Natural Resource Concerns

A Natural Resource Concern is defined as an expected degradation of the soil, water, air, plant, or animal resource base to an extent the sustainability or intended use of the resource is impaired.

Because NRCS quantifies or describes resource concerns as part of a comprehensive conservation planning process that includes client objectives, human and energy resources are considered components of the resource base.

Natural Resource Concerns

(/conservation-basics/natural-resource-concerns/soil)

Soil

America's vitality is rooted in the soil. Today, private landowners across the country are partnering with NRCS to conserve and improve

(/conservation-basics/natural-resource-concerns/water)

Water

Farmers, ranchers, and forest landowners recognize water as our Nation's most precious resource. Every day, new producers are stepping up to work hand-in-hand with NRCS soil. Additionally, NRCS is also a leader in soil science, playing a pivotal role in...

to implement systems that conserve water and keep valuab...

(/conservation-basics/natural-resource-concerns/plants)

Plants

Plants are common ingredients in many NRCS conservation practices. That’s because they hold soil in place, protect stream banks and shores, filter pollutants, offer food for livestock and cover for wildlife. They also heal th...

(/conservation-basics/natural-resource-concerns/animals)

Animals

Both domestic and wild animals are a critical component of ecosystems and our environment. Domesticated animals, such as livestock, provide us with food and fiber, while wildlife support healthy ecosystems.

(/conservation-basics/natural-resource-concerns/land)

Land

No matter if you grow crops or raise livestock, or you manage timber or want to improve your private land, NRCS has options for you that are good for your land and its natural resources.

(/conservation-basics/natural-resource-concerns/air)

Air

NRCS helps private landowners conserve our air resources and address air quality issues on farms and ranches.

(/conservation-basics/natural-resource-concerns/energy)

Energy

Farmers and ranchers can cut input costs, maintain production, protect soil and water resources, reduce the nation's dependence on fossil fuels, and save money by using conservation practices.

(/conservation-basics/natural-resource-concerns/wildlife-habitat)

Wildlife Habitat

Two-thirds of the land in the lower 48 states is privately owned, and produce much of the country's food and fiber. They also provide much of our nation's open space and the habitats that wildlife need.

(/conservation-basics/natural-resource-concerns/invasive-species-and-pests)

Invasive Species and Pests

Invasive plants and pests can ruin crop fields and forests and drastically alter the natural processes of ecosystems.

(/conservation-basics/natural-resource-concerns/watersheds)

Watersheds

Watersheds impact everyone; every community, farm, ranch, and forest. They provide a vital resource for all living things to survive and thrive. All watersheds are interconnected, creating a land-water system that conveys wat...

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Soil Facts

Definitions of soil and soil survey, information on careers, some basics on soil formation and classification, and a soil science glossary.

Quick Links

What is Soil? (#soil)
What is Soil Survey? (#soil_survey)
Careers in Soil Science (#careers)
Soil Formation and Classification (#formation)
Soil Science Glossary (https://www.soils.org/publications/soils-glossary/) (from the Soil Science Society of America)

What is Soil?

This definition is from the Soil Science Society of America.

soil - (i) The unconsolidated mineral or organic material on the immediate surface of the Earth that serves as a natural medium for the growth of land plants. (ii) The unconsolidated mineral or organic matter on the surface of the Earth that has been subjected to and shows effects of genetic and environmental factors of: climate (including water and temperature effects), and macro- and microorganisms, conditioned by relief, acting on parent material over a period of time. A product-soil differs from the material from which it is derived in many physical, chemical, biological, and morphological properties and characteristics.

This definition is from Soil Taxonomy, second edition.

soil - Soil is a natural body comprised of solids (minerals and organic matter), liquid, and gases that occurs on the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers, that are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment.

The upper limit of soil is the boundary between soil and air, shallow water, live plants, or plant materials that have not begun to decompose. Areas are not considered to have soil if the surface is permanently covered by water too deep (typically more than 2.5 meters) for the growth of rooted plants.

The lower boundary that separates soil from the nonsoil underneath is most difficult to define. Soil consists of horizons near the Earth's surface that, in contrast to the underlying parent material, have been altered by the interactions of climate, relief, and living organisms over time. Commonly, soil grades at its lower boundary to hard rock or to earthy materials virtually devoid of animals, roots, or other marks of biological activity. For purposes of classification, the lower boundary of soil is arbitrarily set at 200 cm.

What is Soil Survey?

This definition is from the Soil Science Society of America:

soil survey - (i) The systematic examination, description, classification, and mapping of soils in an area. Soil surveys are classified according to the kind and intensity of field examination. (ii) The program of the National Cooperative Soil Survey that includes developing and implementing standards for describing, classifying, mapping, writing, and publishing information about soils of a specific area.

Expanded Definition and Uses

Soil survey, or **soil mapping**, is the process of classifying soil types and other soil properties in a given area and geo-encoding such information. It applies the principles of soil science, and draws heavily from geomorphology, theories of soil formation, physical geography, and analysis of vegetation and land use patterns. Primary data for the soil survey are acquired by field sampling and by remote sensing. Remote sensing principally uses aerial photography but LiDAR and other digital techniques steadily gaining in popularity. In the past, a soil scientist would take hard-copies of aerial photography, topo-sheets, and mapping keys into the field with them. Today, a growing number of soil scientists bring a rugidized tablet computer and GPS into the field with them. The tablet may be loaded with digital aerial photos, LiDAR, topography, soil geo-data-bases, mapping keys, and more.

The information in a soil survey can be used by the public as well as the scientific community. For example, farmers and ranchers can use it to help determine whether a particular soil type is suited for crops or livestock and what type of soil management might be required. An architect or engineer might use the engineering properties of a soil to determine whether or not it was suitable for a certain type of construction. A homeowner may even use the information for maintaining or constructing their garden, yard, or home.

Soil Survey Components

Typical information in a county soil survey includes:

- A brief overview of the county's geography.
- A general soil map with a brief description of each of the major soil types found in the county along with their characteristics.
- Detailed aerial photographs with specific soil types outlined and indexed.
- Photographs of some of the typical soils found in the area.
- Tables containing general information about the various soils such as total area, comparisons of production of typical crops and common range plants. They also include extensive interpretations for land use planning such as limitations for dwellings with and without basements, shallow excavations, small commercial buildings, septic tank adsorptions, suitability for development, construction, and water management.
- Tables containing specific physical, chemical, and engineering properties such as soil depth, soil texture, particle size and distribution, plasticity, permeability, available water capacity, shrink-swell potential, corrosion properties, and erodibility.

The term **soil survey** may also be used to describe the published results. In the United States, these surveys were once published in book form for individual counties by the National Cooperative Soil Survey. Today, soil surveys are no longer published in book form; they are published to the web and can be freely accessed by the public on NRCS' Web Soil Survey (WSS) (http://websoilsurvey.nrcs.usda.gov/), where a person can create a custom soil survey. By making the data and information available online, it allows for the rapid flow of the latest soil information to the user. In the past, it could take years to publish a paper soil survey sometime making the published information almost obsolete. Many of the published manuscripts have been scanned for historical purposes.

Understanding the Value

Soil lies beneath each activity.

Soil surveys commonly identify the more important soil characteristics that determine the limitations and qualities of the soil. These interpretations are designed to warn of possible soil related hazards in an area. Knowledge of soil landscapes, soil formation, and the various soil properties and function has expanded with a classification system oriented to the interpretations of the soil survey. Various divisions and subdivisions of the basic system of classification called soil taxonomy provide a basis for application of the information to engineering and agricultural uses of the soil. Information about soil properties provides a basis for assessing risks and hazards when making land use decisions. Additionally, during the soil inventory process, we learn the relationship of various landscapes features to soil geography. Identifying and mapping soil landscape relationships strengthen soil interpretations and the associated interpretations involving hydrology and landscape stability. The separation of geology and soils is not a clear division, but rather the interpretations enhance the delivery of information through the connection of soils to the landscape and the corresponding geology.

Careers in Soil Science

What is a soil scientist?

A soil scientist studies the upper few meters of the Earth's crust in terms of its physical and chemical properties; distribution, genesis and morphology; and biological components. A soil scientist needs a strong background in the physical and biological sciences and mathematics.

What is soil science?

Soil science is the science dealing with soils as a natural resource on the surface of the Earth including soil formation, classification, and mapping; physical, chemical, biological, and fertility properties of soils; and these properties in relation to the use and management of the soils.

Soils play multiple roles in the quality of life throughout the world. Soils are not only the resource for food production, but they are the support for our structures, the medium for waste disposal, they maintain our playgrounds, distribute and store water and nutrients, and support our environment. They support more life beneath their surface than exists above. They facilitate the life cycle of growth, sustenance and decay. They influence the worldwide distribution of plants, animals, and people.

What does a soil scientist do?

Soil scientists work for federal and state governments, universities, and the private sector. The job of a soil scientist includes collection of soil data, consultation, investigation, evaluation, interpretation, planning or inspection relating to soil science. This career includes many different assignments and involves making recommendations about many resource areas.

A soil scientist needs good observation skills to be able to analyze and determine the characteristics of different types of soils. Soil types are complex and the geographical areas a soil scientist may survey are varied. Aerial photos or various satellite images are often used to research the areas. Computer skills and geographic information systems help the scientist to analyze the multiple facets of geomorphology, topography, vegetation, and climate to discover the patterns left on the landscape.

Soil scientists work in both the office and field. The work may require walking over rough and uneven land and using shovels and spades to gather samples or examine a soil pit exposure.

