4 gal per plot
	Stop watch or watch with second hand	1
	Small mister bottle	1
Penetration resistance	Pocket penetrometer, regular point; with set of four springs	2*
	Pocket penetrometer, wide foot; with set of four springs	2*
	30 cm ruler, with mounting hole (wooden is best)	2*
	Golf tee	8*
Forest floor (O horizon)	25 cm dia. metal hoop	2*
	Tape measure or ruler (cm)	2*
	Large cloth sample bag, clean! (4 gal.) for O horizon	1 per soil sample location
Soil samples	Sharp shooter, shovel	2*
	Auger	1

	Hand pick or other small digging tool	2*
	Wood block (10” long 2 x 4)	6*
	Canvas tarp, 4” x 6”	2*
	Metal hoop, 25 – 50 cm dia. (for O horizon)	2*
	Metal surface soil sample scoop, 2 cm deep, flat bottom with handle	2*
	Metal sample ring, 15 cm long x 57 mm dia.	2*
	Metal sample ring, 25 cm long x 57 mm dia.	2*
	Wide spackle blade, square tip (wider than ring dia.)	2*
	Rubber bands (height marker for metal ring)	8 plus extra*
	Rubber mallet	2*
	Large soil cutting knife	2*
	Serrated edge knife (steak knife)	2*
	Clippers, grass	2*
	Hand pruners, 8 - 9” total length (for shrubs)	2*
	Tape measure, cm	2*
	School ruler, 30 cm	2*
	Paint brush, 2” wide	2*
	Mechanics rag	2*
	Soil sample pan, 15” x 7”x 3” (for mixing soil)	2*
	Gloves	2 pr*
	Soil sample bags-sealable for bulk density cores (1 qt. plastic ziplock or equivalent with write-on labels);	~5 bags per soil sample location
	Soil sample bags for laboratory analysis (1gal. ziplock or equivalent with write-on label)	~5 bags per soil sample location
	Cloth sample bags for O horizon (2 gals. with write-on label)	1 per soil sample location
	Soil sample bags - to carry other bags (2 kg bag);	1 per soil sample location
	Felt pen, fine to medium point (to label bags); e.g., Sharpie	2*
Site index		
Overstory		
Understory vegetation		
Understory/Ground cover clipping	Grass clippers	1*
	Hand pruners, 8-9” total length (for shrubs)	1*
	Spring-loaded scale with clip (kg and gm)	1*
	Paper sacks	~12 per plot plus extra
	1 m sq. frame OR standard hoop	1*
Visual disturbance classes	Sharp shooter	1*

3.4 Standard Methods and Field Forms for Cropland Agroecosystems

Summary

Standard methods include procedures that characterize soil horizons and the pedoderm (air-soil interface). Soil samples will be collected, and field measurements for soil will be gathered. The standard methods can utilize a square, rectangular, or circular plot or transects.

Plot layout and data collection at the soil sample location

If a plant community phase and a cropland system are included in the same project, use the same plot configuration for each of them. If only cropland systems are included in a project, plots comprised of a single transect should be considered because they can be quickly set up. All plots for all state phases in a project should be similar in size in order to capture the spatial variability at the same scale.

After the plot configuration is determined, refer to the appropriate plot layout discussion of square or circular plots described in the two previous sections. The plot configuration for a single transect has not been developed yet.

Field forms and equipment

For cropland agroecosystems within a project, use the field forms listed in Table A3-10. List forms that will be used for each project on the Workplan Worksheet: Item 27. On each form, record the required plot and sample identification codes for a comparison study. Refer to the field form for method instructions. Additional sources of instructions are provided in the table. Equipment needs are listed in Table A3-11.

Table A3-10. Standard Methods and Field Forms for Cropland Agroecosystems. Unless otherwise stated, all forms are provided with this **Guide**.

Form	Description
Plot Master_RANGE_square or Plot Master_FOREST_circular	Primary record for geospatial information, plot and pedon identification codes, and completed field forms. Includes instructions for plot layout. *Complete only appropriate items for cropland.*
Photocard	Plot identification card for photographs. Photocard template to be completed for each plot prior to field work.
Photo Record	Record for photograph identification and description.
Soils-232	Pedon description form or use PEDON PC, PEDON CE. Form at http://soils.usda.gov/technical/aids/investigations/
Soil Sample, Db(core), Penetration Resistance, Pedoderm_RANGE or Soil Sample, Db(core), Penetration Resistance, Forest Floor_FOREST	Soil sample location and horizon ID codes. Field observations related to bulk density, penetration resistance, cover, and pedoderm classes at the soil sample location. Includes instructions. *Complete only appropriate items for cropland.*
Soil Aggregate Stability Test(field)_RANGE	Soil aggregate stability (field kit) observations. Use form modified for replicate sample collection at each soil sample location. For instructions, see Herrick et al., 2005. http://usda-ars.nmsu.edu/monit_assess/PDF_files/Quick_Start.pdf *Complete only appropriate items for cropland.*

Herrick et al., 2005. Monitoring Manual for Grasslands, Shrublands and Savanna Ecosystems http://usda-ars.nmsu.edu/monit_assess/monitoring.php

Table A3-11. List of Sampling Equipment for Cropland Agroecosystems. Includes equipment to sample one plot using two soil sampling crews. Where additional sampling crews are available, increase amount of equipment for items marked with an asterisk (*).

Method	Equipment	Number for two sampling crews
General	Clip boards	1 per person
	Pencils.	1 per person
	Field forms	1 for each method per plot
	Field briefcase or file box for completed data sheets	1
	5 gal bucket for carrying equipment and samples	3 or 4*
Plot set-up	Compass	1
	Transect tapes (20 m)	4
	Chain pins	8
	Pin flags, 1 color	10 each
	GPS unit	1
Photopoint	Digital camera	1
	Extra camera batteries	4
	Photo point ID cards	1 per plot
	Clipboard	1
	4 ft. tall stake and fastener to hang clipboard (optional)	1
	Felt pen (wide point)	1
Soil stability	Soil Stability Kit (three boxes of sieves and one box for dipping	3 kits
	Deionized (distilled) water for stability kit	0.4 gal per plot
	Stop watch or watch with second hand	1
	Small mister bottle	1
Penetration resistance	Pocket penetrometer, regular point; with set of four springs	2*
	Pocket penetrometer, wide foot; with set of four springs	2*
	30 cm ruler, with mounting hole (wooden is best)	2*
	Golf tee	8*
Soil samples	Sharp shooter, shovel	2*
	Auger	1
	Hand pick or other small digging tool	2*
	Wood block (10” long 2 x 4)	6*
	Canvas tarp, 4” x 6”	2*
	Metal hoop, 25 – 50 cm dia. (for O horizon and residue)	2*
	Metal surface soil sample scoop, 2cm deep, flat bottom with handle	2*
	Metal sample ring, 15 cm long x 57 mm dia.	2*
	Metal sample ring, 25 cm long x 57 mm dia.	2*
	Wide spackle blade, square tip (wider than ring dia.)	2*

	Rubber bands (height marker for metal ring)	8 plus extra*
	Rubber mallet	2*
	Large soil cutting knife	2*
	Serrated edge knife (steak knife)	2*
	Clippers, grass	2*
	Hand pruners, 8-9” total length	2*
	Tape measure, cm	2*
	School ruler, 30 cm	2*
	Paint brush, 2” wide	2*
	Mechanics rag	2*
	Soil sample pan, 15” x 7”x 3” (for mixing soil)	2*
	Gloves	2 pr*
	Soil sample bags-sealable for bulk density cores (1qt. plastic ziplock or equivalent with write-on label)	~5 bags per soil sample location
	Soil sample bags for laboratory analyses (1 gal. ziplock or equivalent with write-on label)	~5 bags per soil sample location
	Cloth sample bags for O horizon and residue	2 per soil sample location
	Soil sample bags - to carry other bags (2 kg bag);	1 per soil sample location
	Felt pen, fine to medium point (to label bags); e.g., Sharpie	2*

3.5 Standard Methods for Sampling Layers and Horizons

Instructions for sampling layers and horizons

Prepare a soil profile description for each pedon sampled. At a minimum, include all horizons sampled. Use the same lower depth or mineral soil thickness (e.g., 40 or 60 cm) for all pedons within a project. The default value is 40 cm. If any horizon is greater than 25 cm thick, divide the horizon for sampling. Subdivide the horizon approximately in half or on 5the basis of morphological features, if present. Label all samples with the actual depth sampled, even if it is different from the soil profile description. Use the same sampling rules for the entire project. Follow the depth in the instructions below, including additional rules for soils with a thin A horizon:

1. Soils cultivated each year.
    a. Collect samples for each horizon to a depth of 40 cm. Sample the Ap or O horizon and underlying layers by horizon to a depth of 40 cm.
    b. If mineral soil material occurs below an O horizon and above 40 cm, extend the sampling depth to include 40 cm of mineral material.
2. Soils that are not cultivated every year and that have an A horizon (or an Ap horizon not cultivated in recent years) at the soil surface.
    a. Collect samples of the 0 - 2 cm layer and for each horizon below 2 cm to a depth of 40 cm.
    b. If the A horizon is less than 5 cm thick, follow the rules for soils with a thin A horizon, (see below).
3. Soils that are not cultivated every year and that have an O horizon at the surface and an underlying A horizon.

   a. Collect samples of the O horizon and a layer 2 cm thick directly below the upper boundary of the A horizon. Continue sampling by horizon and extend the depth of sampling to include 40 cm of mineral material.
   b. If the A horizon is less than 5 cm thick, follow the rules for soils with a thin A horizon.
4. Soils that are not cultivated every year and that have organic soil material from the surface to a depth of 40 cm.
   a. Collect samples of the 0 - 2 cm layer and for each horizon below 2 cm to a depth of 40 cm.

Additional rules for soils with a thin A horizon

Collecting comparable samples for soils with a thin A horizon can be problematic. In these situations, sample as described below.

1. All soils with an A horizon less than 5 cm thick.
   a. If the A horizon is less than 2 cm thick, sample a layer 2 cm thick starting at the upper boundary of the A horizon. Continue to sample by horizon starting directly below this layer.
   b.. If the A horizon is 2 to 5 cm thick, sample the entire A horizon. Sample by horizon below this layer.

3.6 Methods for Special Situations and for Supplemental and Experimental Properties

About this section

Standard methods are not appropriate for all soils. For example, bulk density cores are difficult or impossible to collect in gravelly soils. In some projects, it may be desirable to determine supplemental or experimental properties. Suggested methods to be used in place of or in addition to standard methods are described in this section.

Bulk density

Use of metal rings for bulk density sampling may be difficult in some situations. Refer to Table A3-12 for alternative bulk density methods. If something other than a standard method is used, be sure to use the same method for the entire project.

Table A3-12. Bulk Density Methods. Suitability of a variety of methods in different field conditions. Method numbers refer to the Soil Survey Laboratory Investigations Report No. 42 at http://soils.usda.gov/technical/lmm/

Method	Description	Field conditions
Saran-coated natural clods – SSL method 3B1	The whole soil bulk density may be overestimated because the sampled clods frequently exclude the space between cracks and peds.	Soils that are at or above field capacity and/or the soils have low extensibility and do not exhibit desiccation cracks even if below field capacity.
Compliant cavity – SSL method 3B3		Fragile cultivated near-surface layers, some O horizons, cohesionless soils, and layers with rock fragments
Rind excavation – SSL method 3B4 or modified Soil Quality Test Kit method	Similar to the core method except only a partial volume within the ring is filled with soil. The depth from the top of the ring to the soil surface outside the ring is determined and soil volume calculated.	Thin layers (≤ 5 cm thick).
Frame excavation – SSL method 3B5		For O horizons in the woods where local variability is large (rock fragments can also be present).
Soil cores – SSL method 3B6	Determines the bulk density of a soil core of known volume. The standard method results in variable length soil cores corresponding to horizon or layer thickness.	For soils that are at or above field capacity and/or the soils have low extensibility and do not exhibit desiccation cracks even if below field capacity.

Infiltration and saturated hydraulic conductivity

A variety of methods are available for infiltration and hydraulic conductivity. See Table A3-13. For these properties, the replication required to get “good numbers” is usually very high. Even though these properties are very import for interpreting soil function, include them in a project only if there is a high benefit:cost ratio. The cost should reflect the staff and time required to make sufficient measurements to detect a functionally important difference (See Appendix 2).

Table A3-13. Infiltration and Hydraulic Conductivity Methods. Suitability of a variety of methods in different field conditions.

Method	Description	Field conditions	Interfering conditions
Single-ring infiltrometer (Constant head)	Provides a relative indication of infiltration capacity under saturated conditions.	Soils that have few rock fragments in the upper 3 cm. Cannot be used on slopes or areas with dense root mats at the surface.	Macropores and cracks[1]
Single-ring (Falling head)	Provides a relative indication of infiltration capacity under saturated conditions.	Soils that have few rock fragments in the upper 3 cm. Cannot be used on slopes or areas with dense root mats at the surface.	Macropores and cracks[1]
Cornell sprinkle infiltrometer	A portable rainfall simulator that provides infiltration and runoff measures based on pre-set rainfall rates over a 241 mm (9.5") diameter ring	Soils that are firm or firmer when moist and have few rock fragments. Cannot be used on slopes or in areas that have dense root mats. Use on cool days or prevent water chamber from heating by providing shade.	Macropores and cracks[1]
Ammozemeter (Constant level permeameter)	Measures saturated hydraulic conductivity at various soil depths.	For soils that can be excavated with a 5 cm diameter auger.	
Mini-disk or tension infiltrometer	Measures hydraulic conductivity at specified suction rates.	For soils where good contact can be made with the porous disk of the instrument. Difficult to use where pores are fine or larger or soil is water repellant. Cannot be used on slopes without disturbing the soil surface. Limited by a small volume of water.	

[1] Very large numbers of replicate measurements are needed where these conditions exist, causing the benefit:cost ratios to be low.

Soil organic matter and biological measures

Specific fractions of soil organic matter or the biological component of soil can be analyzed through a variety of method, but our ability to interpret the results across a wide range of soils is limited. The most promising methods are described in Table A3-14. Further research and evaluation of these methods for inventory purposes is needed.

Table A3-14. Soil Organic Matter Fractions and Biological Methods. Descriptions and general interpretations of a variety of methods. Method numbers refer to the Soil Survey Laboratory Investigations Report No. 42 at http://soils.usda.gov/technical/lmm/

Method	Description	Interpretation
Active C - SSL method 6A2a1a1	Chemical oxidation of active soil organic matter followed by extraction of carbon associated with the oxidized fraction.	Active soil organic matter is accessed by soil organisms and turns over more quickly than particulate organic matter and total soil organic matter. Management-induced changes in the ratio of active C to total C can be used as an indicator of soil quality.
Particulate organic matter; POM (Total, POM-C and POM-N – SSL method 6A4a1a1-3 thru 3a1	Particulate organic matter is a physical fraction of soil > 53um in diameter. The weight of this fraction and its C and N content are measured.	Particulate organic matter represents an intermediate fraction of soil organic matter with respect to decomposition. It decomposes more slowly than active soil organic matter and more rapidly recalcitrant organic matter forms, such as lignin or humus. Decreases in POM can occur over periods of 1 to 5 years in environments that promote decomposition, such as cultivated fields.
Microbial biomass-C	Fumigation-incubation-extraction method to measure C in living microbial biomass.	The microbial biomass in the soil varies with the plant growth stage and season of the year. It may be difficult to interpret unless sampled at the same time of year.
Potentially mineralizable N	Fumigation-incubation-extraction method to measure N in living microbial biomass.	The microbial biomass in the soil varies with the plant growth stage and season of the year. It may be difficult to interpret the results for potentially mineralizable N unless sampled at the same time of year.
β-glucosidase (beta-glucosidase)	A measure of potential enzymatic activity for cellulose decomposition under controlled conditions. Measures enzymes in living cells and those attached to soil particles.	This measure is under evaluation. It has the potential to provide information about decompsition, biological activity, and carbon cycling in soil. It must be interpreted within the context of the specific soil and local environment.
FDA hydrolysis (fluorescein diacetate)	A measure that represents soil enzyme activity.	An indicator of overall soil microbial activity.

3.7 Data Entry Sheets, Calculations, and Data Storage (Interim)

The files listed below are available for data entry and interim storage. The letter "G" in the file name indicates that the file is provided with this **Guide**. An asterisk (*) indicates that data can be entered on the Excel sheet or the Rangeland Database and Field Data Entry System at http://usda-ars.nmsu.edu/monit_assess/rangedb_main.php.

A file to compute random points on a circular plot is also provided. An information system will eventually be available for data entry, data storage, calculations, and report generation.

Plot Master, Project Metadata_G.xls

Soil Sample Db(core_ovendry subsample)_G.xls

Soil Sample Db(core_ovendry full sample)_G.xls

Penetration Resistance_G.xls

Forest Floor_G.xls

Stability(3 observations)_G.xls

Pattern(plot)_G.xls

* LPI_G.xls

* Gap_G.xls

* Double Sampling for Production_G.xls

Random Points_circular_G.xls

Appendix 4 Strategies for Comprehensive Sampling of Soil Property Variability

Appendix 4 Strategies for Comprehensive Sampling of Soil Property Variability

4.1 Sampling Soil Property Variability

Background
Most comparison studies are limited to only a few management systems or land uses on a specific soil map unit component phase. Consequently, they will not account for the full extent of soil property variability across all land uses. In order to capture this variability, a comprehensive sampling design must be employed.

Comprehensive sampling strategies
The comprehensive sampling strategy for documenting dynamic soil property variability should accurately and precisely represent the variability of soil properties in both the entire population (the soil in question) and sub-populations (e.g., individual land uses, management systems, plant communities, and soil phases). Samples must be selected in a way that maximizes the number of conditions sampled while not biasing conclusions and interpretations. A comprehensive sampling design should allow sample locations to be selected randomly across the entire area of interest. Every point on the landscape should have some known possibility of being sampled. This arrangement ensures that all land management systems have a possibility of being sampled and that those that have not been preidentified are not inadvertently excluded. In many areas, the entire population of land management systems and soil combinations has not been defined.
A comprehensive design also allows the statistical methods that predict the likely attainable (or best) condition for each soil or group of soils to be used

Comprehensive sampling strategies can select samples in a number of ways. A simple random sampling approach spreads samples randomly throughout the entire population. This is the simplest methodology; however, it may not properly represent small, but important, areas. An alternative approach, stratified random sampling, allocates samples independently within sub-populations or strata. The number or density of samples within each stratum can be distributed by weights based on extent or expected variability. Implementation of the comprehensive sampling strategy with stratification requires new techniques to create these sampling weights so that the full extent of variability is likely to be captured for each stratum.

Additional development is needed before comprehensive sampling strategy can be implemented for soil survey. Many techniques are currently available, however for groups conducting surveys or inventory that wish to ensure that they are reflecting the entire range of variability in the area. Refer to references at:

http://www.pwrc.usgs.gov/brd/SamplingCourse.htm and
http://www.epa.gov/NHEERL/arm/bibliography.htm

Future work should focus on the most efficient way to capture the full variability of dynamic soil properties across multiple land uses. The approach should balance sampling objectives and cost. It will depend on 1) the nature of the variability, 2) our knowledge of the sources of that variability (including land use and geomorphic features), and 3) the extent to which the variability can be mapped as defined spatial strata. Important factors include the amount, scale, and pattern of variability in the soil being investigated. It is unnecessary and impossible to know or map all sources of variability to apply a comprehensive approach.

Gap Intercept

Project:________________ State phase name:______________ Page ____ of _____

State Phase ID:__________ Plot replicate no: _________

Observer: _______________ Recorder: _______________ Date: ________ Length: ____(m or ft)

Transect: _______				**Transect: _______**				**Transect: _______**			
Canopy Gap		**Basal Gap**		**Canopy Gap**		**Basal Gap**		**Canopy Gap**		**Basal Gap**	
Starts	**Ends**	**Starts**	**Ends**	**Starts**	**Ends**	**Starts**	**Ends**	**Starts**	**Ends**	**Starts**	**Ends**

Includes only perennial vegetation. Basal gap can be broken up by embedded stem.

Record the beginning (Gap Starts) and end (Gap Ends) of Canopy Gaps in cm.

Record the beginning (Basal Gap Starts) and end (Basal Gap Ends) of Plant Basal Gaps in cm.

Canopy Gap/ Min Size = 20 cm, 50% of 3 cm to break up the Gap

Line-Point Intercept (Intercept interval = 0.5m)

Project:_______________ State phase name:________________ Page ___ of ___

State phase ID:________ **Plot replicate no.:**___________ **Observer:**_______ **Recorder:**__________ Date:_________

Transect____________ **Length**____________ **(m or ft)**

Point	Top	Lower Canopy Layers			Soil *	Point	Top	Lower Canopy Layers			Soil *
	Canopy	Code1	Code2	Code3	Surface		Canopy	Code1	Code2	Code3	Surface
0.5						10.5					
1						11					
1.5						11.5					
2						12					
2.5						12.5					
3						13					
3.5						13.5					
4						14					
4.5						14.5					
5						15					
5.5						15.5					
6						16					
6.5						16.5					
7						17					
7.5						17.5					
8						18					
8.5						18.5					
9						19					
9.5						19.5					
10						20					

Top canopy

Species code, common name, or NONE (no canopy)

Lower Canopy Layers

Species code, common name, L (herbaceous litter), WL (woody litter, >5mm (1/4") diameter)

Note: Bare Ground occurs ONLY when Top Canopy = NONE, Lower Layers are empty, and Soil Surface = S.

Unknown Species Codes

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

Soil Surface (do not use litter)

Species code (for basal intercept)
R = rock fragment (> 5mm (1/4") diameter)
BR = bedrock
M = Moss
LC = Visible lichen crust on soil
S = soil, without any other soil surface code
EL (embedded litter, see manual)
D = Duff (see manual)
DC = Dark cyanobacteria*
C = Cyanobacteria*
AC = cracking or curling algal crusts*
PC = physical crust (not biological)*
* Soil surface codes added for soil survey

Line-Point Intercept (Intercept interval = 1m)

Project:_______________ State phase name**:**________________ Page ____ of ____

State Phase ID:_________ **Plot replicate no:**_________ **Observer:**_________ **Recorder:**_________ Date:_________

Transect_________		**Length**______(m or ft)			
Point	**Top**	**Lower Canopy Layers**			**Soil ***
	Canopy	**Code1**	**Code2**	**Code3**	**Surface**
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

Transect__________		**Length**________(m or ft)			
Point	**Top**	Lower Canopy Layers			**Soil ***
	Canopy	Code1	Code2	Code3	**Surface**
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

Top canopy

Species code, common name, or NONE (no canopy)

Lower Canopy Layers

Species code, common name, L (herbaceous litter), WL (woody litter, >5mm (1/4") diameter)

Note: Bare Ground occurs ONLY when Top Canopy = NONE, Lower Layers are empty, and Soil Surface = S.

Unknown Species Codes

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

Soil Surface (do not use litter)

Species code (for basal intercept)
R = rock fragment (> 5mm (1/4") diameter)
BR = bedrock
M = Moss
LC = Visible lichen crust on soil
S = soil, without any other soil surface code
EL (embedded litter, see manual)
D = Duff (see manual)
DC = Dark cyanobacteria*
C = Cyanobacteria*
AC = cracking or curling algal crusts*
PC = physical crust (not biological)*
* Soil surface codes added for soil survey

Pedoderm and Pattern Classes (plot)

9/2008

Project:________________ State phase name:__________________

State phase ID:________ **Plot replicate no.**____________ Collector______________ Date________

	Slope complexity: simple or complex	Slope shape:	L L L V L C V L V V V C C L C V C C

Instructions: Rapidly traverse the entire plot and select one class each for soil surface properties (pedoderm/crust class), resource retention and erosion pattern to repesent the entire plot.

Pedoderm/Crust class in _____x______ (e.g., 20 x20m) plot

	Select one	**Notes:**
S = No crust; may be plant base or soil without any other surface feature		
WP = Weak physical or biological crust, may have few cyanobacterial sheaths dangling from ped, no darkening from cyanobacteria.		
SP = Strong physical crust		
PDB = Poorly developed biological crust assemblage, few to many cyanobacterial sheaths, may be slightly dark, can include other morphological group (algal crust, lichen, moss)		
SDB = Strongly developed biological crust assemblage, obvious dark cyanobacteria, rubbery algal, moss or lichen crust.		
CB = Cracking or curling, rubbery algal crusts, with or without lichen		
RA = Uniform rock armor		
CEM = Cemented		
D = Duff		
EL = Embedded litter		

Resource retention class in __ x __ (e.g., 20 x 20m) plot

Class		Select one	**Notes:**
1	Interconnected grass cover or dense bunchgrasses; and surrounding ellipsoid bare patches < 30 cm		
2	Grass cover interconnected and surrounding ellipsoid bare ground patches from 30-__cm	cm	
3	Grass cover fragmented by elongate bare ground areas to __ cm wide but bounded in plot	cm	
4	Grass cover fragmented by elongate bare ground areas to __ cm wide that cross entire width of plot	cm	
5	Bare ground interconnected in several directions and isolated grass patches up to __ cm	cm	
6	Bare ground interconnected with scattered or no grass plants		

Erosion pattern class in __ x __ (e.g., 20 x 20m) plot

Class		Select one	**Notes:**
1	No evidence of erosion or deposition		
2	Erosion limited to small (< 50 cm) blowouts or flow patterns, few pedestals		
3	Erosion across large (> 50 cm) bare patches, gullies, flow patterns, but low soil loss		
4	Erosion across large areas with minor deflation, coppicing, flow patterns, pedestals		
5	Erosion across large areas with deflation, coppicing, and truncation of horizons		
6	Deposition* across large areas, may have rills, flow patterns		

*Confirm deposition by digging a hole and observing recent deposition. Recently deposited material is usually finely stratified.

Notes:

Pedoderm and Pattern Classes (plot)

11/21/2008

Project:________________ State phase name:__________________

State phase ID:________ **Plot replicate no.**____________ Collector__________ Date__________

Slope (%):	**Aspect:**	**Slope complexity:** simple or complex	**Slope shape:**	L L L V L C V L V V V C C L C V C C

Instructions: Rapidly traverse the entire plot. Select one class each for soil surface properties (pedoderm/crust class), resource retention and erosion pattern to repesent the entire plot.

Pedoderm Class in ___ x ___ m

		Select one	**Dominant Biol Crust Group***	**Notes**
S =	Soil; pedoderm is characterized by bare mineral soil and none of the classes below			
WP =	Weak physical or biological crust; can be disrupted by rainfall, none to few cyanobacterial sheaths dangling from ped, no darkening from cyanobacteria			
SP =	Strong physical crust, usually platy or massive (structure not disrupted by rainfall), no substantial biological component			
VC =	Vesicular crust; a layer of many unconnected spherical or ovoid pores; at the soil surface			
CEM =	Cemented pan exposed at surface			
SC =	Salt crust of fine to extremely coarse evaporite crystals or visible whitening on the soil surface; may include biological components			
PDB =	Poorly developed biological crust assemblage, many cyanobacterial sheaths, may be slightly dark, can include other functional/structural groups (algae, lichen, moss)			
SDB =	Strongly developed biological crust assemblage, obvious dark cyanobacteria, rubbery algal, moss or lichen crust			
CB =	Cracking or curling, rubbery algal crusts, with or without lichen			
EP =	Erosion pavement; a concentration of rock fragments at the soil surface caused by erosion and removal of finer soil material; individual fragments may be displaced during runoff events			
DP =	Desert pavement; a concentration of closely packed and polished rock fragments at the soil surface, embedded in a vesicular crust			
D =	Duff (partially and fully decomposed plant & organic matter; above the A horizon)			
SA =	Well-formed or distinct structural aggregates at the soil surface and no other class above (well aggregated, stable soils)			

* Enter 1-2 dominant biological crust functional/structural groups from this list: Cyano (Cyanobacteria), LC (Lichen Crust), M (Moss), LV (Liverwort), A (Algae).