Soil scientists work in a variety of activities that apply soil science knowledge. This work is often done with non-soil science professionals. A soil scientist's job may involve:

- conducting general and detailed soil surveys

- determining the hydric (wetness) characteristics of the soil
- recommending soil management programs
- helping to design hydrologic plans in suburban areas
- monitoring the effects of farm, ranch, or forest activities on soil productivity
- giving technical advice used to help plan land management programs
- predicting the effect of land management options on natural resources
- preparing reports describing land and soil characteristics
- advising land managers of capabilities and limitations of soils (e.g., timber sales, watershed rehabilitation projects, transportation planning, soil productivity, military maneuvers, recreation development)
- training other personnel
- preparing technical papers and attending professional soil science meetings
- conducting research in public and private research institutions
- managing soils for crop production, forest products and erosion control management.
- evaluating nutrient and water availability to crops
- managing soils for landscape design, mine reclamation, and site restoration
- investigating forest soils, wetlands, environmental endangerment, ecological status, and archeological sites
- assessing application of wastes including non-hazardous process wastes (residue and sludge management)
- conducting studies on soil stability, moisture retention or drainage, sustainability, and environmental impact
- assessing environmental hazards, including hazardous waste sites that involve soil investigation techniques, evaluation of chemical fate and transport phenomena, and remediation alternatives
- regulating the use of land and soil resources by private and public interests (government agencies)

These are some of the activities which soil scientists regularly practice. This work is most often conducted in coordination with other professionals with lesser training and knowledge of soil systems.

Well-trained soil scientists are in high demand for a wide array of professional positions with public agencies or private firms. Here are some specific examples of positions currently held by soil science graduates from just one university over the past 10 years.

- Wetland specialist
- Watershed technician
- Hydrologist with Board of Health
- Environmental technician
- State soil and water quality specialist
- Soil Conservationist
- County Agricultural Agent
- Landscaping business
- Farming
- On-site evaluation
- Crop consultant
- Soil scientist, mapping and interpretation, U.S. Department of Agriculture
- Research technician
- Conservation planner
- District marketing manager for an agricultural firm

- County conservationist
- Crop production specialist
- Research scientist

What kind of people become soil scientists?

People that become soil scientists usually have one or more of the following characteristics:

- love of science
- enjoy working outdoors
- enthusiasm for maps and relationships in nature
- desire to be an integral in environmental decisions related to soil conservation, land use, water quality, or waste management
- willingness to communicate their knowledge about soils and the environment to all aspects of society
- hunger for answers to questions and solutions to problems in agricultural and environmental settings
- desire to contribute to the success of others

How do people become soil scientists?

Most soil scientists have earned at least a bachelor degree from a major agricultural university. At many universities, two choices are available for specialized training in soils. The Soil Science option prepares students to enter the agricultural sector as farm advisors, crop consultants, soil and water conservationists, or as representatives of agricultural companies. The Environmental Soil Science option prepares soil scientists for careers in environmental positions dealing with water quality concerns, remediation of contaminants or for on-site evaluation of soil properties in construction, waste disposal, or recreational facilities.

How do people become soil scientists with USDA?

The minimum requirement for a soil scientist position at USDA–NRCS or USDA Forest Service is a 4-year Bachelor of Science degree that includes 30 semester hours in the natural sciences (e.g., biological, physical, and earth science) and 15 semester hours in soil science (e.g., soil genesis and morphology, soil chemistry, soil physics, and soil fertility). Most of the major universities that still have a soil science program now offer soils courses only at the graduate level.

Where do you find career opportunities?

Soil Science Society of America (https://www.soils.org/careers)

Office of Personnel Management (https://www.usajobs.gov/) - Openings for Federal soil scientist positions. Specific qualifications are listed for each vacancy. Search for the 0470 job series to find all soil scientist eligible vacancies.

Soil Formation and Classification

The National Cooperative Soil Survey identifies and maps over 20,000 different kinds of soil in the United States. Most soils are given a name, which generally comes from the locale where the soil was first mapped. Named soils are referred to as soil series.

Soil survey reports include the soil survey maps and the names and descriptions of the soils in a report area. These soil survey reports are published by the National Cooperative Soil Survey and are available to everyone.

Soils are named and classified on the basis of physical and chemical properties in their horizons (layers). "Soil Taxonomy" uses color, texture, structure, and other properties of the surface two meters deep to key the soil into a classification system to help people use soil information. This system also provides a common language for scientists.

Soils and their horizons differ from one another, depending on how and when they formed. Soil scientists use five soil factors to explain how soils form and to help them predict where different soils may occur. The scientists also allow for additions and removal of soil material and for activities and changes within the soil that continue each day.

Soil Forming Factors

Parent material. Few soils weather directly from the underlying rocks. These "residual" soils have the same general chemistry as the original rocks. More commonly, soils form in materials that have moved in from elsewhere. Materials may have moved many miles or only a few feet. Windblown "loess" is common in the Midwest. It buries "glacial till" in many areas. Glacial till is material ground up and moved by a glacier. The material in which soils form is called "parent material." In the lower part of the soils, these materials may be relatively unchanged from when they were deposited by moving water, ice, or wind.

Sediments along rivers have different textures, depending on whether the stream moves quickly or slowly. Fast-moving water leaves gravel, rocks, and sand. Slow-moving water and lakes leave fine textured material (clay and silt) when sediments in the water settle out.

Climate. Soils vary, depending on the climate. Temperature and moisture amounts cause different patterns of weathering and leaching. Wind redistributes sand and other particles especially in arid regions. The amount, intensity, timing, and kind of precipitation influence soil formation. Seasonal and daily changes in temperature affect moisture effectiveness, biological activity, rates of chemical reactions, and kinds of vegetation.

Topography. Slope and aspect affect the moisture and temperature of soil. Steep slopes facing the sun are warmer, just like the south-facing side of a house. Steep soils may be eroded and lose their topsoil as they form. Thus, they may be thinner than the more nearly level soils that receive deposits from areas upslope. Deeper, darker colored soils may be expected on the bottom land.

Biological factors. Plants, animals, micro-organisms, and humans affect soil formation. Animals and micro-organisms mix soils and form burrows and pores. Plant roots open channels in the soils. Different types of roots have different effects on soils. Grass roots are "fibrous" near the soil surface and easily decompose, adding organic matter. Taproots open pathways through dense layers. Micro-organisms affect chemical exchanges between roots and soil. Humans can mix the soil so extensively that the soil material is again considered parent material.

The native vegetation depends on climate, topography, and biological factors plus many soil factors such as soil density, depth, chemistry, temperature, and moisture. Leaves from plants fall to the surface and decompose on the soil. Organisms decompose these leaves and mix them with the upper part of the soil. Trees and shrubs have large roots that may grow to considerable depths.

Time. Time for all these factors to interact with the soil is also a factor. Over time, soils exhibit features that reflect the other forming factors. Soil formation processes are continuous. Recently deposited material, such as the deposition from a flood, exhibits no features from soil development activities. The previous soil surface and underlying horizons become buried. The time clock resets for these soils. Terraces above the active floodplain, while genetically similar to the floodplain, are older land surfaces and exhibit more development features.

These soil forming factors continue to affect soils even on “stable” landscapes. Materials are deposited on their surface, and materials are blown or washed away from the surface. Additions, removals, and alterations are slow or rapid, depending on climate, landscape position, and biological activity.

When mapping soils, a soil scientist looks for areas with similar soil-forming factors to find similar soils. The colors, texture, structure, and other properties are described. Soils with the same kind of properties are given taxonomic names. A common soil in the Midwest reflects the temperate, humid climate and native prairie vegetation with a thick, nearly black surface layer. This layer is high in organic matter from decomposing grass. It is called a “mollic epipedon.” It is one of several types of surface horizons that we call “epipedons.” Soils in the desert commonly have an “ochric” epipedon that is light colored and low in organic matter. Subsurface horizons also are used in soil classification. Many forested areas have a subsurface horizon with an accumulation of clay called an “argillic” horizon.

Soil Orders

Soil taxonomy at the highest hierarchical level identifies 12 soil orders. The names for the orders and taxonomic soil properties relate to Greek, Latin, or other root words that reveal something about the soil. Sixty-four suborders are recognized at the next level of classification. There are about 300 great groups and more than 2,400 subgroups. Soils within a subgroup that have similar physical and chemical properties that affect their responses to management and manipulation are families. The soil series is the lowest category in the soil classification system.

Maps

The distribution of these soil orders in the United States corresponds with the general patterns of the soil forming factors across the country. A map of soil orders is useful in understanding broad areas of soils. Detailed soil maps found in soil survey reports, however, should be used for local decision making. Soil maps are like road maps, for very general overview, a small scale map in an atlas is helpful, but for finding a location of a house in a city, a large scale detailed map should be used.

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Soils Program: An Interdisciplinary Scientific Approach

Soil is a complex and dynamic natural resource on the Earth's surface. It supports plant growth, affects water and air quality, and helps clean up natural and human-made wastes. We depend on soils for the food we eat, the water we drink, and the environment in which we live and play. NIFA is involved in a diverse range of research, education, and outreach activities to better understand, maintain, and restore the health of this vital natural resource.

Soils profoundly affect agricultural productivity and sustainability, ecosystem stability, and global change. Soils provide physical support, water, air, and nutrients for plants, and they receive natural and man-made materials and wastes. At the same time, soils contain an immense diversity of microorganisms, plants, and animals. This dynamic combination of life, water, nutrients, and minerals can remove and transform harmful products while storing and recycling water, nutrients, and other elements needed for life on Earth.