Resource Retention Class in ___ x ___ m

		cm (for one class only)	**Notes:**
1	Interconnected grass cover or dense bunchgrasses; and surrounding ellipsoid bare patches <30cm		
2	Grass cover interconnected and surrounding ellipsoid bare patches from 30-___cm		
3	Grass cover fragmented by elongate bare areas to ___ cm wide but bounded in plot		
4	Grass cover fragmented by elongate bare areas to ___ cm wide that cross entire width of plot		
5	Bare ground interconnected in several directions and isolated grass patches up to ___ cm		
6	Bare ground interconnected with scattered or no grass plants		

Erosion Pattern Class in ___ x ___ m

		Select one	**Notes:**
0	No evidence of erosion or deposition		
1	Erosion limited to small (< 50 cm) patches (may see: minimal sheet erosion, wind scouring)		
2	Erosion across large (> 50 cm) patches (may see: no to few small pedestals, terracettes, water flow patterns, wind scouring)		
3	Erosion across large areas (>50 cm) with extensive loss of A horizon (may see: prominent pedestals, water flow patterns, rills, gullies, extensive wind scouring or deflation, coppicing)		
4	Erosion across large areas with exposed subsoil (may see: scarplets, patchy remnant surface horizons, water flow patterns, rills, gullies, extensive wind scouring, deflation, large coppices, prominent pedestals, exposed roots)		
5	Deposition across large areas (may see: water flow patterns, rills, large coppices, small dunes, sand sheets)**		

** Confirm depostion by digging a hole and observing recent deposition. Recently deposited material is usually finely stratified with alternating thin layers of varying textures; lacks structure.

Notes:

Photo Record (one form per plot) 9/2008

Project:___________________________ State phase name :_______________________

State phase ID:______ **Plot replicate no.**:_______ Collector:_____________ Date:________

Instructions

1. Place photocard at the center of circular plots, at the corner of square or rectangular plots, and at the beginning of single transect plots. Include Photocard in at least one photo per plot.
   Circular plots: Take photos in cardinal directions from plot center.
   Square plots: Facing plot center, take photos from plot corners.
   Single transect plots: From the beginning of the transect tape, take photo facing towards the end.
2. For multi-strata plots, photograph individual strata.
3. Georeference information for the plot will be obtained from the Plot Master.
4. Take action shots and close-up shots as needed to document sampling procedures or other items of interest.

Photos

Plot type (circular, square or transect)**:**		
Photo number	**Compass direction**	**Description** (stratum, subject matter, wide angle, close-up, etc)

Project:

State phase ID:

Plot replicate no:

Date:

Project:

Threebear Soil

State phase ID: **MF**

Plot replicate no: **1**

Date:

Project:

State phase ID:

Plot replicate no:

Date:

Plot Master (Circular Plot)

9/2008

Project:____ State phase name:_______________________

State phase ID:_______ **Plot replicate no**:________ Landowner field or stand ID (optional):_______________________
Random plot number:_______________________

Plot, Terrain, and Location

Plot setup by ______________________
Date ___________________________
Recorder _______________________
On-plot strata to be sampled:
Kind_________________ ID________
Kind_________________ ID________

Map unit symbol _________________
Component name _________________
Slope _______% Aspect ________°
Shape: Up________ Across________
Ecological site name _________________
____
ES number _________________________

Plot size: Radius __________ m or ft
Location (of plot center):
Easting (m) _______________
Northing (m) _______________
Projection (circle one):
UTM or Latitude/ Longitude
Datum (circle one): NAD83 Other___
UTM zone ______________
Elevation: GPS _________m or ft?
Topo _________m or ft?
Topo (Quad) ID____________________

FS habitat type __________________

Soil description (primary, commonly at plot center)
(1 per plot to rock or 2 m)
User pedon ID___________________

FIPS codes for project

County ____________ Code _______
County ____________ Code _______
County ____________ Code _______
County ____________ Code _______

Sample Locations and ID

Stratum-soil replicate ID	Azimuth from plot center	Distance from plot center (m)	Easting (m)	Northing (m)	User pedon ID ex. S07IDxxx-xxx

Ground Cover Clip Plot

V1				
V2				
V3				

Completed Sampling Checklist – Vegetation Forms (no. per plot)

Photo record (1)___________ Site index (1)______________

Overstory veg.(1)___________ Understory veg.(1)___________ Understory/groundcover (1)___________

Notes

Completed Sampling Checklist: Soil field forms and samples Recorder _____________Date ____________

Stratum- soil replicate ID	No. of horizons	Soil sample _FOREST form	SOILS-232 or NASIS Pedon	Woody debris transect	Surface disturbance transect		Samples collected: Bulk density	Samples collected: Lab analysis	

Plot Master (Circular Plot)

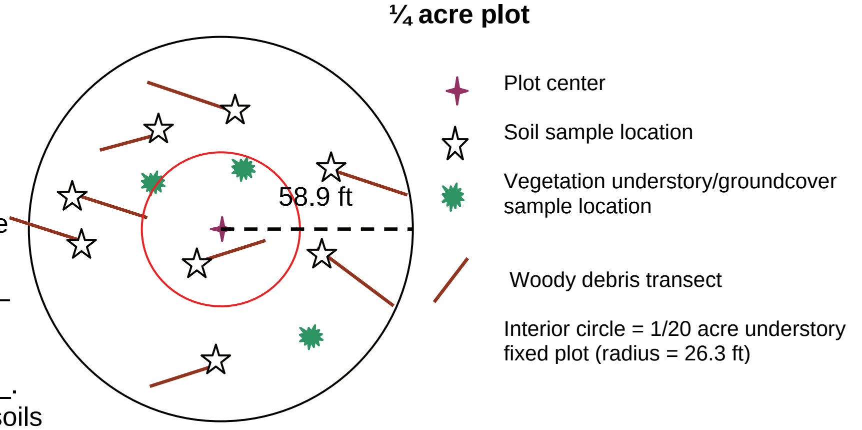
9/2008

Plot layout instructions-Forest.

1. Mark plot center point with labeled stake and enter information on the Plot Master for plot, terrain, and location. The same plot center will be used for the variable radius overstory vegetation plot, the ¼ acre overstory vegetation fixed radius plot (58.9 ft radius), the 1/20 acre understory vegetation fixed radius plot (26.3 ft radius), and site index measurement.
2. Make a detailed soil description, preferably at the plot center, and record the primary soil description ID on the Plot Master.
3. From plot center use prepared list of random azimuths and distances to locate soil sample locations. Evaluate each potential point in order using **Plot acceptance criteria**. Mark acceptable locations with flags until the required number are located and enter sample location information on Plot Master. The flags will be pre-labeled with the appropriate **Stratum-soil replicate ID** (e.g., W1, W2… for woody and H1, H2,… for herbaceous stratum)
4. Soil sample locations will also serve as the origin for woody debris transects and surface disturbance transects.
5. Continue using azimuths and distances list to locate three points that meet acceptance criteria to use for understory/groundcover cover estimation and clipping. Mark with flags (labeled V1 through V3) and record location information on Plot Master.

Plot acceptance criteria.
Evaluate potential plots in order as they appear on the potential points list.

- Plots are > 1 mile apart.
- Only 1 plot per polygon.
- Plot boundaries are > 30 m from state phase and soil map unit boundaries and roads.
- Plant community is ___________________
- Aspect is between ______° and ______°.
- Slope is _______to ________ %.
- Soil component is ____________________.
- Plot boundaries are > 20 m from dissimilar soils
- Habitat type is ______________________.



Plot photos and vegetation.
Hang photocard at plot center. Take photo of card and one photo in each cardinal direction (5 total). Record photo information on Photo Record.
Complete data sheets for vegetation as listed on Plot Master.

Soil sampling protocol at soil sample locations.
At each soil sample location, record the Visual Disturbance Class and cover attributes, collect a forest floor sample, describe and sample soil to ~ 40* cm. Measure penetration resistance at each sample location. Collect a root biomass sample if applicable.

* or to depth specified in workplan.

Completed sampling checklists.
Use the sampling checklists to keep track of work completed on each plot.

Woody debris transect (optional).
Brown's protocol. Includes collection of whole and rotten wood sample from each size class found in the transect.

1. Do transects without trampling soil sample locations.
2. Use soil sample location as origin and proceed in direction of randomly selected azimuth.
3. Complete one for each soil sample location.

Sample bag needs and destinations table. Complete the table prior to field work.

Analysis	Horizons to sample	Amount (g)	Bag type	Number of bags	Bags from	Send samples to

Plot Master (Square Plot)

9/2008

Project:____ State phase name:_________________________

State phase ID:________ **Plot replicate no**:_______ Landowner field or plot ID (optional):_______________ Random plot number:______

Plot setup by _______________
Date ____________________
Recorder _______________
On-plot strata to be sampled:
Kind____________ ID_____
Kind____________ ID_____

Plot, Terrain, and Location

Map unit symbol_____________
Component name _____________
Slope _____% Aspect _____°
Shape: Up______ Across______
Ecological site name __________
____
ES number _________________

Location (of baseline, 0 m mark):
Easting (m) _______________
Northing (m)_ _____________
Azimuth baseline transect _____°
Plot size:_______ l ;______ w(m)
Projection (circle one):
UTM or Latitude/ Longitude
Datum (circle one):
NAD83 Other___________
UTM zone__________________
Elevation:
GPS _________m or ft?
Topo_________ m or ft?
Topo (Quad) ID______________

Soil description (primary)
(1 per plot to rock or 2 m):
User pedon ID________________

FIPS
County ___________Code _____
County ___________Code _____
County ___________Code _____

Sample Locations and ID

Stratum-soil replicate ID	Transect no.	Baseline meter	Transect meter mark	Easting (m)	Northing (m)	User pedon ID ex: S05UTxxx-xxx

Completed Sampling Checklist – Vegetation Forms (no. per plot)

Photo record (1)__________ Pedoderm/ pattern (1) __________ Production (1) __________
Line point ( ) _________ Gap ( )__________

Completed Sampling Checklist: Soil Field Forms and Samples

Recorder_________ Date________

Stratum-soil replicate ID	No. of horizons	Soil sample_ RANGE form	Soils-232 or NASIS Pedon	Soil stability			Samples collected: Bulk density	Samples collected: Lab analysis	

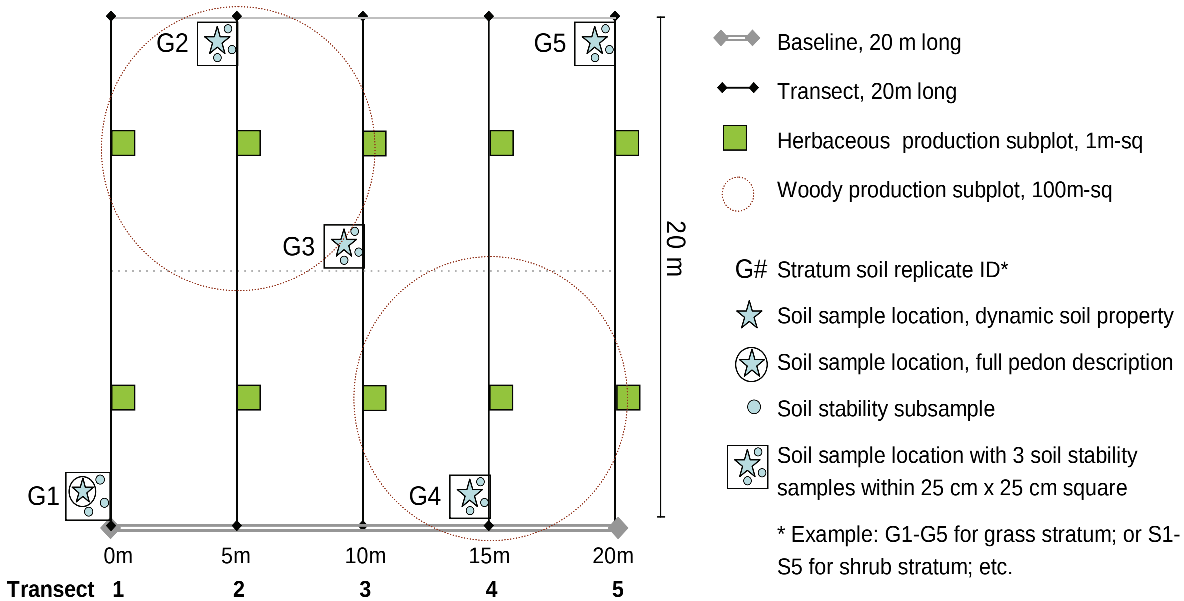
Plot Master (Square Plot)

9/2008

Plot layout and photo instructions. Use **Plot acceptance criteria** below to evaluate potential plot locations. Once selected, layout the plot. The baseline should be positioned obliquely to the slope and 5 transects should be positioned parallel to one another and approximately 90^{o} from the baseline. Flag each soil sample location according to transect number and meter mark in table below. The flags will be pre-labeled with the **Stratum-soil replicate ID** (e.g. G1, G2, G3…). Make a detailed soil description, preferably at the plot center, and record the primary soil description ID on the Plot Master. Enter information on the Plot Master for plot, terrain, location and "Sample Locations and ID." Hang photocard at the 0 meter mark of transect 1. Take photo of card and additional photos to cover plot. Record photo information on Photo Record.

Soil and vegetation sampling. At each soil sample location, describe and sample the soil to ~ 40* cm, collect stability samples and measure penetration resistance. Complete line-point intercept and gap along each transect. Place herbaceous subplots at meter marks 5 and 15 on each transect. Woody subplots are centered at transect 2, meter mark 15 and transect 4, meter mark 5. Complete one "Pedoderm, Pattern Classes" form for each plot. Use the Completed Sampling checklists to keep track of work completed on each plot. * or to depth specified in workplan.

Example: Plot with one stratum (G), and 5 soil sample locations for that stratum labeled as **Stratum-soil replicate ID** G1, G2, etc).



Plot acceptance criteria.
Evaluate potential plots in order as they appear on the potential points list.

- Plots are > 1 mile apart.
- Only 1 plot per soil polygon.
- Plot boundary is > 30 m from state phase and soil map unit boundaries and roads.
- Plant community is ____________________
- Aspect is between ______^{o} or ______^{o}.
- Slope is _______to ________ %.
- Soil component is ______________________.
- Plot boundaries are > 20 m from dissimilar soils.
- ____________________________________

Samples per plot	Sample location replicate no.	Transect	Meter mark	Samples per plot	Sample location replicate no.	Transect	Meter mark
5	1	1	1	6	1	1	1
	2	2	19		2	2	7.5
	3	3	10		3	2	19
	4	4	1		4	4	1
	5	5	19		5	4	12.5
					6	5	19
7	1	1	1	9	1	1	1
	2	1	19		2	1	12.5
	3	2	12.5		3	2	7.5
	4	3	7.5		4	2	19
	5	4	12.5		5	3	12.5
	6	5	1		6	4	1
	7	5	19		7	4	17.5
					8	5	7.5
					9	5	19

Sample bag needs and destinations. Complete prior to field work.