The program aims to address the issues surrounding soil as applied to agroecosystems with focus to specific areas such as:

- Greenhouse Gases
- Contaminants
- Soilborne Pathogens, Pests, and Microbial Communities
- Wetland Ecosystems and Subaqueous Soils
- Soil Conservation and Health

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Soil Conservation and Health.pdf (pdf - 35.34 KB)

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Page last updated: July 24, 2023

USDA National Institute of Food and Agriculture

Soils Program: An Interdisciplinary Scientific Approach

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Page last updated: July 24, 2023

United States Department of Agriculture

Soil Survey Manual

Soil Science Division Staff

Agriculture Handbook No. 18

United States Department of Agriculture

Soil Survey Manual

By Soil Science Division Staff

United States Department of Agriculture
Handbook No. 18

Issued March 2017

Minor Amendments February 2018

This manual is a revision and enlargement of U.S. Department of Agriculture Handbook No. 18, the *Soil Survey Manual,* previously issued October 1962 and October 1993. This version supersedes both previous versions.

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Table of Contents

CHAPTER 1

Soil and Soil Survey

By Soil Science Division Staff. Revised by Craig Ditzler and Larry West, USDA-NRCS.

This chapter describes the term "soil survey" within the context of the National Cooperative Soil Survey (NCSS) in the United States. It discusses the development of pedology and the important concept of soils as natural three-dimensional bodies that form as a result of the interaction of five soil-forming factors. The repeating patterns formed by these natural bodies of soil in the landscape allow soil scientists to develop predictive soil-landscape models, which serve as the scientific foundation for making soil surveys. Important milestones in the development of the Soil Survey in the United States are discussed at the end of this chapter.

Soil Survey—Definition and Description

A soil survey describes the characteristics of the soils in a given area, classifies the soils according to a standard system of taxonomy, plots the boundaries of the soils on a map, stores soil property information in an organized database, and makes predictions about the suitability and limitations of each soil for multiple uses as well as their likely response to management systems. The information collected in a soil survey helps in the development of land use plans and can be used to evaluate and predict the effects of land use on the environment.

A soil map consists of many individual delineations showing the location and extent of different soils. The collection of all delineations that have the same symbol on the map (e.g., 34B) are a "map unit." Each map unit is named for one or more soils or nonsoil areas (e.g., Sharpsburg silt loam). Each kind of soil or nonsoil (e.g., Rock outcrop) making up the composition of a map unit is a map unit component. See chapter 4 for a full discussion of map units and their components.

The soils are natural three-dimensional bodies occupying a characteristic part of the landscape. Soil survey maps are therefore different from other maps that show just one or a few specific soil properties or other environmental information. The concept of soil survey as defined for the NCSS is related to, but does not include, maps showing the distribution of a single soil property (such as texture, slope, or depth) alone or in limited combinations; maps showing the distribution of soil qualities (such as productivity or erodibility); and maps of soil-forming factors (such as climate, topography, vegetation, or geologic material). A soil map from a soil survey, as defined here, delineates areas occupied by different kinds of soil, each of which has a unique set of interrelated properties characteristic of the material from which it formed, its environment, and its pedogenic history. The soils mapped by the NCSS are identified by names that serve as references to a national system of soil classification.

The geographic distribution of many individual soil properties or soil qualities can be extracted from soil maps and shown on separate maps for special purposes, such as showing predicted soil behavior for a particular use. Numerous interpretative maps can be derived from a soil map, and each of these maps would differ from the others according to its purpose. A map made for one specific interpretation rarely can serve a different purpose.

Maps that show one or more soil properties can be made directly from field observations without making a basic soil map. Such maps serve their specific purposes but have few other applications. Predictions of soil behavior can also be mapped directly; however, most of these interpretations will need to be changed with changes in land use and in the cultural and economic environment. For example, a map showing the productivity of crops on soils that are wet and undrained has little value after drainage systems have been installed. If the basic soil map is made accurately, and a wide array of soil property data is collected and stored in an organized database, interpretative maps can be revised as needed without additional fieldwork. In planning soil surveys, this point needs to be emphasized. In some cases, inventories are made for some narrow objective, perhaps at a cost lower than that of a soil survey. Generally, maps for these inventories quickly become obsolete. They cannot be revised without fieldwork because vital data are missing, facts are mixed with interpretations, or boundaries between significantly different soil units have been omitted.

The basic objective of soil surveys is the same for all kinds of land, but the number of map units, their composition, and the detail of mapping vary with the complexity of the soil patterns and the specific needs of the users. Thus, a soil survey is designed for the soils and the soil-related problems of the area. Soil surveys increase general knowledge about soils and serve practical purposes. They provide soil information about specific geographic areas needed for regional or local land use plans. These plans include resource conservation for farms and ranches, development of reclamation projects, forest management, engineering projects, as well as other purposes.

Early Concepts of Soil

One of the earliest scholars of soils in the United States was Edmund Ruffin of Virginia. He worked diligently to find the secret of liming and discovered what is now called exchangeable calcium. After writing a brief essay in the *American Farmer* in 1822, he published the first edition of *An Essay on Calcareous Manures* in 1832. Much of what Ruffin learned about soils had to be rediscovered because his writings were circulated only in the South.

E.W. Hilgard was one of the first modern pedologists in the United States. His early concepts of soil (Hilgard, 1860, 1884, 1906) were based on ideas developed by the German chemist Justus von Liebig and modified and refined by agricultural scientists who worked on soil samples in laboratories, in greenhouses, and on small field plots. Soils were rarely examined below the depth of normal tillage. The chemists had a "balance-sheet" theory of plant nutrition. Soil was considered a more or less static storage bin for plant nutrients—the soils could be used and replaced. This concept still has value when applied within the framework of modern soil science, although a useful understanding of soils goes beyond the removal of nutrients from soil by harvested crops and their return to soil through manure, lime, and fertilizer.

Early geologists generally accepted the balance-sheet theory of soil fertility and applied it within the framework of their own discipline. They described soil as disintegrated rock of various sorts—granite, sandstone, glacial till, etc. However, they also described how the weathering processes modified this material and how geologic processes shaped it into landforms (such as glacial moraines, alluvial plains, loess plains, and marine terraces). N.S. Shaler's monograph on the origin and nature of soils summarized the late 19th century geological concept of soils (Shaler, 1891). Other details were added by G.P. Merrill (1906).

Near the end of the 19th century, Professor Milton Whitney inaugurated the National Soil Survey Program (Jenny, 1961). In the newly organized soil research unit of the U.S. Department of Agriculture, Whitney and his coworkers discovered great variations among natural soils—persistent variations that were in no way related to the effects of agricultural use. They emphasized the importance of soil texture and the capacity of the soil to furnish plants with moisture as well as nutrients. About this time, Professor F.H. King of the University of Wisconsin also reported the importance of the physical properties of soils (King, 1910).

Early soil surveys were made to help farmers locate soils responsive to different management practices and to help them decide what crops and management practices were most suitable for the particular kinds of soil on their farms. Many who worked on these early surveys were geologists because only geologists were skilled in the field methods and scientific correlation needed for the study of soils. They thought of soils as mainly the weathering products of geologic formations, defined by landform and lithologic composition. Most of the soil surveys published before 1910 were strongly influenced by these concepts. Those published from 1910 to 1920 were further refined and recognized more soil features but retained fundamentally geological concepts.

Early field workers soon learned that many important soil properties were not necessarily related to either landform or kind of rock. They noted that soils with poor natural drainage had different properties than soils with good natural drainage and that many sloping soils were unlike level ones. Topography was clearly related to soil profile differences. Soil structure was described in soil survey as early as 1902, in the soil survey of the Dubuque Area, Iowa (Fippin, 1902). The 1904 soil survey of Tama County, Iowa (Ely et. al., 1904) reported that soils that had formed under forest contrasted markedly with other soils that had similar parent material but formed under grass.

Soils as Natural Bodies

The balance-sheet theory of plant nutrition dominated laboratory work, while the geological concept dominated fieldwork. Both approaches were taught in many classrooms until the late 1920s. Although broader and more generally useful concepts of soil were being developed by some soil scientists, especially Hilgard (1860) and Coffey (1912) in the U.S. and soil scientists in Russia, the necessary data for formulating these broader concepts came from the fieldwork of the Soil Survey during the first decade of its operations in the United States. The concept of the solum and the A-B-C horizon nomenclature were becoming central to pedology and soil survey (Tandarich et al., 2002). After the work of Hilgard, the most significant advance toward a more satisfactory concept of soil was made by G.N. Coffey. Coffey determined that the ideal classification of soil was a hierarchical system based on the unique characteristics of soil as "a natural body having a definite genesis and distinct nature of its own and occupying an independent position in the formations constituting the surface of the earth" (Cline, 1977).

Beginning in 1870, the Russian school of soil science under the leadership of V.V. Dokuchaev and N.M. Sibertsev was developing a new concept of soil. The Russian scientists conceived of soils as independent natural bodies, each with unique properties resulting from a unique combination of climate, living matter, parent material, relief, and time (Gedroiz, 1925). They hypothesized that properties of each soil reflected the combined effects of the particular set of genetic factors responsible for the soil's formation, emphasizing the importance of the "zonal" concept (i.e., the bioclimatic zone in which the soil formed). Hans Jenny later emphasized the functional relationships between soil properties and soil formation. The results of this work became generally available to Americans through the publication in 1914 of K.D. Glinka's textbook in German and especially through its translation into English by C.F. Marbut in 1927 (Glinka, 1927).

The Russian concepts were revolutionary. Soil properties were no longer based wholly on inferences from the nature of rocks or from climate or other environmental factors, considered singly or collectively. Instead, the integrated expression of all these factors could be seen in the morphology of the soils. This concept required that *all properties* of soils be considered collectively in terms of a completely integrated natural body. In short, it made possible a science of soil.

As a result of the early enthusiasm for the new concept and for the rising new discipline of soil science, some suggested that the study of soil could proceed without regard to the older concepts derived from geology and agricultural chemistry. Certainly, the reverse was true. Besides laying the foundation for a soil science with its own principles, the new concept made the other sciences even more useful. Soil morphology provides a firm basis on which to group the results of observation, experiments, and practical experience and to develop integrated principles that predict the behavior of soils.

Under the leadership of C.F. Marbut, the Russian concept was broadened and adapted to conditions in the United States (Marbut, 1921). As mentioned earlier, this concept emphasized individual soil profiles and subordinated external soil features and surface geology. By emphasizing soil profiles, however, soil scientists initially tended to overlook the natural variability of soils, which can be significant even within a small area. Overlooking the variability of soils seriously reduced the value of maps that showed the location of soils. This weakness soon became evident in the U.S., perhaps because of the emphasis on making detailed soil maps for their practical, predictive value. Progress in transforming the profile concept into a more reliable predictive tool was rapid because a large body of important field data had already been accumulated. By 1925, a large amount of morphological and chemical work was being done on soils throughout the country. The data collected by 1930 were summarized and interpreted in accordance with this concept, as viewed by Marbut in his work on the soils of the United States (Marbut, 1935).

Early emphasis on genetic soil profiles was so great as to suggest that material lacking a genetic profile, such as recent alluvium, was not soil. A sharp distinction was drawn between rock weathering and soil formation. Although a distinction between these sets of processes is useful for some purposes, rock and mineral weathering and soil formation commonly are indistinguishable.

The concept of soil was gradually broadened and extended during the years following 1930, essentially through consolidation and balance. The major emphasis had been on the soil profile. After 1930, morphological studies were extended from single pits to long trenches or a series of pits in an area of a soil. The morphology of a soil came to be described by ranges of properties deviating from a central concept instead of by a single "typical" profile. The development of techniques for mineralogical studies of clays also emphasized the need for laboratory studies.

The clarification and broadening of soil science also was due to the increasing emphasis on detailed soil mapping. Concepts changed with increased emphasis on predicting crop yields for each kind of soil shown on the maps. Many of the older descriptions of soils had not been quantitative enough and the units of classification had been too heterogeneous to use in making the yield and management predictions needed for planning the management of individual farms or fields.

During the 1930s, soil formation was explained in terms of loosely conceived processes, such as "podzolization," "laterization," and "calcification." These were presumed to be unique processes responsible for the observed common properties of the soils of a region (Jenny, 1946).

In 1941, Hans Jenny's *Factors of Soil Formation*: *A System of Quantitative Pedology* concisely summarized and illustrated many of the basic principles of modern soil science to that date (Jenny, 1941). Since 1940, time has assumed much greater significance among the factors of soil formation and geomorphological studies have become important in determining the time that soil material at any place has been subjected to soil-forming processes. Meanwhile, advances in soil chemistry, soil physics, soil mineralogy, and soil biology, as well as in the basic sciences that underlie them, have added new tools and new dimensions to the study of soil formation. As a consequence, the formation of soil has come to be treated as the aggregate of many interrelated physical, chemical, and biological processes. These processes are subject to quantitative study in soil physics, soil chemistry, soil mineralogy, and soil biology. The focus also has shifted from the study of gross attributes of the whole soil to the co-varying detail of individual parts, including grain-to-grain relationships.

Early Development of Soil Classification

C.F. Marbut strongly emphasized that the classification of soils should be based on morphology instead of on theories of soil genesis, because theories are both ephemeral and dynamic. He perhaps overemphasized this point because some scientists assumed that soils had certain characteristics without ever actually examining them. Marbut stressed that examination of the soils themselves was essential in developing a system of soil classification and in making usable soil maps. However, Marbut's work reveals his personal understanding of the contributions of geology to soil science. His soil classification of 1935 relied heavily on the concept of a "normal soil," the product of equilibrium on a landscape where downward erosion keeps pace with soil formation. Continued work in soil classification by the U.S. Department of Agriculture culminated in the release of a new system published in the 1938 Yearbook of Agriculture in the chapter "Soil Classification" (Baldwin et al., 1938).

In both the early classification developed by Marbut and the later 1938 classification developed by USDA, the classes were described mainly in qualitative terms. Because the central concept of each class was described but the limits between classes were not, some soils seemed to be members of more than one class. The classes were not defined in quantitative terms that would permit consistent application of the system by different scientists. Neither system definitely linked the classes of its higher categories, which were largely influenced by the genetic concepts initiated by the Russian soil scientists, to the soil series and their subdivisions that were used in soil mapping in the United States. Both systems reflected the concepts and theories of soil genesis of the time, which were themselves predominantly qualitative in character. Modification of the 1938 system in 1949 corrected some deficiencies but also illustrated the need for a reappraisal of concepts and principles. One continuing problem was that a scientist required knowledge about the genesis of the soil to classify it. This information was often lacking or was disagreed upon by soil surveyors. It was determined that a new classification system was required, one that could be applied consistently by an increasingly large and varied cadre of soil surveyors.

Modern Concept of Soil

Soil as defined in *Soil Taxonomy* (Soil Survey Staff, 1999) is "a natural body comprised of solids (minerals and organic matter), liquid, and gases that occurs on the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers, that are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment."

The "natural bodies" of this definition include all genetically related parts of the soil. A given part, such as a cemented layer, may not be capable of supporting plants. However, it is still a part of the soil if it is genetically related to the other parts and if the body as a unit is either capable of supporting plants or has horizons or layers that are the result of the pedogenic processes, i.e., additions, losses, transfers, and transformations (Simonson, 1959). Nearly all natural bodies recognized as "soil" are capable of supporting plants. Some that cannot support higher plants are still recognized as soil because they are affected by pedogenic development. Soils in very harsh environments, such as Antarctica, are an example. The definition of soil also includes natural bodies that are capable of supporting plants even though they do not have genetically differentiated parts. For example, a fresh deposit of alluvium or earthy constructed fill is soil if it can support plants.

Bodies of water that support floating plants, such as algae, are not considered soil because these plants are not rooted. However, the sediment below shallow water is soil if it can support bottom-rooting plants (such as cattails, reeds, and seaweed) or if the sediment exhibits changes due to pedogenic processes. These soils are commonly referred to as "subaqueous soils" (see chapter 10). The above-ground parts of plants are also not soil, although they may support parasitic plants. Also excluded is rock that mainly supports lichens on the surface or plants only in widely spaced cracks.

The transition from nonsoil to soil can be illustrated by recent lava flows in warm regions under heavy and very frequent rainfall. In those climates, plants become established very quickly on the basaltic lava, even though there is very little earthy material. They are supported by the porous rock filled with water containing plant nutrients. The dominantly porous, broken lava in which plant roots grow is soil.

Marbut's definition of soil as "the outer layer" of the Earth's crust implied a concept of soil as a continuum (Marbut, 1935). The current definition refers to soil as a collection of natural bodies on the surface of the Earth. It divides Marbut's continuum into discrete, defined parts that can be treated as members of a population. The perspective of soil has changed from one in which the whole was emphasized and its parts were loosely defined to one in which the parts are sharply defined and the whole is an organized collection of these parts.

Development of Soil Taxonomy

More than 15 years of work under the leadership of Dr. Guy Smith culminated in a new soil classification system. Categories and classes of the new taxonomy were direct consequences of new and revised concepts and theories. This system became the official classification system of the U.S. National Cooperative Soil Survey in 1965 and was published in 1975 as *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys* (Soil Survey Staff, 1975). The system's most significant contribution was the establishment of taxonomic class limits and their quantitative definitions, whereby an individual soil could belong to only one class. Soil genesis was no longer used directly in determining the correct classification. Instead, diagnostic horizons and features that are the morphological expression of major known genetic processes were defined and used. In this way the current understanding of soil genesis, while indirectly incorporated in the taxonomy, is one step removed from the process of classifying a soil (Smith, 1963). The application of quantitative diagnostic horizons and features as criteria to be used in soil classification has been widely adopted in other soil classification systems around the world, perhaps most notably by the World Reference Base (IUSS Working Group WRB, 2014), sponsored by the Food and Agriculture Organization of the United Nations.

The system of soil classification discussed in *Soil Taxonomy* is dynamic and can change as new knowledge is obtained. The theories on which the system is based are tested every time the taxonomy is applied. During the 1980s and 1990s, nine international committees contributed to major revisions of the taxonomy. This work culminated in the printing of the second edition of *Soil Taxonomy* (Soil Survey Staff, 1999). In addition, many individual proposals for change have been incorporated in editions of the *Keys to Soil Taxonomy,* which have been published periodically since the first edition of *Soil Taxonomy* was published in 1975. The work of a 10th international committee, which addressed the impact of human influences on soils, resulted in important changes. These changes are reflected in the 12th edition of the *Keys to Soil Taxonomy* (Soil Survey Staff, 2014).

Scientific Foundation of Soil Survey

Soil survey is grounded in scientific principles that can be described by the factors of soil formation and by the relationships between landscapes, landforms, and soils. The soil-forming factors are responsible for the genetic development of soil profiles. The relationships between landscapes, landforms, and soils are used to understand the predicable patterns of natural soil bodies in the landscape.

Factors that Control the Distribution of Soils

The properties of soil vary from place to place, but this variation is not random. Natural soil bodies are the result of climate and living organisms acting on parent material, with topography or local relief exerting a modifying influence and with enough time for soil-forming processes to act. For the most part, soils are the same wherever all elements of the five factors are the same. Under similar environments in different places, soils are similar. This regularity permits prediction of the location of many different kinds of soil. This fundamental principle makes soil survey practical (Hudson, 1992).