Analysis	Horizons to sample	Amount (g)	Bag type	Number of bags	Send samples to

Overstory Veg Plot (Variable Radius)

Project: ______________________________ State phase name :__________________

State phase ID:________ **Plot replicate no**.:______________ Stand ID:___________

Date: ____________ Observer: ________________ Collector______________ Radius____(m or ft)

Stand inventory

Tree No.	Species	DBH (> 5 in.)	Age @ DBH	Health Status [1]	Tree Condition Code	Height (ft)	H.C.B. (ft)	Comments
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
BAF FACTOR USED:								

Photo Numbers:

Take photos of ID card and in cardinal directions from plot center

Photo ID card	North Wide-angle	South Wide-angle	East Wide-angle	West Wide-angle

Densiometer **CIRCLE ONE** (Canopy / Sky)

North	East	South		West

1 Health status definitions and condition codes are on reverse side of page

Record "Condition" classes as follows:

"Good" (code G)

Attributes:	**USFS "Tree Condition" code from list below**
● Reasonably Straight ● Sound & Full Crown ● Not excessively limby ● no evidence of scars, wounds or disease	No quantifiers are used for Good condition trees—Use code 0

"Poor" (Code P)

Attributes:	**USFS "Tree Condition" code from list below**
● Broken Top ● Bad crotch ● Excessive limbs ● Cankers, wounds, scars, diseases, etc.se	Use up to three codes as appropriate. Select from USFS category list.

"Fair" (Code F)

Attributes:	**USFS "Tree Condition" code from list below**
This is an intermediate rating between Good and Poor.	Use up to three codes as appropriate. Select from USFS category list.

"Dead" (Code D)

Attributes:	**USFS "Tree Condition" code from list below**
Sound snag	Use Code 25
Rotted snag	Use Code 26

Condition classes "good", "poor" and "fair" are from NRCS National Forestry Handbook. "Dead" is added.

USFS Tree Condition Codes:

Place the appropriate condition code (up to three per tree) for each species recorded for the plot:

0	Healthy
1	Mountain Pine Beetle
2	Fir Engraver Beetle
3	Ips Beetle
4	Other Bark Beetles
5	Shoot Borers
6	Defoliators
7	Other Insects
8	Root Rot
9	Stem Rot
10	Mistletoe
11	Needle Disease
12	Fire
13	Livestock
14	Big Game
15	Porcupine
16	Rodents
17	Other Animals
18	Chemical
19	Weather (Windthrow, Snowbreak, Hail)
20	Suppression
21	Logging (Mechanical Damage)
22	Old Age
23	Unknown
24	Poor Form
25	Sound snag
26	Rotted Snag

Understory Veg (high) Plot (1/20 acre - Small Trees and Tall Shrubs: 3 to 14 ft tall)

Project: ________________________________ State phase name:________________

State phase ID :__________ **Plot replicate no.:**________ Stand ID:____________

Date: ____________ Observer: _______________ Collector______________ Radius_______(m or ft)

Tree and shrub inventory

Coniferous Tree No.	Species	DBH (1<x< 5 in)	Health Status [1]	Comments	Other tree or Tall Shrub	Species	DBH (1<x< 5 in.) other trees only	Comments:
1					1			
2					2			
3					3			
4					4			
5					5			
6					6			
7					7			
8					8			
9					9			
10					10			
11					11			
12					12			
13					13			
14					14			
15					15			
16					16			
17					17			
18					18			
19					19			
20					20			

Understory canopy characteristics Make occular estimate of cover.

Species	% Cover	Average Height (ft.)	Average H.C.B (ft)

Cover and height by type Make occular estimate of cover.

Type	% Cover	Average Height (ft.)	Comments (Note dominant form of 'other' as moss, lichen, char, CWD, etc.)
SOIL			
ROCK			
Litter			
Non-WD			
Shrub			
Tree			
Other			

1 Health status definitions and condition codes are on reverse side of page

Understory Veg (low) Plot ($1m^2$ - Small Shrubs: < 3 ft tall)

Project: ________________________________ State phase name:________________

State phase ID :_________ **Plot replicate no.:**________ Stand ID:____________ Radius______(m or ft)

Cover by species and height (occular estimate)

Subplot ID #: __V1__ Location[1] *UTM Zone* ___ E: N:

Species	*% Cover*	*Average Height (ft.)*	**Groundcover Clip Plot ($1m^2$ - Grasses, Forbs, Sub-shrubs)**		
			Lifeform	***wet weight (g)***	***dry weight (g)***
			Grasses		
			Forbs		
			Subshrubs		
			Total		

Subplot ID#: __V2_ Location *UTM Zone* ______ E: N:

Species	*% Cover*	*Average Height (ft.)*	**Groundcover Clip Plot ($1m^2$ - Grasses, Forbs, Sub-shrubs)**		
			Lifeform	***wet weight (g)***	***dry weight (g)***
			Grasses		
			Forbs		
			Subshrubs		
			Total		

Subplot ID#: __V3_ Location *UTM Zone* ___ E: N:

Species	*% Cover*	*Average Height (ft.)*	**Groundcover Clip Plot ($1m^2$ - Grasses, Forbs, Sub-shrubs)**		
			Lifeform	***wet weight (g)***	***dry weight (g)***
			Grasses		
			Forbs		
			Subshrubs		
			Total		

1 Get UTM reading from plot master and record here for reference.

Soil Aggregate Stability Test (field)_RANGE

9/2008

Project:____ State phase name:__________________________________

State phase ID: ______ **Plot replicate no**:______ Collector:__________ Stability tester:__________ Date:________________

Stratum name 1: _______________ **Stratum ID 1:** _______ **Stratum name 2:** _______________ **Stratum ID 2:** _______

Instructions

1. Record the stratum soil-replicate ID, transect line number, position on transect and vegetation cover code for the 25cm x 25cm plot at each soil sample location. Note: if samples are collected from within the circular hoop on a forest plot, disregard line number and position.
2. Within each 25cm x 25cm plot collect 3 soil stability samples at the surface and 3 at 2.5 cm. Place in sample box cells that correspond to cells as labeled on the field form.
3. If loose sand is resting on the soil surface, collect sample from soil layer under the sand sheet and add **LS** (loose sand) to the veg. column.
4. Enter **# = stability value** (1-6) for surface and 2.5cm samples. Circle if samples are hydrophobic.

Veg. cover (select one)
(25cm x 25cm)

NC = No canopy
PG = Perennial grass
AG = Annual grass
F = Perennial forb or herbaceous
G/S = Grass or herbaceous; and shrub
Sh = Shrub
T = Tree

LS= loose sand

Sample box no.:_______

Stratum-soil replicate ID	Line #	Position	Veg	TIME IN DIP	Surface #	TIME IN DIP	2.5cm #	Stratum-soil replicate ID	Line #	Position	Veg	TIME IN DIP	Surface #	TIME IN DIP	2.5cm #	Stratum-soil replicate ID	Line #	Position	Veg	TIME IN DIP	Surface #	TIME IN DIP	2.5cm #
				0:00		0:45						1:30		2:15						3:00		3:45	
				5:00		**5:45**						**6:30**		**7:15**						**8:00**		**8:45**	
				0:15		1:00						1:45		2:30						3:15		4:00	
				5:15		**6:00**						**6:45**		**7:30**						**8:15**		**9:00**	
				0:30		1:15						2:00		2:45						3:30		4:15	
				5:30		**6:15**						**7:00**		**7:45**						**8:30**		**9:15**	

Sample box no.:_______

Stratum-soil replicate ID	Line #	Position	Veg	TIME IN DIP	Surface #	TIME IN DIP	2.5cm #	Stratum-soil replicate ID	Line #	Position	Veg	TIME IN DIP	Surface #	TIME IN DIP	2.5cm #	Stratum-soil replicate ID	Line #	Position	Veg	TIME IN DIP	Surface #	TIME IN DIP	2.5cm #
				0:00		0:45						1:30		2:15						3:00		3:45	
				5:00		**5:45**						**6:30**		**7:15**						**8:00**		**8:45**	
				0:15		1:00						1:45		2:30						3:15		4:00	
				5:15		**6:00**						**6:45**		**7:30**						**8:15**		**9:00**	
				0:30		1:15						2:00		2:45						3:30		4:15	
				5:30		**6:15**						**7:00**		**7:45**						**8:30**		**9:15**	

Notes:

Soil sample, Db (core), Penetration Resistance, Forest Floor_FOREST 11/06//2008

Project:_________________________________ State phase name: ________________________

State phase ID:_____ **Plot replicate no:** ______ Stratum: Kind_____________________ ID____

Collector:_______________ Date:___________

Cover and forest floor (O horizon) (at hoop)

Special sampling instructions: If soil sample location falls on an unsuitable location, move 2 m in a random direction until a suitable location is found. Unsuitable locations include gullies, rock outcrop, soil inclusions, etc.

Veg cover (canopy)				
Over-story	**Woody under-story**	**Ground**	**Soil surface cover**	**Litter* cover (%)**

Enter cm to nearest 0.1cm

Stratum-soil replicate ID	Horizon sequence number	Horizon symbol	Horizon depth upper (cm)	Horizon depth lower (cm)	Litter* moisture status D/M/W	User Pedon ID and horizon sequence no.	Hoop dia-meter (cm)	Litter* depth 1 (cm)	Litter* depth 2 (cm)	Litter* depth 3 (cm)	Litter* depth 4 (cm)

***Litter** refers to the O horizon, duff.

Veg. cover (canopy) (select one)
(Over 30 cm hoop)
- **NC =** No perennial canopy
- **PG =** Perennial grass
- **AG =** Annual grass
- **F =** Perennial forb or herbaceous
- **Sh =** Shrub
- **T =** Tree

Soil surface cover codes (select one)
(Within the 30 cm hoop)
- **S =** Soil, without other surface code
- **R =** Rock fragments
- **M =** Moss
- **LC =** Lichen
- **D =** Duff/O horizon/litter
- **W =** Wood >1/4" diameter
- **PC =** Physical crust
- **Other**____________________

NOTES: Describe features at the soil sample location that may affect fine-scale variability (e.g., trail, tree-throw…)

Bulk density (core)

Enter cm to nearest 0.1 cm

Stratum-soil replicate ID	Horizon sequence no.	Horizon symbol	Horizon depth upper (cm)	Depth lower (cm)	Soil moisture status D/M/W	User pedon ID and horizon sequence no.	Ring diameter (cm)	Total ring length (cm)	Ring ht 1 (cm)	Ring ht 2 (cm)	Ring ht 3 (cm)	Ring ht 4 (cm)

Penetration resistance

Depth (cm)	Soil moisture status D/M/W	Penetrometer tip Rod or Foot ?	Type of spring	Reading 1	Reading 2	Reading 3	Reading 4
Surface							
2							
5							
8							
11							
14							
17							
20							
23							
26							
29							

Penetrometer tip
(diameter)

Rod, flat end (6.4mm)
Foot (25mm)

Spring type
(in order of increasing strength)

- **L=** Lee
- **O=** Original
- **J1=** Jones 11
- **J3=** Jones 323

INSTRUCTIONS: Soil Sample Location for FOREST

11/06/2008

(Complete only appropriate items for other land uses)

Follow this sequence at each soil sample location:

Soil sample location

1. Go to flag marking a soil sample location (the stratum-soil replicate). Flags are placed during plot layout, see Plot Master_FOREST_circular.
2. Record project, plot, and sample ID and data on forms: Soil Sample,Db(core),Penetration Resistance,Forest Floor_FOREST. Use Soil Aggregate Stability Test(field)_RANGE only if suitable.
3. Visualize a north-south line and an east-west line through the point marked by a flag as in diagram below.
4. Place 30 cm diameter hoop for forest floor sample in the SW quadrant in relation to the flag.
5. Locate the nearest 30 cm diameter area that is at least 1 m from the flag and mimics the surface features of the SW quadrant. Assess visual class attributes for that area (draft FS method).

Cover

6. Assign codes for vegetative and soil surface cover to the 30 cm area within the hoop.
7. Carefully remove all plants, but not the O horizon. Clip as close to the soil surface as possible. Do not disturb roots or soil surface.

Forest floor (O horizon) sample

8. Within 30 cm hoop, estimate litter/O horizon/duff cover (%) and make 4 measurements of depth (to nearest 0.1 cm) along the perimeter of the hoop. Discard surface wood > 6 mm (¼ in) diameter and live above-ground plant material. Collect remaining surface wood and litter, O horizon, and all roots and place in paper or cloth bag. Sample Oi, Oe, Oa horizons and current-year litter separately if necessary.

Penetration resistance and soil stability

9. Place bulk density ring over area where sample will be collected (for protection), but do not insert.
10. Randomly select points for 4 penetration readings of the soil surface and if suitable, 3 soil stability samples. Measure and collect these pedoderm properties before the surface is disturbed for soil sample collection.
11. Excavate a small hole about 40 cm wide and 50 cm deep adjacent to the bulk density ring.
12. Place a 30 cm ruler against the pit face; secure with golf tees. The top of the ruler should be flush with the top of the O horizon. Collect 4 penetration resistance readings from the pit face, starting at 2 cm, and at each depth listed on the form *before the soil dries*.

Description

13. Describe the soil profile, including O horizon, to the bottom of the hole. If a horizon is greater than 25 cm thick, subdivide, describe, and sample as two layers. Subdivide based on morphology, if present, or at the midpoint. Note any horizons that need special analysis.