When soils are studied in small areas, the effects of topography (or local relief), parent material, and time on soil become apparent. In humid regions, for example, wet soils and the properties associated with wetness are common in low-lying places while better drained soils are common in higher lying areas. The correct conclusion to draw from these relationships is that *topography* or *relief* is important. In arid regions, the differences associated with relief may be manifested in variations in salinity or sodicity, but the conclusion is the same. In a local environment, different soils are associated with contrasting parent materials, such as residuum from shale and residuum from sandstone. The correct conclusion to draw from this relationship is that *parent material* is important. Soils on a flood plain differ from soils on higher and older terraces where there is no longer deposition of parent material on the surface. The correct conclusion to draw from this relationship is that *time* is important. The influence of topography, parent material, and time on the formation of soil is observed repeatedly while studying the soils of an area.

With the notable exception of the contrasting patterns of vegetation in transition zones, local differences in vegetation are closely associated with differences in relief, parent material, or time. The effects of microclimate on vegetation may be reflected in the soil, but such effects are likely associated with differences in local relief.

Regional climate and vegetation influence the soil as well as topography/relief, parent material, and time. In spite of local differences, most of the soils in an area typically have some properties in common, which reflect the soil-forming factors influencing the soils regionally. The low-base status of many soils in humid regions or regions with naturally acid rock or sediment stands in marked contrast to the typical high-base status in arid regions or regions with calcareous sandstone or limestone. In old landscapes of humid regions, however, low-base status is so commonplace that little significance is attached to it when considered only from the narrow perspective of old landscapes in a humid region alone.

Regional patterns of climate, vegetation, and parent material can be used to predict the kinds of soil in large areas. The local patterns of topography/relief, parent material, and time, and their relationships to vegetation and microclimate, can be used to predict the kinds of soil in small areas. Soil surveyors learn to use local features, especially topography and associated vegetation, as indicators of unique combinations of all five soil-forming factors. These features are used to predict boundaries of different kinds of soil and to predict some of the properties of the soil within those boundaries.

Soil-Landscape Relationships

Geographic order suggests natural relationships. For example, weathering and erosion of bedrock by running water commonly sculpt landforms within a landscape. Over the ages, earthy material has been removed from some landforms and deposited on others. Landforms are interrelated. An entire area has unity through the interrelationships of its landforms.

Each distinguishable landform may have one kind of soil or several. Climate, including its change over time, commonly will have been about the same throughout the extent of a minor landform. In addition, the kinds of vegetation associated with climate will likely have been fairly uniform. Relief varies within some limits that are characteristic of the landform. The time that the material has been subjected to soil formation will probably have been about the same throughout the landform. The surface of the landform may extend through one kind of parent material and into another. Of course, position on the landform may have influenced soil-water relationships, microclimate, and vegetation.

Just as different kinds of soil are commonly associated in a landscape, several landscapes are commonly associated in still larger areas. These areas cover thousands or tens of thousands of square kilometers. Many can be identified on photographs taken from satellites. From this vantage point, broad physiographic regions are apparent. Examples in the U.S. are the East Gulf Coastal Plain, the Appalachian Plateau, the Wyoming Basin, and the Great Plains. These broad units typically have some unity of landscape, as indicated by such terms as “plain,” “plateau,” and “mountain.” These physiographic units are composed of many kinds of soil.

The main relief features of a physiographic unit are commonly the joint products of deep-seated geologic forces and a complex set of surface processes that have acted over long spans of time. Within a physiographic unit, groups of minor landforms are shaped principally by climate-controlled processes. The climate and biological factors, however, vary much less within a geomorphic unit than across a continent.

Still broader than the geomorphic units are great morphogenetic regions that have distinctive climates. For example, one classification recognizes glacial, periglacial, arid, semiarid-subhumid, humid-temperate, and humid-tropical climatic regions associated with distinctive sets of geomorphic processes. Other major regions are characterized by seasonal climatic variation. These geomorphic-climatic regions are related to soil moisture and soil temperature regimes. Thus, the great climatic regions are divided into major physiographic units. Landscapes and associated landforms are small parts of these units and are commonly of relatively recent origin.

The landforms important in soil mapping may include constructional units, such as glacial moraines and stream terraces, and elements of local sequences of graded erosional and constructional land surfaces. These bear the imprint of local, base-level controls under climate-induced processes. Most surfaces that have formed within the last 10,000 years have been subject to climatic and base-level controls similar to those of the present. Older surfaces may retain the imprint of climatic conditions and related vegetation of the distant past. Most present-day landforms started to form during the Quaternary period; some started in the late Tertiary period. In many places, conditions of the past differed significantly from those of the present. Understanding climatic changes, both locally and worldwide, into the far past contributes to understanding the attributes of present-day landforms.

Geomorphic processes are important in mapping soils. Soil scientists need a working knowledge of local geomorphic relationships in areas where they map. They should also understand the interpretations of landforms and land surfaces made by geomorphologists. The intricate interrelationships of soil and landscape are best studied by collaboration between soil scientists and geomorphologists. Standards and protocols for describing landscapes and geomorphology are discussed in chapter 2.

Development of the Soil Survey in the U.S.

Soil surveys were authorized in the United States by the U.S. Department of Agriculture Appropriations Act for fiscal year 1896, which provided funds for an investigation "of the relation of soils to climate and organic life" and "of the texture and composition of soils in field and laboratory." In 1966, Congress expanded the scope of the Soil Survey Program and further clarified its intent in Public Law 89-560, the Soil Survey for Resource Planning and Development Act. This legislation recognized that soil surveys are needed by States and other public agencies to support community planning and resource development in order to protect and improve the quality of the environment, meet recreational needs, conserve land and water resources, and control and reduce pollution from sediment and other pollutants in areas of rapidly changing uses.

Many soil surveys have been initiated, completed, and published cooperatively by the U.S. Department of Agriculture, State agencies, and other Federal agencies. The total effort is the National Cooperative Soil Survey (NCSS). The NCSS is a nationwide partnership of Federal, regional, State, and local agencies and private entities and institutions. This partnership works to cooperatively investigate, inventory, document, classify, interpret, disseminate, and publish information about soils of the United States and its trust territories and commonwealths.

The following discussion highlights some of the important developments that helped shape the U.S. soil survey over its more than 100-year history.

1896 to 1920

In 1899, the U.S. Department of Agriculture completed field investigations and soil mapping of portions of Utah, Colorado, New Mexico, and Connecticut. Reports of these soil surveys and similar works were published by legislative directive. At the same time, the State of Maryland, using similar procedures and State funds, completed a soil survey of Cecil County.

The early soil surveys investigated the use of soils for farming, ranching, and forestry. Eventually, soil survey data began to be applied to other uses, such as highways, airfields, and residential and industrial developments. As more surveys were made and their use expanded, the knowledge about soils—their nature, occurrence, and behavior for defined uses and management—also increased. The Highway Department of Michigan was applying soil survey data and methods in planning highway construction in the late 1920s. At about the same time, soil surveys in North Dakota were being used in tax assessment.

1920 to 1950

Soil surveys published between 1920 and 1930 reveal a marked transition from earlier concepts that emphasized soil profiles and soils as independent bodies. The maps retained significant geologic boundaries as soil maps do today. Many of the surveys of that period provide excellent general maps for evaluating engineering properties of geologic material. In addition, maps and texts of the period show more recognition of other soil properties significant to farming and forestry than do earlier surveys and have value for broad generalizations about farming practices in large areas. To meet the needs of planning the management of individual fields and farms, greater precision of interpretation was required. The changing objectives of soil surveys initiated changes in methods and techniques that would make surveys more useful and forced scientists to reconsider the concept of soil itself.

Beginning in the 1930s, the Soil Conservation Service (SCS) emphasized the control of soil erosion as it used soil surveys for the resource conservation planning of farms and ranches. In the 1950s, soil survey information was used extensively in urban land development in Fairfax County, Virginia, and in the subdivision design of suburban areas of Chicago, Illinois. Soil surveys were an important base for resource information in regional land use planning in southeastern Wisconsin. Rural land zoning also relied on soil surveys.

Several other advancements contributed to the expansion and increased precision of soil survey. An early change was the use of aerial photographs as base maps in detailed soil mapping during the late 1930s and early 1940s. Aerial photos served not only as base maps that improved the surveyor’s ability to locate their positions in the field but also were used in stereo pairs to view the landscape in three dimensions.

The use of stereo pairs greatly enhanced the surveyor's ability to place soil boundaries correctly in relation to position on the landform.

Before 1950, the primary applications of soil surveys were farming, ranching, and forestry. Applications for highway planning were recognized in some States as early as the late 1920s, and soil interpretations were placed in field manuals for highway engineers of some States during the 1930s and 1940s. However, the changes in soil surveys during this period were mainly responses to the needs of farmers, ranchers, and forest managers.

1950 to 1970

During the 1950s and 1960s, nonfarm uses of the soil increased rapidly. This created a great need for information about the effects of soils on these nonfarm uses. Beginning around 1950, cooperative research with the Bureau of Public Roads and with State highway departments established a firm basis for applying soil surveys to road construction. The laboratories of many State highway departments assisted soil survey operations by characterizing soils for properties such as particle-size distribution, plasticity index, and liquid limit in order to determine their proper placement in engineering classification systems. Soil scientists, engineers, and others worked together to develop interpretations of soils for roads and other nonfarm uses. These interpretations, which have become standard parts of published soil surveys, require different information about soils. Some soil properties that are not important for plant growth are very important for building sites, sewage disposal systems, highways, pipelines, and recreational development. Because many of these uses of soil require very large capital investments per unit area, errors can be extremely costly. Consequently, the location of soil boundaries, the identification of the delineated areas, and the quantitative definition of map units have assumed great importance.

In 1966, the Soil Survey for Resource Planning and Development Act recognized the expanding role of soil survey in supporting efforts to protect and improve the environment. It led to increased efforts to provide technical assistance in the use of soil survey information for land use planning, conservation, and development activities.

1970 to 2000

The use of aerial photography in soil survey was further enhanced by the introduction of orthophotography for the base map in publications. Aerial photographs contain inherent cartographic distortion and are therefore not true to scale across all parts of the image. Orthophotographs are digitally rectified to correct the spatial relationship of locations on the photo. Therefore, they provide a cartographically accurate base map to which field-drawn boundaries can be transferred. This advancement, coupled with advances in computer technology, soon led to the proliferation of digitized soil surveys throughout the 1990s and early 2000s. These surveys became widely available for use in geographic information systems (GIS) and over the Internet. Combining soil survey data with other resource and cultural data layers in a GIS greatly enhanced the ways in which soil survey information could be used.

The adoption of Soil Taxonomy in 1975 as the official system for classifying soils in the U.S. (discussed above) had several important effects on soil survey. Through the use of quantitative class limits and diagnostic horizon definitions, all soil scientists, regardless of experience, were now able to classify soils correctly and consistently. Because of the need for data to properly classify the soil, the quality of field morphological descriptions was enhanced and efforts to obtain data measured in the laboratory increased. The use of Soil Taxonomy also improved the process of correlating soils from one soil survey project to another.

From the 1970s onward, much emphasis was devoted to the development of automated systems to store observations and manage data and interpretations, culminating in the National Soil Information System (NASIS). In addition, many soil surveys were digitized and made available electronically for use in geographic information systems. The development of digital soil information is discussed in greater detail in chapter 7.

In the mid-1970s, a new and important interest in soil survey emerged. The U.S Fish and Wildlife Service was charged with developing a wetland inventory of the United States. It partnered with the Soil Survey Division of the Soil Conservation Service to develop the concept and definition of "hydric soils" in support of the broader definition used to identify wetland areas for the inventory. Many established soil series were identified as likely to meet the definition of a hydric soil. The areas shown on soil survey maps that are composed of these soils were considered likely wetland areas for inclusion in the National Wetland Inventory. The soil survey became an important tool, along with other sources of hydrologic and vegetative information, for identifying wetlands for the inventory. A decade later, as a result of the Farm Bill passed by Congress in 1985, the demand for soil survey information increased further with the need to support the environmentally important "Swamp Buster" and "Sod Buster" provisions of the legislation. The soil survey maps and information were crucial for identifying hydric soil areas as well as areas considered to be "highly erodible." As a result, soil survey has been a major supporter of national efforts to protect and enhance the Nation's resources.

2000 and Onward

More recent efforts (since about 2000) to digitize all soil surveys and make them widely available through Internet access via the Web Soil Survey (Soil Survey Staff, 2016) have led to yet greater use of and demand for soil survey information for an ever wider group of users (see appendices). Now that users have electronic access to soil survey maps and information, the demand for hard-copy soil survey reports has decreased (see chapter 7 for a fuller discussion).

In addition to aerial photography, a wealth of multi-spectral data sources from airborne platforms and satellites have provided a wide range of remotely sensed information that can be used to infer the kinds and influence of soil-forming factors in digital soil mapping efforts (discussed in chapter 5). Noninvasive field tools, such as ground-penetrating radar, electromagnetic induction, portable X-ray fluorescence, and other proximal sensing technologies, also are being used to rapidly assess soil properties. These tools are discussed in greater detail in chapter 6.

A series of specialized interpretations have been developed for use by emergency response agencies. Soil information can be useful in providing rapid response to natural disasters and other civil emergencies. For example, it can be used to address oil spills or mass animal mortality in the agricultural sector (such as by avian flu) and the need to dispose of carcasses safely.

In the United States, after more than 100 years of soil survey work, nearly all of the Nation's lands have been surveyed. The emphasis is no longer on making soil surveys where none existed but on maintaining and modernizing existing soil surveys. Technology and standards have evolved, and the kinds of information needed have changed. In addition, there remains an ongoing effort to better coordinate and join the individual soil surveys over large areas. The NCSS program is focused upon completing soil surveys for the few remaining unmapped areas and coordinating and updating existing soil surveys through correlation activities and data collection. It provides a cadre of trained soil scientists to assist soil survey users with the application of soil survey information for land resource management. The four fundamental goals guiding the NCSS program are: (1) completing the inventory of soils in the United States, (2) keeping the inventory current, (3) providing interpretive information about the soils, and (4) providing access to and promoting use of soil information. The NCSS motto is "Helping people understand soils."

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- **Regulating water**
  Soil helps control where rain, snowmelt, and irrigation water goes. Water flows over the land or into and through the soil.
- **Sustaining plant and animal life**
  The diversity and productivity of living things depends on soil.

- **Filtering and buffering potential pollutants**
  The minerals and microbes in soil are responsible for filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including industrial and municipal by-products and atmospheric deposits.
- **Cycling nutrients**
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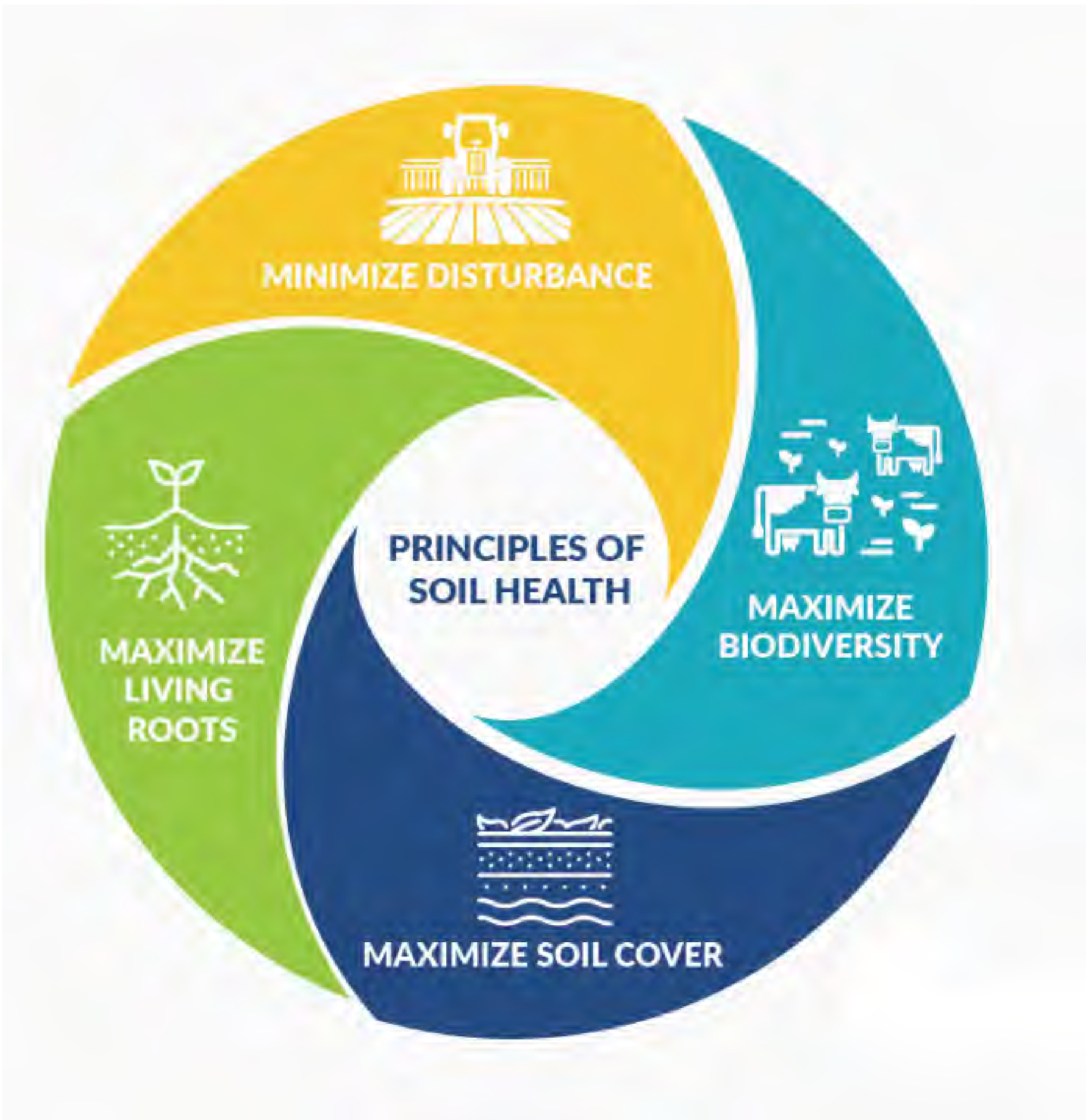

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- **Maximize Presence of Living Roots** (#roots)

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- **Maximize Soil Cover** (#cover)
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As world population and food production demands rise, keeping our soil healthy and productive is of paramount importance. By farming using soil health principles and systems that include no-till, cover cropping, and diverse rotations, more and more farmers are increasing their soil's organic matter and improving microbial activity. As a result, farmers are sequestering more carbon, increasing water infiltration, improving wildlife and pollinator habitat—all while harvesting better profits and often better yields.

The Four Principles of a Soil Health Management System

Implementing Soil Health Management Systems can lead to increased organic matter, more diverse soil organisms, reduced soil compaction and improved nutrient storage and cycling. As an added bonus, fully functioning, healthy soils absorb and retain more water, making them less susceptible to runoff and erosion. This means more water will be available for crops when they need it.

Soil Health Management Systems allow farmers to enjoy profits over time because they spend less on fuel and energy while benefiting from less variable crop yields resulting from improved soil conditions. Healthy soils also provide a buffer for precipitation extremes (too wet or too dry).