Bulk density and mineral soil samples

14. Record stratum soil replicate ID, horizon sequence number, symbol and depth to be sampled. Base of final sample should be exactly _________cm below the mineral surface. Use 40 cm for most projects.
15. Starting at the mineral soil surface, insert bulk density ring to 2 cm (or the base of the A if less than 5 cm thick). Make 4 measurements (nearest 0.1 cm) of ring height above soil sample; measure *on the outside of the ring*. Insert spackle blade directly under the ring and carefully remove soil core. *Do not disturb the soil below.* Place in sealed bag as soon as sampled for field moist weights. (Oven dry weights will be measured in the laboratory.)
16. Collect a1500 g **sample of each layer**, essentially as a slice from top to bottom of the horizon or layer. Mix, and split for analyses, if needed, as follows:

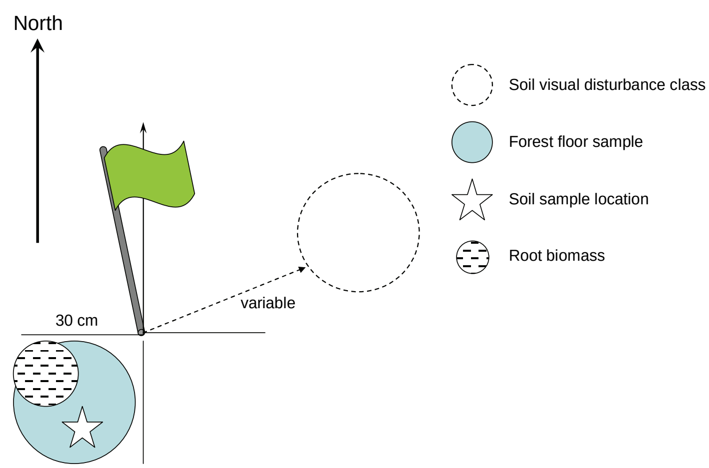
    a. _____ g for ________________________

    b. _____ g for ________________________

    c. _____ g for ________________________

    d. _____ g for ________________________

17. Repeat 15 and 16 for the remainder of the surface horizon (from 2 cm to the upper boundary of the next horizon). Handle each layer sampled as a separate horizon and number consecutively.
18. Repeat 15 and 16 for the remaining horizons or layers. Handle each layer sampled as a separate horizon and number consecutively. Base of last sample should be exactly _____cm below the mineral surface.
19. ***Optional root biomass*.** Place 15 cm diameter ring on top of mineral soil surface and within or adjacent to 30 cm hoop. Insert ring 10 cm deep. Measure ring height (4 places on outside of ring). Carefully remove soil core with spackle blade. Place soil and all roots in sealed bag as soon as sampled for field and oven dry weights.



Soil sample, Db (core), Penetration Resistance, Pedoderm_RANGE

11/20/2008

Project:________________________________ State phase name: ________________________

State phase ID:_____ **Plot replicate no:** ______ Stratum: Kind__________________ ID____

Collector:________________ Date:___________

Cover, litter and O horizon (at hoop)

Veg cover (canopy)		Litter* cover (%)	Pedoderm / Soil crust class	Dominant biological crust group
Over-story	Ground			

Special sampling instructions: If soil sample location falls on an unsuitable location, move 2 m along transect tape until a suitable location is found. Unsuitable locations include gullies, rock outcrop, manure piles, soil inclusions, etc.

NOTES:

Enter cm to nearest 0.1cm

Stratum -soil replicate ID	Horizon sequence number	Horizon symbol	Horizon depth upper (cm)	Horizon depth lower (cm)	Litter* moisture status D/M/W	User Pedon ID and horizon sequence no.	Hoop dia-meter (cm)	Litter* depth 1 (cm)	Litter* depth 2 (cm)	Litter* depth 3 (cm)	Litter* depth 4 (cm)

***Litter** refers to the O horizon, duff.

Over 25 cm x 25 cm plot
Veg. cover (canopy) (select one)
- **NC =** No perennial canopy
- **PG =** Perennial grass
- **AG =** Annual grass
- **F =** Perennial forb or herbaceous
- **Sh =** Shrub
- **T =** Tree

Biological crust functional/structural group (select 1 or 2 dominants)
- **Cyan =** Cyanobacteria
- **LC =** Lichen
- **M =** Moss
- **LV =** Liverworts

Pedoderm class (25 cm x 25 cm) (select one)

- **S =** Soil; pedoderm is characterized by bare mineral soil and none of the classes below
- **WP =** Weak physical or biological crust; can be disrupted by rainfall, none to few cyanobacterial sheaths dangling from ped, no darkening from cyanobacteria
- **SP =** Strong physical crust, usually platy or massive (structure not disrupted by rainfall), no substantial biological component
- **VC =** Vesicular crust; a layer of many unconnected spherical or ovoid pores; at the soil surface
- **CEM =** Cemented pan exposed at surface
- **SC =** Salt crust of fine to extremely coarse evaporite crystals or visible whitening on the soil surface; may include biological components
- **PDB =** Poorly developed biological crust assemblage, many cyanobacterial sheaths, may be slightly dark, can include other functional/structural groups (algae, lichen, moss)
- **SDB =** Strongly developed biological crust assemblage, obvious dark cyanobacteria, rubbery algal, moss or lichen crust
- **CB =** Cracking or curling, rubbery algal crusts, with or without lichen
- **EP =** Erosion pavement; a concentration of rock fragments at the soil surface caused by erosion and removal of finer soil material; individual fragments may be displaced during runoff events
- **DP =** Desert pavement; a concentration of closely packed and polished rock fragments at the soil surface, embedded in a vesicular crust
- **D =** Duff (partially & fully decomposed plant & organic matter; above the A horizon)
- **SA =** Well-formed or distinct structural aggregates at the soil surface and no other class above (well aggregated, stable soils)

Bulk density (core)

Enter cm to nearest 0.1 cm

Stratum-soil replicate ID	Horizon sequence no.	Horizon symbol	Horizon depth upper (cm)	Depth lower (cm)	Soil moisture status D/M/W	User pedon ID and horizon sequence no.	Ring diameter (cm)	Total ring length (cm)	Ring ht 1 (cm)	Ring ht 2 (cm)	Ring ht 3 (cm)	Ring ht 4 (cm)

Penetration resistance

Depth (cm)	Soil moisture status D/M/W	Penetrometer tip Rod or Foot ?	Type of spring	Reading 1	Reading 2	Reading 3	Reading 4
Surface							
2							
5							
8							
11							
14							
17							
20							
23							
26							
29							

Penetrometer tip (diameter)
- **Rod,** flat end (6.4mm)
- **Foot** (25mm)

Spring type (in order of increasing strength)
- **L=** Lee
- **O=** Original
- **J1=** Jones 11
- **J3=** Jones 323

INSTRUCTIONS: Soil Sample Location for RANGE

11/20/2008

(Complete only appropriate items for other land uses)

Follow this sequence at each soil sample location:

Soil sample location

1. Go to flag marking a soil sample location (the stratum-soil replicate). Flags are placed during plot layout, see Plot Master_RANGE.
2. Record project, plot, and sample ID, and data on forms: Soil Sample, Db(core), Penetration Resistance, Pedoderm_RANGE and Soil Aggregate Stability Test(field)_RANGE.
3. Identify a 25 cm x 25 cm plot adjacent to the transect tape and the flag as in diagram below. Always place soil plots on one side of tape and herbaceous subplots on the other side of the tape.

Cover

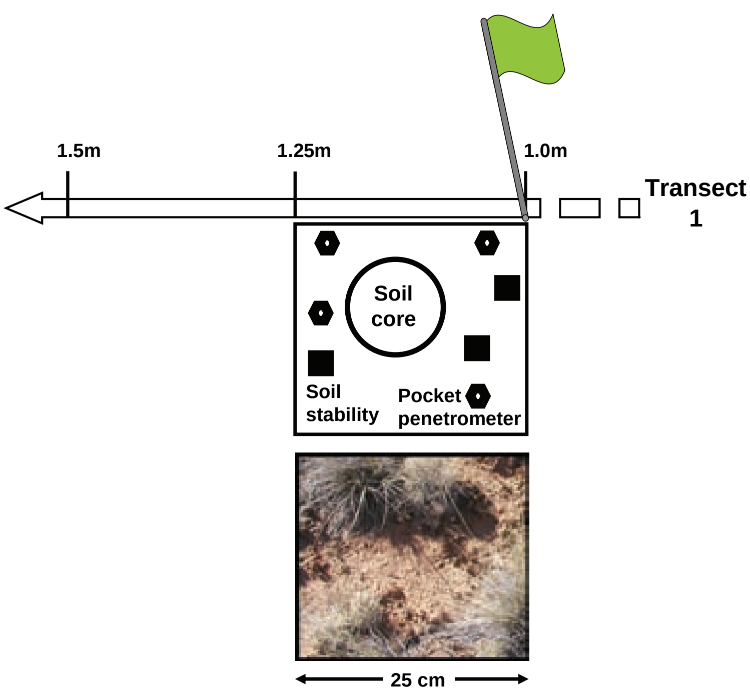
4. Assign codes for vegetative and soil surface cover and pedoderm/soil crust class to the 25 cm x 25 cm plot.
5. Carefully remove all plants, but not the O horizon. Clip as close to the soil surface as possible. Do not disturb roots or soil surface.

Litter and O horizon sample

6. Place a standard size hoop over the 25 cm x 25 cm plot. Estimate litter/O horizon/duff cover (%) and make 4 measurements of depth (to nearest 0.1 cm) along the perimeter of the hoop. Discard surface wood > 6 mm (¼ in) diameter and live above-ground plant material. Collect remaining surface wood, litter, O horizon and all roots and place in paper or cloth bag. Sample Oi, Oe, Oa horizons and current-year litter separately if necessary.

Penetration resistance and soil stability

7. Place bulk density ring over area where sample will be collected (for protection), but do not insert.
8. Randomly select points for 4 penetration readings of the soil surface and 3 soil stability samples. Measure and collect these pedoderm properties before the surface is disturbed for soil sample collection.



9. Excavate a small hole about 40 cm wide and 50 cm deep adjacent to the bulk density ring.
10. Place a 30 cm ruler against the pit face; secure with golf tees. The top of the ruler should be flush with the top of the O horizon. Collect 4 penetration resistance readings from the pit face, starting at 2 cm, and at each depth listed on the form *before the soil dries*.

Description

11. Describe the soil profile, including O horizon, to the bottom of the whole. If a horizon is greater than 25 cm thick, subdivide, describe, and sample as two layers. Subdivide based on morphology, if present, or at the midpoint. Note any horizons that need special analysis.

Bulk density and mineral soil samples

12. Record stratum soil replicate ID, horizon sequence number, symbol and depth to be sampled on this form. Base of final sample should be exactly __________cm below the mineral surface. Use 40 cm for most projects.
13. Starting at the mineral soil surface, insert bulk density ring to 2 cm (or the base of the A if less than 5 cm thick). Make 4 measurements (nearest 0.1 cm) of ring height above soil sample; measure *on the outside of the ring*. Insert spackle blade directly under the ring and carefully remove soil core. *Do not disturb the soil below.* Place in sealed bag as soon as sampled for field moist weights (Oven dry weights will be measured in the laboratory.)
14. Collect a1500 g **sample of each layer**, essentially as a slice from top to bottom of the horizon or layer. Mix and split for analysis, if needed, as follows:

    a. ______ g for ___________________________

    b. ______ g for ___________________________

    c. ______ g for ___________________________

    d. ______ g for ___________________________

15. Repeat 13 and 14 for the remainder of the surface horizon (from 2 cm to the upper boundary of the next horizon). Handle each layer sampled as a separate horizon and number consecutively.
16. Repeat 13 and 14 for the remaining horizons or layers. Handle each layer sampled as a separate horizon and number consecutively. Base of last sample should be exactly ______cm below the mineral soil surface.

USDA-NRCS	PEDON DESCRIPTION	Pedon ID # :		*Basic Soils Course*	May-04

Series or Component Name:	Map Unit Symbol:	Photo #:	Classification:	Soil Moist. Regime (Tax.):

Describer(s):	Date:	Weather: Temp.: *Air:* *Soil:* *Depth:*	Latitude: ° ' " N Longitude: ° ' " W Datum:	Location: Sec. T. R.

UTM: *Zone:* *mE:* *mN:*	Topo Quad.:	Site ID: *YR:* *State:* *County:* *Pedon #:*	Soil Survey Area:	MLRA / LRU:	Transect: *ID:* *Stop #:* *Interval:*

Landscape:	Landform:	Microfeature:	Anthro:	Elevation:	Aspect:	Slope (%):	Slope Complexity:	Slope Shape: (*Up & Dn / Across*)

Hillslope Profile Position:	Geom. Component:	Microrelief:	Physio. Division:	Physio. Province:	Physio. Section:	State Physio. Area:	Local Physio. Area:

Drainage:	Flooding:	Ponding:	Soil Moisture Status:	Profile Saturated Hydraulic Conductivity Ksat:	Land Cover / Use:

Parent Material:	Bedrock: *Kind:* *Fract.:* *Hard.:* *Depth:*	Lithostrat. Units: *Group:* *Formation:* *Member:*

Erosion: *Kind:* *Degree:*	Runoff:	Surface Frag %: *GR:* *CB:* *ST:* *BD:* *CN:* *FL:* *Kind:*	Diagnostic Horz. / Prop.: *Kind:* *Depth:*

P.S. Control Section: *Ave. Clay* %: *Ave. Rock Frag* %: *Depth Range:*	

VEGETATION :

SYMBOL	COMMON NAME	%GD COVER

MISCELLANEOUS FIELD NOTES / SKETCH :

	Component Name:						Map Unit Symbol:					Date:	
	Obser. Method	Depth (cm) (TOP) (BOT)	Horizon	Bnd	Matrix Color Dry	Matrix Color Moist	Texture	Rock Frag Knd % Rnd Sz	Structure Grade Sz Type	Sand %	Silt %	Clay %	LEP	Mottles % Sz Cont. Col Mst Shp Loc
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														

	Redoximorphic Features	Concentrations	Ped / V. Surface Features	Roots	Pores	Notes	Notes
	Knd % Sz Cont. Col. Mst Shape	Knd % Sz Cont. Col Mst Shp Loc	Knd % Con Dst Loc Col Mst	Qty Sz Loc	Qty Sz Shp	Ksat	Unified
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

Glossary of Terms

For a more comprehensive discussion of these terms, refer to the text of the **Guide**. Primary sources include *GSQT* and *IIRH*.

GSQT. Glossary of Soil Quality Terms, Soil Quality Thunderbook, March, 2004.
http://soils.usda.gov/sqi/publications/resources.html

IIRH. Pellent et al., 2005. Interpreting Indicators of Rangeland Health, Version 4
http://usda-ars.nmsu.edu/monit_assess/

anthropogenic:
Generated or influenced by humans. Used to indicate soil conditions, ***disturbances,*** or ***stressors*** that are created or modified by people. *GSQT*

assessing, assessment:
Rangeland health context. The process of estimating or judging the value or functional status of ***ecological processes*** (e.g., ***rangeland health***) in a location at a moment in time. *IIRH*

Soil quality context. Estimating the ***functional capacity*** of soil by comparing a soil to a standard, such as an ***ecological site*** description, a similar soil under native vegetation, a ***reference soil condition***, or quality criteria. The objective of the assessment dictates the standard to be used. (Compare to ***monitoring***.) *GSQT*

attainable:
Attainable is the functional level that is possible for a given soil under a given management system. Attainable soil conditions occur under a management system or ***plant community*** at ***steady-state***. The attainable condition can be lower or higher than ***inherent*** levels. (Compare to ***functional capacity*** and ***reference state***.)

attributes of soil change:
Quantifiable characteristics used to describe the nature of ***soil change***, including ***state variables*** (***dynamic soil properties***), ***fluctuation***, ***trend***, rate, feedback, ***pathway of change***, ***threshold***, ***reversibility***, and ***characteristic response time*** (Arnold et al., 1990; Tugel et al., 2005). *GSQT*

baseline:
Soil context. The soil condition at the initiation of ***monitoring soil quality***. Subsequent measurements on the same soil are compared to the baseline measurement. Baseline can apply to initial condition of other resources, such as water and species composition. (Compare to ***benchmark ecological site, benchmark soil***.) *GSQT*

benchmark ecological site:
An ecological site that has the greatest potential to yield ***data*** and information about ecological ***functions***, ***processes***, and the effects of management or climate change that can apply to a broad area, critical ecological zone, or other similar sites (proposed definition, Benchmark Ecological Sites Ad Hoc Advisory Group, 2008). (Compare to ***benchmark soil***.)

benchmark soil:
A soil of large extent that holds a key position in the soil classification system or is of special significance to farming, engineering, forestry, livestock production, or other uses. The purpose of benchmark soils is to focus ***data collection*** and research efforts on soils that have the greatest potential for expansion of ***data*** and interpretations (USDA, NRCS, 2007). (Compare to ***benchmark ecological site***.) *GSQT*

characteristic response time:
The time period required for soil properties to reach a ***steady-state*** following changes in environmental factors (e.g., climate, precipitation) in the absence of ***disturbance*** or ***stressors*** (Arnold et al., 1990).

conceptual model:
A purposeful representation of reality that provides a mental picture of how something works to communicate that explanation to others (Starfield et al., 1993). A model that represents key ***processes***, interactions, and feedbacks (Gross, 2003). (Compare to ***state and transition model***.)

data:
Observations or measurements that are recorded during a study or project.

data collection:
The process of recording ***observations*** and measurements and collecting soil ***samples***. (Compare to ***sampling***.)

disturbance:
Ecosystem context. Any relatively discrete event in time that disrupts ***ecosystem***, community, or ***population*** structure and changes resources, substrate availability, or the physical environment (White and Pickett, 1985).

Soil function context. Any relatively discrete event that alters the capacity of soil to ***function*** and changes soil morphology, composition, or ***processes***.

Each occurrence of the following is an example of a disturbance: plowing, fertilization, irrigation, brush removal, animal burrowing, fire, flooding, short-term drought, high-intensity storms, and high winds. In many instances disturbances are an integral feature of natural systems and necessary operations in managed systems. (Compare to ***stressors.*)** *GSQT*

disturbance regime:
Disturbance regimes are described primarily by the distribution, frequency, and magnitude of the ***disturbance*** and can be natural or ***anthropogenic*** (White and Pickett, 1985).

dynamic soil properties:
Dynamic soil properties are those that change within the ***human time scale*** in response to management, natural and ***anthropogenic disturbances***, and ***stressors***. Many are important for characterizing ***soil functions*** *and* ***ecological processes*** and for predicting soil behavior within the ***human time scale*** (Tugel et al., 2005). (Compare to ***use-dependent soil properties***.) *GSQT*

ecological processes:
See ***primary ecological processes***.

ecological site:
As defined for rangeland, a distinctive kind of land with specific physical characteristics that differs from other kinds of land in its ability to produce a distinctive kind and amount of vegetation or in its response to disturbance. (USDA, NRCS, 2003).

ecological state:
See ***state***.

ecosystem:
Organisms together with their abiotic environment, forming an interacting system, inhabiting an identifiable space (USDA, NRCS, 2003).

ecosystem services:
The benefits people obtain from ***ecosystems,*** including agroecosystems. These include:

- Provisioning services, such as food and water (products),
- Regulating services, such as regulation of floods, drought, ***land degradation***, and disease,
- Supporting services, such as soil formation and nutrient cycling, and
- Cultural services, such as recreational, spiritual, religious, and other nonmaterial benefits (Hassan et al., 2005).

fluctuation:
Soil context. Temporal variation or change in a ***dynamic soil property*** that is nonsystematic and random or systematic with regular periodic or cyclic variation. Systematic fluctuations may have a ***trend*** or cyclic ***pattern*** that can be predicted, while nonsystematic changes may be impossible to model or predict. The frequency of measurements determines the magnitude and rate of recurrence that can be detected (Arnold et al., 1990).

forest land:
Land on which the historic climax ***plant community*** is dominated by trees (USDA, NCRS, 2003).

forest land health:
Conditions under which the integrity of the soil and ***ecological processes*** are sustained, resulting in systems that maintain their diversity, resiliency, and productivity with associated sustainable human resource (Quigley and Arbelbide, 1997).

function:
A service, role, or task that meets objectives for sustaining life and fulfilling humanity's needs and is performed by soil or an ***ecosystem***. (Compare to ***soil function***.) *GSQT*

functional capacity:
The quantified or estimated measure of physical and biophysical mechanisms or ***processes*** that represent the soil's ability to carry out the ***function***. *GSQT*

functionally important difference
A difference in soil or vegetation properties that is sufficiently large to reflect or cause an important difference in one or more soil or ***ecosystem function***. (Compare to ***minimum detectable difference.***)

grams per plot to kilograms per hectare:

Plot size	Multiply grams by:
0.25 m^2	40
1.0 m^2	10
10.00 m^2	1
100 m^2	0.10
400 m^2	0.025

grams per plot to pounds per acre:

Plot size	Multiply grams by:
1.92 ft^2	50
2.4 ft^2	40
4.8 ft^2	20
9.6 ft^2	10
96 ft^2	1

human time scale:
That portion of the pedogenic time scale that spans periods of centuries, decades, or less (Tugel et al., 2005). *GSQT*

indicator:
A component of a system that is sensitive to changes in the environment and management and that has characteristics (e.g., presence or absence, quantity, amount, or distribution) that are used to reflect a ***process*** or ***function*** that is too difficult, inconvenient, or expensive to measure directly. May be a quantitative measurement or qualitative ***observation***. *GSQT, IIRH*

inherent:
Inherent refers to the innate capacity of a given soil to ***function***. The inherent capacity is determined by environmental factors, called capacity factors (climate, parent material, relief, and organisms over time). Inherent soil conditions occur under nondegraded native ***plant communities*** where past management has not degraded the soil. Following the comparison study procedures in this **Guide**, inherent soil conditions are documented for mature or late succession plant communities at ***steady-state***. (Compare to ***attainable, functional capacity, reference state***.)

inventory:
The systematic acquisition of resource information needed for planning and management. *GSQT*

land degradation:
Land degradation is the reduction or loss of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, ***rangeland***, pastureland, ***forest land*** or woodland resulting from natural ***processes***, land uses or other human activities and habitation ***patterns,*** such as land contamination, soil erosion, and destruction of the vegetation cover (OECD, 1997).

major land resource area (MLRA):
Major land resource areas are geographically associated land resource units. A land resource unit is a geographic area, generally several thousand acres in extent, that is characterized by a particular ***pattern*** of soils, climate, water resources, and land uses (USDA, SCS, 1981; USDA, NRCS, 2006).

metapedogenesis:
The study of human-altered pedogenesis (Yaalon and Yaron, 1966).

minimum detectable change
The size of the change that you want to be able to detect through ***monitoring*** (Elzinga et al., 1998). (Compare to ***minimum detectable difference.***)

minimum detectable difference
The size of the difference to be detected. This can refer to 1) the desired size of the difference you wish to detect and that is initially used to determine ***sampling requirements***, or 2) the actual size of the difference that can be detected with statistical significance using a project data set. Minimum detectable difference as applied in this **Guide** is the difference between ***state phase*** means. (Compare to ***functionally important difference, minimum detectable change.***)

monitoring:
The orderly and quantitative collection, analysis, and interpretation of resource ***data*** from the same locations over time. Monitoring ***soil quality*** involves tracking ***trends*** in quantitative ***indicators*** or the ***functional capacity*** of the soil in order to document changes in soil conditions, determine the success of management practices, or the need for management changes. (Compare to ***assessing***.)

observation:
A single item of ***data*** (datum); a measurement (Dytham, 1999).

pasture condition:
The status of the vegetative cover and soil in a permanent pasture in relation to its highest condition under "ideal" management. Ideal management means that grazing pressure and agronomic inputs are managed to keep the standard ***plant community*** stable at the species proportions considered ideal (proposed, Grazing Lands Team, NRCS). (Compare to ***attainable***.)

patch:
A small contrasting part of a larger whole. Implies a relatively discrete spatial ***pattern***. In the context of this **Guide,** a vegetative component within the ***plant community*** or morphological feature within a landscape. It is discrete because of its relationship to other like patches in space. For example, a group of coppiced shrubs within a grassland ***plant community*** (White and Pickett, 1985). (Compare to ***stratum, strata.***)

pathway of change:
The trajectory and rate of change in a property over time. The change in the property over time can involve linear change, positive and negative feedbacks and ***thresholds***, singly or in combination (Arnold et al., 1990).

pattern:
A recognizable spatial arrangement of a set of recurring objects (e.g., ***patches***).

pedoderm:
The top few centimeters of mineral soil, i.e., the interface between the atmosphere and the soil body (after Mills and Fey, 2004). Properties of the pedoderm can include the following: soil horizon features as well as biological crusts, physical-chemical crusts, cracks, and rock fragments. Features associated with, but not a part of, the pedoderm include loose material, such as litter and small twigs.

pedon:
A three-dimensional soil body commonly with a horizontal area of $1m^2$ and extending with depth to the base of the soil. The smallest body of one kind of soil (Soil Survey Staff, 1999).

pedotransfer function:
A mathematical relationship between two or more soil properties that shows a significant level of statistical confidence. Pedotransfer functions are used to predict difficult-to-measure soil properties from readily obtained properties of the same soil. *GSQT*

plant community:
An assemblage of plants occurring together at any point in time, while denoting no particular ecological status. A unit of vegetation. (USDA, NRCS, 2003). (Compare to ***plant community phase, state phase***.)

plant community phase:
A component of an ecological ***state*** characterized by a unique community of plants. Plant community phases represent individual plant communities within an ecological ***state*** of an ***ecological site***. (Stringham et al., 2003). (Compare to ***state phase***.)

plot element:
Secondary ***sampling units,*** such as transects, vegetation subplots, and soil sample locations, that occur within the primary ***sampling unit*** (plot).

polypedon:
A group of similar contiguous ***pedons*** (Soil Survey Staff, 1999).

population:
The entire pool of possible individuals from which the ***sample*** is selected (Dytham, 1999). The complete set of individual objects (***sampling units***) that a project pertains to and about which you want to make inferences (Elzinga et al., 1998). (Compare to ***target population.***)

primary ecological processes:
Fundamental ecological processes to which all other ecological processes contribute. Primary ecological processes include the following: 1) the water cycle (the capture, storage, and redistribution of precipitation), 2) energy flow (conversion of sunlight to plant and animal matter), and the 3) nutrient cycle (the cycle of nutrients, such as nitrogen and phosphorus, through the physical and biotic components of the environment). *GSQT, IIRH*

processes:
Physical, chemical, and biological mechanisms that follow fundamental scientific laws. Examples include pedogenic processes, geomorphic processes, ***ecological processes***, and degradation processes. *GSQT*

rangeland:
A type of land on which the native vegetation, climax, or natural potential consists dominantly of grasses, grasslike plants, forbs, or shrubs. Rangeland includes lands revegetated naturally or artificially to provide a plant cover that is managed like native vegetation. Rangelands may consist of natural grasslands, savannas, shrublands, moist deserts, tundra, alpine communities, coastal marshes, and wet meadows (USDA, NRCS, 2003).

rangeland health:
The degree to which the integrity of the soil, vegetation, water, and air, as well as the ***ecological processes*** of the rangeland ***ecosystem***, are balanced and sustained. Integrity is defined as maintenance of the structure and functional attributes characteristic of a locale, including normal variability. *IIRH*

reference:
A source of information; can constitute a standard for measuring. Resource ***assessments*** (e.g., ***soil quality***, ***rangeland health, pasture condition, and forest land health***) commonly evaluate actual conditions of a system by comparing them to a reference. The management system or condition used for reference varies with the objectives of the ***inventory***, ***assessment***, or ***monitoring*** activity.

reference area:
A landscape unit or monitoring unit at the ***reference state***. Often used or referred to for qualitative and quantitative ***assessments*** (Herrick et al., 2005).

reference soil condition (soil quality):
The condition of the soil to which ***functional capacity*** is compared. Using ***indicators***, ***soil quality*** is usually assessed by comparing a management system to a reference condition. The reference condition may be represented with 1) ***baseline*** measurements taken previously at the same location; 2) established and achievable ***indicator*** values, such as salinity levels related to salt tolerance of crops; and 3) measurements from the same or similar soil under the ***reference state*** or ***inherent*** or ***attainable*** conditions. (Compare to ***benchmark soil***.) *GSQT*

reference state (state and transition model)
The ***state*** where ***functional capacities*** represented by soil and site stability, hydrologic function, and biotic integrity are performing at an optimum level under the natural ***disturbance regime***. The ***state*** usually includes, but is not limited to, what is often referred to as the potential native ***plant community*** (Herrick et al., 2005). (Compare to ***inherent***.)

reversibility:
An estimate of the ease of reversing a change in a soil property. This is expressed as the ratio of the rate or velocity of the primary change process to the reverse process (Arnold et al., 1990).

sample:
A subset of a ***population*** used to estimate something about the entire ***population*** (Elzinga et al., 1998). Also, a bag of soil.

sample size:
The number of ***observations*** in the ***sample***; determined after ***sampling*** is complete (Dytham, 1999).

sampling:
The process of selecting a subset of the ***population*** for ***data collection*** (Dytham, 1999). Evaluating a portion of a ***population*** so you can make inferences about the entire ***population*** (Elzinga et al., 1998).

sampling objectives:
Specific goals for the measurement of values that ensure usable information. The goals can specify information, such as target levels of precision, power, acceptable false-change error rate, and the magnitude of difference you are hoping to detect (Elzinga et al., 1998).

sampling requirements:
The number of ***sampling units*** required to meet the ***sampling objectives***.

sampling unit:
A singular unit of the ***sample***. In this **Guide,** plots are the primary ***sampling unit*** while individual ***observation,s*** such as soil ***samples*** or transects within the plot, are the secondary ***sampling*** units or ***plot elements***. Individual points along a transect are not considered ***sampling units*** unless they are far enough apart to be considered independent (Elzinga et al., 1998).

scoring function:
Soil quality context. A standardization procedure used to convert measured values or subjective ratings to unitless values, generally between 0 and 1. This allows all soil property measurements to be integrated into one value or index for ***soil quality***. The four general types of scoring functions often used in ***soil quality assessments*** are:

1. more is better (higher measurements mean higher ***soil quality***, e.g. SOM);
2. less is better (lower measurements mean higher ***soil quality***, e.g. salinity);
3. optimum range (a moderate range of values is desirable, e.g. pH); and
4. undesirable range (a specific range of values is undesirable). *GSQT*

soil change:
Temporal variation in soil properties at a specific location over time (Tugel et al., 2005). *GSQT*

soil degradation:
Changes in soil properties and ***processes*** leading to a reduction in ***ecosystem services*** and ***soil function*** (Palm et al., 2007). Soil degradation can be physical, chemical, biological, or mineralogical. (Compare to ***land degradation***.)

soil function:
General context. Any service, role, or task that soil performs.