Maximize Presence of Living Roots

Living plants maintain a rhizosphere, an area of concentrated microbial activity close to the root. The rhizosphere is the most active part of the soil ecosystem because it is where the most readily available food is, and where peak nutrient and water cycling occurs. Microbial food is exuded by plant roots to attract and feed microbes that provide nutrients (and other compounds) to the plant at the root-soil interface where the plants can take them up. Since living roots provide the easiest source of food for soil microbes, growing long-season crops or a cover crop following a short-season crop, feeds the foundation species of the soil food web as much as possible during the growing season.

Healthy soil is dependent upon how well the soil food web is fed. Providing plenty of easily accessible food to soil microbes helps them cycle nutrients that plants need to grow. Sugars from living plant roots, recently dead plant roots, crop residues, and soil organic matter all feed the many and varied members of the soil food web.

Minimize Disturbance

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The benefits of reduced till/no-till include:

- **Aiding in Plant Growth** – Soils managed with reduced/no-till for several years contain more organic matter and moisture for plant use. Healthy soils cycle crop nutrients, support root growth, absorb water and sequester carbon more efficiently.
- **Reducing Soil Erosion** – Soil that is covered year-round is much less susceptible to erosion from wind and water. For cropping systems, practices like no-till keep soil undisturbed from harvest to planting.
- **Saving Money** – Farmers can save money on fuel and labor by decreasing tillage. Improving nutrient cycling allows farmers to potentially reduce the amount of supplemental nutrients required to maintain yields, further reducing input costs.
- **Providing Wildlife Habitat** – Crop residue, grass and cover crops provide food and escape for wildlife.

Soil can also be disturbed through production inputs or improperly managed grazing practices. Inputs are not applied properly could potentially disrupt the delicate relationship between plants and soil organisms. Soil Health Management Systems help minimize potential disturbance, while maximizing nutrient cycling, which can lead to greater profitability for producers.

Improperly managed grazing can also harm the soil health system. There are several ways to graze livestock to reduce environmental impacts. For example, implementing a rotational grazing system instead of allowing livestock to continuously graze pasture allows pasture plants to rest and regrow.

Maximize Soil Cover

Soil cover can be maximized by planting cover crops, annual crops, and perennial crops and leaving crop residues and living mulches on the ground. Soil health practices that maintain cover year-round improve soil health and protect soil from wind and water erosion.
Cover crops can be an integral part of a cropping system and provide soil cover during fallow seasons. Cover crops can be managed to improve soil health, as they help to develop an environment that sustains and nourishes plants, soil microbes and beneficial insects. The introduction of cover crops into your crop rotation can benefit any sized farm from a corn/soybean farm encompassing thousands of acres to a small urban farm.

Cover crops are typically planted in late summer or fall around harvest and before spring planting of the following year's crops. Examples of cover crops include rye, wheat, oats, clovers and other legumes, turnips, radishes, and triticale. Planting several cover crop species together in a mixture can increase their impact on soil health. Each cover crop provides its own set of benefits, so it's important to choose the right cover crop mixture to meet management goals.
The benefits of planting cover crops in between cash crop season include:

- **Restoring Soil Health** – Cover crops help increase organic matter in the soil and improve overall soil health by adding living roots to the soil during more months of the year. Cover crops can improve water infiltration into the soil. Deep rooted crops like forage radishes create natural water passages. Legume cover crops serve as natural fertilizers while grasses scavenge nutrients that are often lost after harvest or during winter.

- **Natural Resource Protection** – Along with crop residue above ground, cover crops protect the soil against erosive heavy rains and strong winds. Cover crops trap excess nitrogen, keeping it from leaching into groundwater or running off into surface water – releasing it later to feed growing crops.
- **Livestock Feed** – Cover crops can provide livestock producers with additional grazing or haying opportunities.
- **Wildlife Habitat** – Cover crops provide winter food and cover for birds and other wildlife. During the growing season, they can provide food for pollinators.

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For Soil Health Management Systems, biodiversity can be increased through a variety of approaches including: plant diversity through the use of diversified crop rotations, cover crop mixes, proper integration of grazing animals (e.g. livestock) into the system and includes animals living within the soils or microbial diversity, as well as direct additions with biological amendments. All four soil health management principles contribute to biodiversity.

Biodiversity helps to prevent disease and pest problems associated with monocultures. Using cover crops and increasing diversity within crop rotations improves soil health and soil function, reduces costs, and increases profitability. Diversity above ground improves diversity below ground, which helps create healthy productive soils.

Lack of biodiversity severely limits the potential of any cropping system and increases disease and pest problems. Biodiversity is ultimately the key to the success of any agricultural system. A diverse and fully functioning soil food web provides for nutrient, energy, and water cycling that allows a soil to express its full potential.

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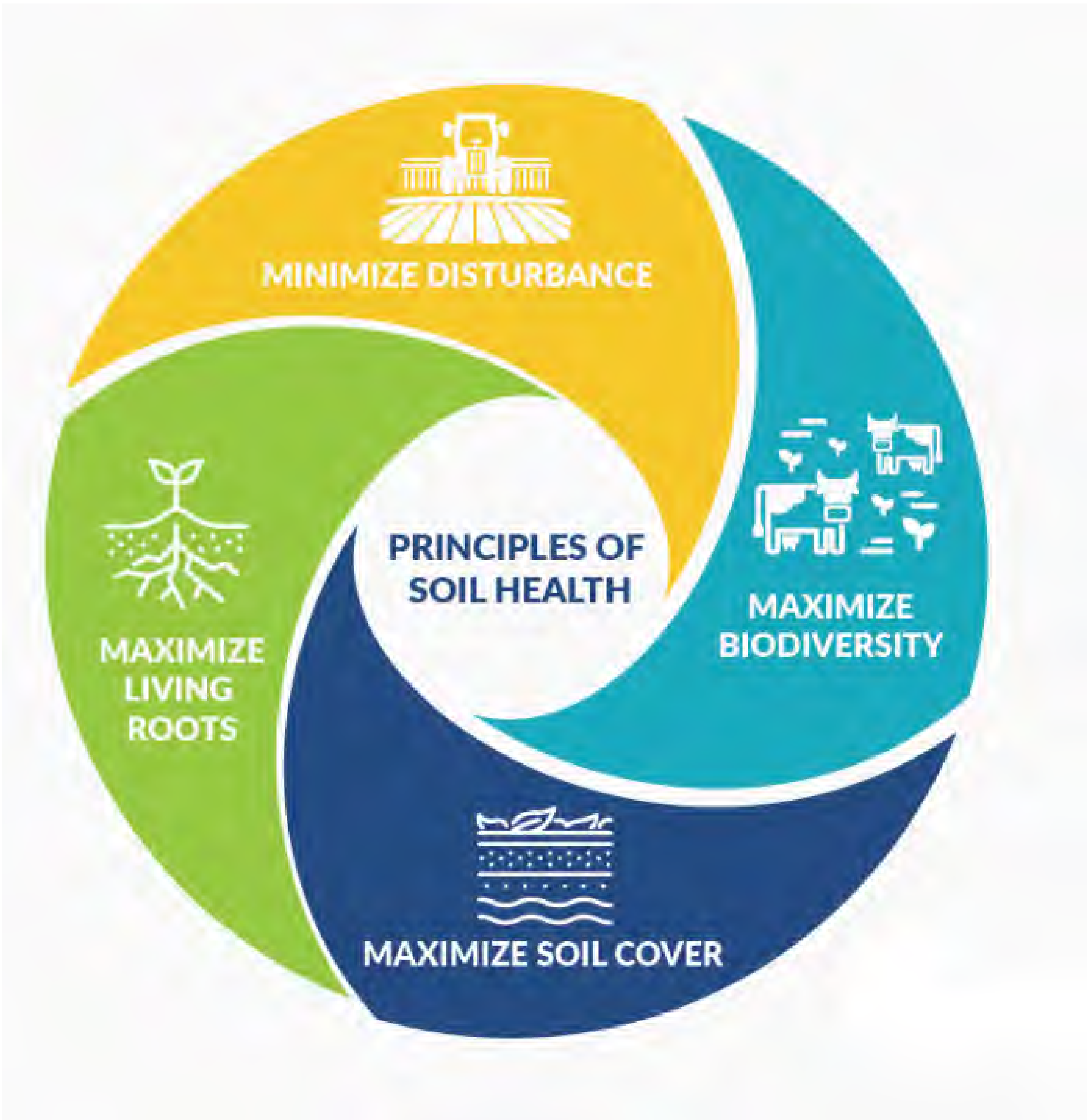

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CHAPTER 9

Assessing Dynamic Soil Properties and Soil Change

By Skye Wills, Candiss Williams, and Cathy Seybold, USDA-NRCS.

Dynamic soil properties (DSPs) are properties that change with land use, management, and disturbance over the human time scale (decades to centuries). In contrast, inherent soil properties (e.g., soil texture) change little, if at all, with changes in land use and management. The term "dynamic soil properties" was used by Tugel et al. (2005) to describe soil properties that can be documented as a part of soil survey activities. The procedures for measuring and recording DSPs were later outlined in the *Soil Change Guide* (Tugel et al., 2008). The term DSPs has gained common usage among soil scientists when referring to properties that can be changed intentionally or inadvertently through human land use and management, either directly (as through tillage) or indirectly (as through causing acid rain). While many soil properties (such as moisture, temperature, and respiration) are dynamic on daily, or smaller, time scales, information about them is not included in current soil survey products. The DSPs addressed by soil survey include properties that reflect soil functions and can serve as indicators of soil quality (or health) or indicators of ecosystem services. Dynamic soil properties are more pronounced at or near the soil surface and can be used to evaluate changes and departure from a benchmark or set of reference soil properties. Conceptually, this allows DSPs to be correlated with map unit components used in traditional soil survey (see chapter 4).