This **Guide** context. Primary soil functions ensure that soil can perform all other ***functions*** and include 1) providing a stable medium for plant growth and human structures 2) buffering and moderating the hydrologic cycle, and 3) maintaining carbon nutrient and elemental cycling.

Soil quality context (NRCS). Specific ***functions*** include 1) sustaining biological activity, diversity, and productivity; 2) regulating and partitioning water and solute flow; 3) filtering, buffering, degrading, and detoxifying potential pollutants; 4) storing and cycling nutrients; and 5) providing support for buildings and other structures and to protection of archaeological treasures. (Compare to ***function***, ***functional capacity***.) *GSQT*

soil map unit component phase:
All similar soil phases of an individual soil map unit component (e.g., series) in one or more soil map units. In this **Guide**, the term representing the same kind of soil (NRCS, 2003).

soil quality or **soil health:**
The capacity of a specific kind of soil to ***function***, within natural or managed ***ecosystem*** boundaries, and to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. In short, the capacity of the soil to ***function***. There are two aspects of the definition: inherent soil quality and dynamic soil quality. (Compare to ***functional capacity, inherent, rangeland health, forest land health.***) *GSCT*

> **dynamic soil quality:**
> That aspect of soil quality relating to soil properties that change as a result of soil use and management or over the ***human time scale***.
>
> **inherent soil quality:**
> That aspect of soil quality relating to a soil's natural composition and properties as influenced by the factors and ***processes*** of soil formation, in the absence of human impacts.

soil resilience:
The capacity of a soil to recover its ***functional capacity*** after a ***disturbance***. *GSQT*

soil resistance:
The capacity of the soil to maintain its ***functional capacity*** through a ***disturbance***. *GSQT*

state:
A resistant and resilient complex of two components, the soil base and the vegetation structure. The vegetation and soil components are connected through integrated ***ecological processes*** (USDA, NRCS, 2003). A suite of states within an ***ecological site*** represent dynamic conditions unique to that site.

state phase:
A component of a ***state***, such as a ***plant community phase*** or cropland management system. (Compare to ***plant community phase***.)

State-and-transition model:
A model of vegetation dynamics and management interactions associated with each ***ecological site*** (USDA, NRCS, 2003). (Compare to ***conceptual model***.)

steady-state:
A condition of a system or ***process*** that exhibits little directional change (***trend***) with time, although it can include natural variation (***fluctuation***) in response to short-term climatic variation (weather).

stratify:
To separate, divide, or delineate into classes.

stratum, strata:
A unique kind of feature the can be distinguished from other features within an area to be sampled. Examples include grass and shrub ***patches,*** footslope, and backslope. (Compare to ***pattern***.)

stressor:
Prolonged or continuous factors that disrupt the ***ecosystem*** or change the capacity of the soil to ***function***. Stressors are either foreign to that system or natural to the system but applied at an excessive or deficient level (Barrett et al., 1976). Examples include climate change, prolonged drought, farming, heavy continuous grazing, fire suppression, and invasive species. (Compare to ***disturbance***.)

target population:
The ***population*** to which inferences will be applied (Elzinga et al., 1998). For comparison studies according to this **Guide**, the target population is the ***soil map unit component phase*** under either the ***state phase***(s) of the particular ***ecological site*** or the particular management system(s) selected for ***data collection*** within the project.

threshold:
Boundary between ***states***. A characteristic of an ***ecosystem***'s ***pathway of change*** as it moves through a ***transition***. The threshold, once crossed, defines a new stable ***state*** that is not easily reversed without significant inputs of resources. Crossing a threshold indicates a change in the integrity of ***ecological processes*** resulting in different ***plant communities*** or ***state phases*** (Bestelmeyer et al., 2003; Stringham et al., 2003).

transition:
The trajectory or ***pathway of change*** from one ***state*** to another involving ***thresholds*** (Stringham et al., 2003) and commonly represented by management actions or ***disturbances*** that drive the change. Can also include the mechanisms (e.g., ***processes*** related to ***soil degradation***) involved in the change.

trend:
Describes the general direction of change: increasing, decreasing, or ***steady-state*** equilibrium (Arnold et al., 1990).

use-dependent or management-dependent properties:
Soil properties that change in response to use and management of the soil, such as soil organic matter levels and aggregate stability (Grossman et al., 2001). A kind of ***dynamic soil property***. (Compare *to* ***use-invariant properties***.) *GSQT*

use-invariant properties:
Soil properties that change relatively little over time in response to use and management of the soil, such as mineralogy and particle-size distribution in most situations (Grossman et al., 2001). (Compare to ***use-dependent properties***.) *GSQT*

variable:
Anything that can vary between individuals (Dytham, 1999). For example, ***dynamic soil properties*** and vegetation characteristics that may vary between different ***pedons***, ***soil map unit component phases***, ***plant communities***, or ***ecological sites***.

References

Acton, D.F., and L.J. Gregorich. 1995. Understanding soil health. p. 5-10. *In* D.F. Acton and L.J. Gregorich (eds.). The health of our soils: Toward sustainable agriculture in Canada. Centre for Land and Biological Resource Research, Research Branch, Agriculture and Agri-Food Canada, Ottawa, Ontario.

Andrews, S.S., D.L. Karlen, and C.A. Cambardella. 2004. The soil management assessment framework: A quantitative soil quality evaluation method. Soil Sci. Soc. Am J. 68:1945-1962.

Archer, S., T.W. Boutton, and K.A. Hibbard. 2001. Trees in grasslands: Biogeochemical consequences of woody plant expansion. p. 115-137. *In* E.D. Schultze, S.P. Harrison, M. Heimann, E.A. Hollan, J. Lloyd, I.C. Prentice, and D. Schimel (eds.). Global biogeochemical cycles in the climate system. Academic Press, San Diego, CA.

Arnold, R.W., I. Szabolcs, and V.O. Targulian (eds.). 1990. Global soil change. Report of an IIASA-ISSS-UNEP task force on the role of soil in global change. International Institute for Applied System Analysis, Laxenburg, Austria.

Ashraf, M., and M.M. Saeed. 2006. Effect of improved cultural practices on crop yield and soil salinity under relatively saline groundwater applications. Irrig. Drain. Sys. 20(1):111-124.

Barrett, G.W., G M. Van Dyne, and E.P. Odum. 1976. Stress ecology. BioScience. 26:192-194.

Bestelmeyer, B.T. 2006. Threshold concepts and their use in rangeland management and restoration: The good, the bad, and the insidious. Restor. Ecol. 14(3):325-329.

Bestelmeyer, B.T., J.R. Brown, K.M. Havstad, R. Alexander, G. Chavez, and J.E. Herrick. 2003. Development and use of state-and-transition models for rangelands. J. Range. Manage. 56(2):114-126.

Bestelmeyer, B.T., D.A. Trujillo, A. J. Tugel, and K.M. Havstad. 2006. A multi-scale classification of vegetation dynamics in arid lands: What is the right scale for models, monitoring, and restoration? J. Arid Environ. 65:296-318.

Bestelmeyer, B.T., A.J. Tugel, G.L. Peacock, D.G. Robinett, P.L. Shaver, J.R. Brown, J.E. Herrick, H. Sanchez, K.M. Havstad. In press. State-and-transition models for heterogeneous landscapes: A strategy for development and application. Rangeland Ecology and Mange.

Bird, S.B., J.E. Herrick, and M.M. Wander. 2001. Exploiting heterogeneity of soil organic matter in rangelands: Benefits for carbon sequestration. P. 121-138. *In*: R.J. Follett, J.M. Kimble, and R. Lal (eds.). The potential of U.S. grazing lands to sequester carbon and mitigate the greenhouse effect. CRC Press LLC, Boca Raton, FL.

Birkeland, P.W. 1999. Soils and geomorphology. Oxford University Press, New York, NY.

Blum, W.E.H. 1997. Basic concepts: Degradation, resilience, and rehabilitation. *In* R. Lal, W. H. Blum, C. Valentine, and B.A. Stewart (eds.). Methods for assessment of soil degradation.

Briske, D.D., B.T. Bestelmeyer, T.K. Stringham, and P.L. Shaver. 2008. Recommendations for development of resilience-based state-and-transition models. Rangeland Ecology and Mange. 61(4):359-367.

Blum, W.E.H., and A.A. Santelises. 1994. A concept of sustainability and resilience based on soil functions. p. 535-542. *In* D.J. Greenland, and I. Szabolcs (eds.). Soil resilience and sustainable land use. CAB Int. Wallingford, Oxon, England.

Buol, S.A., F.D. Hole, R.J. McCracken, and R.J. Southard. 1997. Soil genesis and classification. 4th edition. Iowa State University Press, Ames, IA.

Burt, R. (ed.). 2004. Soil Survey Methods Manual. Soil Survey Investigations Report No. 42 Ver. 4.0. USDA Natural Resources Conservation Service, Washington, DC.

Carter, M.R., S.S. Andrews, and L.E. Drinkwater. 2003. Systems approaches for improving soil quality. p. 261-281. *In* P. Schjonning, S. Elmholt, and B.T. Christensen (eds.). Managing soil quality: Challenges in modern agriculture. CAB International.

Cole, C.V., K. Pausian, E.T. Elliot, A.K. Metherell, D.S. Ojima, and W.J. Parton. 1993. Analysis of agroecosystem carbon pools. Water Air Soil Pollut. 70:357-371.

Daily, G. (ed.). 1997. Nature’s services: Societal dependence on natural ecosystems. Island Press, Washington, DC.

Davidson, E.A., and E.L. Ackerman. 1993. Changes in soil carbon inventories following cultivation of previously untilled soils. Biogeochemistry 20:161-193.

de Gruijter, J., D. Brus, M. Bierkens, and M. Knotters. 2006. Sampling for natural resource monitoring. Springer-Verlag, Heidelberg, Germany.

Dick, W.A., and E.G. Gregorich. 2004. Developing and maintaining soil organic matter levels. p. 103-120. *In* P. Schjonning, E. Elmholt, and B.T. Christensen (eds.). Managing soil quality: Challenges in modern agriculture. CABI Publishing. Wallingford, Oxon, UK.

Doran, J.W., and T.B. Parkin. 1994. Defining and assessing soil quality. p. 3-21. *In* J.W. Doran, D.C. Coleman, D.F. Bezdicek, and B.A. Stewart (eds.). Defining soil quality for a sustainable environment. SSSA Spec. Publ. 35. ASA, SSSA, Madison, WI.

Dytham, C. 1999. Choosing and using statistics: A biologist's guide. Blackwell Science, Malden, MA.

Ehrenfeld, J.G., B. Ravit, and K. Elgersma. 2005. Feedback in the plant-soil-system. Annu. Rev. Resour. 30:75-115.

Elzinga, C.L., D.W. Salzer, and J.W. Willoughby. 1998. Measuring and monitoring plant populations. Technical Reference 1730-1. Available online at http://www.blm.gov/nstc/library/techref.htm.

Foster, D., F. Swanson, J. Aber, I. Burke, N. Brokaw, D. Tilman, and A. Knapp. 2003. The importance of land-use legacies to ecology and conservation. BioScience. 53(1):77-88.

Franzleubbers, A.J. 2002. Soil organic matter stratification ratio as an indicator of soil quality. Soil Tillage Res. 66(2):95-106.

Friedel, M.H. 1991. Range condition assessment and the concept of thresholds: A viewpoint. J. Range Manage. 44(5):422-426.

Gross, J.E. 2003. Developing conceptual models for monitoring programs, NPS Inventory and Monitoring Program, [Online] Available: http://science.nature.nps.gov/im/monitor/docs/Conceptual_Modelling.pdf

Grossman, R.B., D.S. Harms, C.A. Seybold, and J.E. Herrick. 2001. Coupling use-dependent and use-invariant data for soil quality evaluation in the United States. J. Soil and Water Conserv. 56:63-68.

Gunderson, L.H. 2000. Ecological resilience—in theory and application. Annu. Rev. Ecol. Syst. 31:425-439.

Harris, R.F., D.L. Karlen, and D.J. Mulla. 1996. A conceptual framework for assessment and management of soil quality and health. p. 61-83. *In* J.W. Doran and A.J. Jones (eds.). Methods for assessing soil quality. SSSA Spec. Publ. 49. ASA, SSSA, Madison, WI.

Hassan, R., R. Scholes, and N. Ash (eds.). 2005. Ecosystems and human well-being: Current state and trends: Findings of the Condition and Trends Working Group. Island Press, Washington, DC. Also available online at http://www.millenniumassessment.org/en/Condition.aspx

Herrick, J.E, J.W. Van Zee, K.M. Havstad, L.M. Burkett, and W.G. Whitford. 2005. Monitoring manual for grassland, shrubland, and savanna ecosystems. USDA-ARS Jornada Experimental Range. Las Cruces, NM.

Herrick, J.E., and W.G. Whitford. 1999. Integrating soil processes into management: From microaggregates to macrocatchments. p. 91-95. *In* D. Eldridge and D. Freudenberger (eds.). People and rangelands: Building the future. Proc. Int. Rangeland Congr., Vol 1, Townsville, Australia. 19-23 Jul. 1999. Int. Rangeland Congr., Inc., Townsville, Australia.

Holling, C.S. 1973. Resilience and stability of ecological systems. Annu. Rev. Ecol. Syst. 4:1-23.

Homann, P.S., and D.F. Grigal. 1996. Below-ground organic carbon and decomposition potential in a field-forest glacial-outwash landscape. Biol. Fertil. Soils. 23:207-214.

Hussein, A.H., and M.C. Rabenhorst. 1999. Variability of properties used as differentiating criteria in tidal marsh soils. Soil Science 164:48-56.

Ingram, J.S.J., and E.C.M. Fernandes. 2001. Managing carbon sequestration in soils: Concepts and terminology. Agric. Ecosyst. Environ. 87:111-117.

Jenny, H. 1941. Factors of soil formation. A system of quantitative pedology. 1st ed. McGraw-Hill Book Co., New York.

Jenny, H. 1961. Derivation of state factor equations of soils and ecosystems. Soil Sci. Soc. Am. Proc. 25:385-388.

Karlen, D.L., and D.E. Stott. 1994. A framework for evaluating physical and chemical indicators of soil quality. p. 53-72. *In* J.W. Doran, D.C. Coleman, D.F. Bezdicek, and B.A. Stewart (eds.). Defining soil quality for a sustainable environment. SSSA Spec. Publ. 35. SSSA, Madison, WI.

Lal., R., J.M. Kimble, R.F. Follett, and C.V. Cole (eds.). 1998. The SOC pool in U.S. soils and SOC loss from cultivation. p 18. *In* The potential of U.S. cropland to sequester carbon and mitigate the greenhouse effect. Ann Arbor Press, Chelsea, MI.

Lal, R., T.M. Sobecki, J. Iivari, and J.M. Kimble. 2004. Soil degradation in the United States: Extent, severity and trends. Lewis. New York, NY.

Larson W.E., and F.J. Pierce. 1994. The dynamics of soil quality as a measure of sustainable management. p 37-51. *In* J.W. Doran, D.C. Coleman, D.F. Bezdicek, and B.A. Stewart (eds.). Defining soil quality for a sustainable environment. SSSA Spec. Publ. 35. SSSA, Madison, WI.

Larson W.E., and F.J. Pierce. 1991. Evaluation for sustainable land management in the developing world. *In* Vol. 2: Technical Papers, IBSRAM Proc.12(2), Bangkok, Thailand. 1991. Int. Board for Soil Res. and Manage., Bangkok, Thailand.

Lawrence, D., P. D'Odorico, L. Diekmann, M. DeLonge, R. Das, and J. Eaton. 2007. Ecological feedbacks following deforestation create the potential for a catastrophic ecosystem shift in tropical dry forest. Proc. Natl. Acad. Sci. USA. 104(52):20696-20701.

McLauchlan, K. 2006. The nature and longevity of agricultural impacts on soil carbon and nutrients: A review. Ecosystems. 9:1364-1382.

Millar, C.I., and W.B. Woolfenden. 1999. The role of climate change in interpreting historical variability. Ecol. Appl. 9(4):1207-1216.

Mills, A.J., and M.V. Fey. 2004. Frequent fires intensify soil crusting: Physicochemical feedback in the pedoderm of long-term burn experiments in South Africa. Geoderma. 121:45-64.

Miyamoto, S., and I. Cruz. 1987. Spatial variability of soil salinity in furrow-irrigated Torrifluvents. Soil Sci. Soc. Am. J. 51(4):1019-1025.

Natural Resources Conservation Service. 2003. Populating map unit data: Taxonomic classes and map unit components. Soil Survey Technical Note 4. National Soil Survey Center, Lincoln, NE. [Online] Available: http://soils.usda.gov/technical/technotes/

Organization for Economic Cooperation and Development. 1997. Glossary of environment statistics. Studies in Methods, Series F, No. 67. United Nations, New York, NY. [Online] Available http://stats.oecd.org/glossary/detail.asp?ID=1494

Palm, C., P. Sanchez, S. Ahamed, and A. Awiti. 2007. Soils: A contemporary perspective. Annu. Rev. Environ. Resource. 32:99-129.

Parr, J.F., R.I. Papendick, S.B. Hornick, and R.E. Meyer. 1992. Soil quality: Attributes and relationship to alternative and sustainable agriculture. Amer. J. Alter. Ag. 7(1-2):5-11.

Parsons, D.J., T.W. Swetman, and N.L. Christensen. 1999. Uses and limitations of historical variability concepts in managing ecosystems. Ecol. Appl. 9(4):1177-1178

Pellant, M., P. Shaver, D.A. Pyke, and J.E. Herrick. 2005. Interpreting indicators of rangeland health. Ver. 4. Tech. Ref. 1734-6. USDI-BLM, Denver, CO. Also available online at http://usda-ars.nmsu.edu/monit_assess/PDF_files/IIRHv4.pdf

Pickett, S.T.A. 1989. Space-for-time substitution as an alternative to long-term studies. p. 110-135. *In* G.E. Likens (ed.). Long-term studies in ecology: Approaches and alternatives. Springer-Verlag, New York.

Powlson, D.S. 1996. Why evaluate soil organic matter models? p. 3-11 *In* D.S. Powlson, P. Smith, and J.U. Smith. (eds.). Evaluation of soil organic matter models using existing, long-term datasets. NATO ASI series I, vol. 38. Springer-Verlag, Berlin.

Pyke, D.A., J.E. Herrick, P. Shaver, and M. Pellant. 2002. Rangeland health attributes and indicators for qualitative assessment. J. Range Manage. 55:584-597.

Quigley, T.M. and S.J. Arbelbide (ed.). 1997. An assessment of ecosystem components in the interior Columbia basin and portions of the Klamath and Great Basins: Volume 1. *In* T.M. Quigley (ed.). The Interior Columbia Basin Ecosystem Management Project: Scientific Assessment. 4 vol. Gen. Tech. Rep. PNW-GTR-405. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, OR. (Available on-line at http://www.fs.fed.us/pnw/publications/pnw_gtr405/pnw_gtr405_50.pdf)

Reeves, D.W. 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. Soil Tillage Res. 43:1-2:131-167.

Richter, D.D., Jr. 2007. Humanity's transformation of Earth's soil: Pedology's new frontier. Soil Sci. 172:957-967.

Richter, D.D., Jr, and D. Markewitz. 2001. Understanding soil change: Soil sustainability over millennia, centuries, and decades. Cambridge University Press, Cambridge, UK.

Richter, D.D., Jr, D. Markewitz, S.E. Trumbore, and C.G. Wells. 1999. Rapid accumulation and turnover of soil carbon in a re-establishing forest. Nature 400:56-58.

Richter, D.D., Jr., M. Hofmockel, M.A. Callaham, D.S. Powlson, and P. Smith. 2007. Long-term soil experiments: Keys to managing Earth's rapidly changing ecosystems. Soil Sci. Soc. Am. J. 71:266-279.

Scheffer, M., S. Carpenter, J.A. Foley, C. Folke, and B. Walker. 2001. Catastrophic shifts in ecosystems. Nature 413:591-596.

Schoeneberger, P.J., D.A. Wysocki, E.C. Benham, and W.D. Broderson. (eds.). 2002. Field book for describing soils, Ver. 2.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

Seybold, C.A., J.E. Herrick, and J.J. Brejda. 1999. Soil resilience: A fundamental component of soil quality. Soil Science 164:224-234.

Seybold, C.A., M.J. Mausbach, D.L. Karlen, and H.H. Rogers. 1997. Quantification of soil quality. p. 387-404. *In* R. Lal, J.M. Kimble, R.F. Follett, and B.A. Stewart (eds.). Soil processes and the carbon cycle. Advances in Soil Science. CRC Press, Washington, DC.

Simonson. 1959. Outline of a generalized theory of soil genesis. Soil Sci. Soc. Am. Proc. 23:152-156.

Skalski, J.R. 1987. Selecting a random sample of points in circular field plots. Ecology. 68(3):749-749.

Soil Survey Division Staff. 1993. Soil survey manual. United States Department of Agriculture Handbook No. 18. U.S. Government Printing Office, Washington, DC.

Soil Survey Staff. 1999. Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys, 2nd ed. U.S. Government Printing Office, Washington, DC.

Sparling, G. 2006. Quality indicators. p. 1408-1411. *In* R. Lal (ed.). Encyclopedia of soil science, 2nd ed.; Taylor and Francis, New York, NY. [Online] Available: http://prod.informaworld.com/10.1081/E-ESS-120042739 (accessed August 2007).

Starfield, A.M., D.H.M. Cumming, R.D. Taylor, and M.S. Quadling. 1993. A frame-based paradigm for dynamic ecosystem models. Ai Applications 7:1-13.

Stevens, P.R., and T.W. Walker. 1970. The chronosequence concept and soil formation. Q. Rev. Biol., 45:333-350.

Stringham, T.K., W.C. Krueger, and P.L. Shaver. 2003. State-and-transition modeling: An ecological process approach. J. Range. Manage. 56(2):106-113.

Szabolcs, I. 1994. The concept of soil resilience. p. 33-39. *In* D.J. Greenland and I. Szabolcs (eds.). Soil resilience and sustainable land use. CAB Int. Wallingford, Oxon, England.

Tilman, D., M.E. Dodd, J. Silvertown, P.R. Poulton, A.E. Johnston, and M.J. Crawley. 1994. The Park Grass experiment: Insights from the most long-term ecological study. p. 287-303. *In* R.A. Leigh and A.E. Johnston (eds.). Long-term experiments in agricultural and ecological sciences. CAB International, Wallingford, UK.

Tenywa, M.S., J.G.M. Majaliwa, and A. Lufafa. 2006. Resilience. p. 1484-1487. *In* Encyclopedia of soil science, 2nd ed.; R. Lal (ed.). Taylor and Francis, New York, NY. [Online] Available: http://prod.informaworld.com/10.1081/E-ESS-120042742 (accessed August 2007).

Tongway, D.J., and J.A. Ludwig. 1997. The nature of landscape dysfunction in rangelands. p. 49-61. *In* J. Ludwig, D. Tongway, D. Freudenberger, J. Noble, K. Hodgkinson (eds.). Landscape ecology, function and management: Principles from Australia's rangelands. CISRO, Australia.

Tugel, A.J., J.E. Herrick, J.R. Brown, M.J. Mausbach, W. Puckett, and K. Hipple. 2005. Soil change, soil survey, and natural resources decision making: A blueprint for action. Soil Sci. Soc. Am. J. 69:738-747.

Unnasch, R. S., D.W. Salzer, R. Sutter, and D. Gordon. 2000. Vegetation monitoring in a management context. The Nature Conservancy, Boise, ID.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2003. National range and pasture handbook, title 190-VI. [Online] Available: http://www.glti.nrcs.usda.gov/technical/publications/nrph.html

U.S. Department of Agriculture, Natural Resources Conservation Service. 2006. Land resource regions and major land resource areas of the United States, the Caribbean, and the Pacific Basin. U.S. Department of Agriculture Handbook 296. [Online] Available: http://soils.usda.gov/survey/geography/mlra/index.html

U.S. Department of Agriculture, Natural Resources Conservation Service, 2007. National soil survey handbook, title 430-VI. [Online] Available: http://soils.usda.gov/technical/handbook/

U.S. Department of Agriculture, Soil Conservation Service. 1981. Land resource regions and major land resource areas of the U.S. U.S. Department of Agriculture Handbook 296.

Wadleigh, C.H., and M. Fireman. 1949. Salt distribution under furrow and basin irrigated cotton and its effect on water removal. Soil Sci. Soc. Am. J. 13:527-530.

Walker, B., C.S. Holling, S.R. Carpenter, and A. Kinzig. 2004. Ecology and society. 9(2):5 [Online] Available: http://www.ecologyandsociety.org/vo9/iss2/art5

Warkentin, B.P. 1995. The changing concept of soil quality. J. Soil Water Conserv. 50:226-228.

West, T.O., and W.M. Post. 2002. Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis. Soil Sci. Soc. Am. J. 66:1930-1946.

Westoby, M., B. Walker, and I. Noy-Meir. 1989. Opportunistic management for rangelands not at equilibrium. J. Range Manage. 42:266-274.

White, P.S.1979. Pattern, process and natural disturbance in vegetation. Bot. Rev. 45:229-299.

White, P.S., and S.T.A. Pickett. 1985. Natural disturbance and patch dynamics: An introduction. p. 3-13. *In* S.T.A. Pickett and P.S. White (eds.). The ecology of natural disturbance and patch dynamics. Academic Press, Inc., San Diego, CA.

Wiersma, G.B. (ed.). 2004. Environmental monitoring. CRC Press, Boca Raton.

Wilding, L.P., J. Bouma, and D.W. Goss. 1994. Impact of spatial variability on interpretive modeling. p. 61-75. *In*: R.B. Bryant and R.W. Arnold (eds.). Quantitative modeling of soil forming processes. SSSA Special Publication No. 39. SSSA, Madison, Wisconsin.

Wilding, L.P. and L.R. Drees. 1983. Spatial variability and pedology. p. 83-117. *In:* L.P. Wilding, , N.E. Smeck, and G.F. Hall (eds.). Pedogenesis and soil taxonomy. I. Concepts and interactions. Elsevier Science Publishing Company Inc., New York, NY.

Yaalon, D.H. 1975. Conceptual models in pedogenesis: Can soil-forming function be solved? Geoderma 14:189-205.

Yaalon, D.H. 2000. Down to earth: Why soil-and soil science-matters. Nature 407:301.

Yaalon, D.H., and B. Yaron. 1966. Framework for man-made soil changes: An outline of metapedogenesis. Soil Sci. (102)4:272-277.

Zak, D.R., D.F. Grigal, S. Gleeson, and D. Tillman. 1990. Carbon and nitrogen cycling during old-field succession: Constraints on plant and microbial biomass. Biogeochemistry 11:111-129.