Importance of DSPs

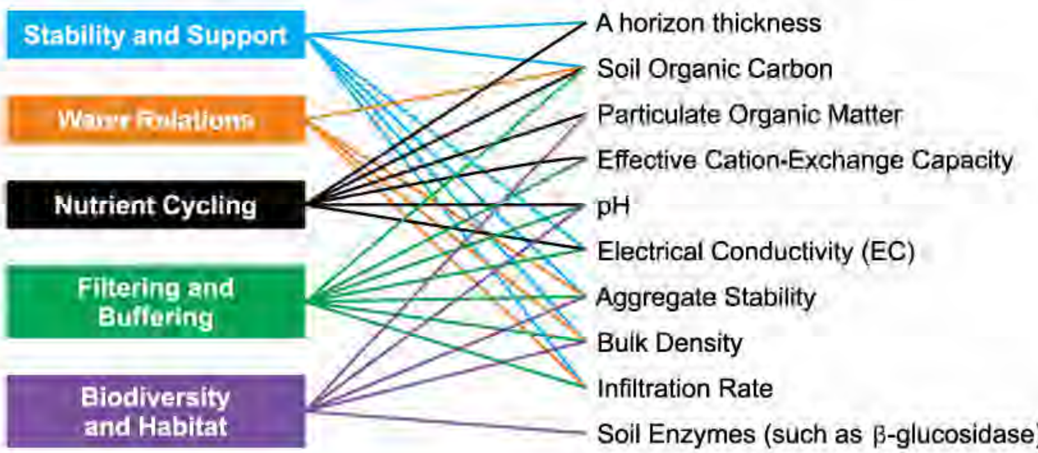
Many land and water conservation programs in the U.S. depend upon management of dynamic soil properties. Proven conservation practices are used to maintain the soil's productivity, health, and long-term sustainability. Conservation planning relies on the knowledge of the current state of the soil resource and what is achievable through conservation practices. DSP assessments provide a range of potential soil property values that define what is achievable.

DSP data is used to document, explain, and predict the effects of land use and management on soil and ecosystem functions. It is collected in a way that documents both soil properties and classifications along with information on land use and management, then stored in an organized database. Information about past and current land use and management can be used to explain current soil properties. It can also be used, through inference or modeling, to predict future soil properties and functions.

Soil function is a way of describing the role of soil in the environment and has been used to define the concept of soil quality and soil health. Essential soil functions include nutrient cycling, water storage and release, biodiversity and habitat, filtering and buffering, and physical stability and support (simplified from Mausbach and Seybold, 1998). Soil stores and moderates the cycling of nutrients and other elements. It regulates the drainage, flow, and storage of water and solutes (N, P, and pesticides). It supports biodiversity and habitat and promotes the growth of plants, animals, and microorganisms. It serves as a filter and buffer for toxic compounds and excessive nutrients and protects the quality of water, air, and other resources. It provides physical stability and support, allowing the passage of air and water through its porous structure, serving as a medium for plant roots, and providing an anchoring support for human structures. While many soil functions are complex and difficult to measure, some key soil properties can be considered indicators of specific soil functions (fig. 9-1) (Doran et al., 1996; Karlen and Stott, 1994; Mausbach and Seybold, 1998). These indicator properties are the focus of soil survey DSP collection.

The framework of soil survey offers an opportunity to collect and disseminate information about how DSPs (and the soil functions they support) change with vegetation, land use, and management across space and time (Wills et al., 2016). DSP data, such as bulk density values under various grazing schemes, enhances soil survey information by providing soil property potentials under various land use and management scenarios. By combining DSP information with spatially linked soil survey information (e.g., soil map unit components), soil survey provides spatial context (maps, areas affected, etc.) to land users, researchers, and decision makers regarding the expected impacts of changes in land use and management. Soil property and function potentials along with collated DSP datasets provide greater specificity of soil interpretations, target values for soil quality and health assessment, guidelines for indicator monitoring, and data for calibration and validation of resource modeling.

Figure 9-1



Relationship between soil functions and some dynamic soil properties (modified from Tugel et al., 2008).

How to Collect DSPs for Soil Survey

DSP projects organize data collection and analysis around specific soils, soil groups, and land management systems. The scope, specificity, and replication of each DSP project depend on the goals for that project. The overarching goal of data collection in a DSP project is to document the range and central tendencies of DSPs for a given set of soils and land management conditions (such as reference and degraded states or best and typical crop management practices). The project should provide information about typical and potential DSP values for soil map unit components and ecological site descriptions. With adequate replication, these projects can be conducted as soil change comparison studies (Tugel et al., 2008) in which alternate conditions are used in a space-for-time substitution framework to make inferences about how soils have changed over time under specific management scenarios. In this approach, all places with the same soil (or group of soils) are assumed to have had the same properties at time zero (i.e., before the specific land management practices were applied). The assumption is that any differences observed are due to management and not inherent spatial variability. Multi-scale replication limits the influence of any spatial variability observed when making conclusions about soil change. DSP projects may also seek to document baseline conditions (such as ecological site reference conditions), best and worst case management scenarios, or alternate conditions of interest.

DSP information for soil survey must be collected, organized, and used in a way consistent with the soil survey protocols and standards used for inherent properties. Data collection for soil survey can be characterized in two ways: dispersed and project based. *Dispersed* DSP data collection refers to the integration of DSP data collection with other routine soil survey project operations. As a result, DSP and land management information is documented throughout a wide range of soil survey activities. Efforts are not concentrated on any single land use or management system but are dispersed throughout all situations in which the soil occurs. In contrast, *project-based* DSP data collection is designed to intensively evaluate specific land management conditions. The most robust DSP data collection includes both approaches and so provides both spatial and land management representation (from dispersed efforts) and detailed comparisons of management scenarios in specific soil landscapes (from project-based efforts). DSP data can be used to evaluate the soil data representativeness (across land use and management systems) and assess spatial variability.

The goal of dispersed DSP collection is to build on other soil survey activities and increase the general knowledge of DSPs across all soils and land management conditions. In this context, "land management condition" is a general term that captures a range of possible situations, including ecological states and vegetative communities, land use, and specific crop and pasture management systems. Advantages of dispersed data collection are that it requires little additional resources and provides information on a wide range of soils and conditions to managers, modelers, and policy makers. Analysis of this data can be used to group soils and land management conditions for further evaluation through DSP projects. It can also be used to validate summaries and predictions made from completed projects.

Dispersed DSP Data Collection

At the location of each observation, it is important to record, at minimum, information on the site, pedon, and land management condition and practice. This data includes any known information about general land use, ecological state, type and amount of vegetation, and cropping systems; e.g., tillage, crop rotation, and pesticide or fertilizer applications. Additional soil properties may be assessed on samples near the soil surface, e.g., enzyme activity and aggregate stability. Procedures and terminology for recording this information should be standardized. Robust soil information systems include data elements related to indicators of soil function and land use and management condition.

Project-Based DSP Data Collection

Project-based DSP data collection requires thorough planning and typically is the most intense type of data collection. The type of project determines how data collection will proceed. Projects can be planned to meet multiple project goals. Site and pedon replication should be planned to meet all project goals on the smallest unit of soil and land management condition targeted. It is helpful if all stakeholders of the project (those who will collect and use the information) can meet to determine the DSP project goal(s) and the target soil(s) and condition(s).

Determining DSP Project Goals

Project goals vary depending on the kind of project. Three kinds of projects are described below and examples are given for each.

DSP range study.—The goal of this kind of project is to evaluate the entire range of values for DSP properties and so provide soil component information regardless of land management or use. A single soil or group of closely related soils is selected. Land management conditions are not closely controlled (i.e., not specifically targeted in sampling) but should be well documented. This type of project requires the least amount of replication. Therefore, while results apply across the area of interest (soil group), the data typically is not sufficient for statistical comparisons between land management conditions.

> Example: The soil of interest occurs in an area used for rangeland, pastureland, and cropland. A DSP range study would sample a range of management systems across all three land uses, including those that are expected to have the smallest and highest DSP values.

> Example: A Midwestern U.S. State wanted to know typical values of DSPs across a region. For 2 years, all projects included sampling for DSPs as well as documentation of land use and management information for at least one pedon. The data provided a general idea of relative conditions across the region. There were no pairs or replications that could be used to make statistical comparisons because this was not the purpose of the project.

DSP baseline or reference study.—The goal of this kind of project is to establish baseline or reference DSP levels for a limited number of reference or land management conditions. The baselines can be used to interpret onsite assessments of soil health as a starting point for modeling or monitoring projects. Results apply across an area (a soil or group of soils) and the land management conditions of interest. Extrapolation beyond these conditions requires expert knowledge and depends on the extent and representativeness of the selected land management conditions. This type of project requires an intermediate level of replication across target soils and land management conditions.

> Example: Kirkland soil has particularly high soil function in a grazed native prairie with occasional fire (this is the reference condition of its ecological site). A reference DSP study would target this condition, and future evaluations and assessments could be compared to the baseline, or reference, levels.

DSP soil change study.—The goal of this kind of project is to assess soil change using the technique of space-for-time substitution. Instead of evaluating the effects of a management system in one location over an extended period of time, this technique compares two different locations that have had different management systems over the same period of time. It assumes that soil properties at the two locations were the same before the management system was applied. Typically, this type of study also serves as a baseline or reference study for a soil or soil group. In addition, soil change studies require the careful selection of land use and management conditions that represent a reference state and an alternative state. Robust multi-scale replication is required to make statistical conclusions about the soil change caused by land management. Pickett (1989) gives the theoretical background of space-for-time substitution, and Tugel et al. (2008) discuss the implementation of this technique in soil survey.

> Example: A group of soil scientists in Michigan wanted to investigate dynamic soil properties under two types of wetland restoration. They determined that they needed to conduct a DSP soil change study that included a baseline or reference state (in this case an undisturbed reference wetland) and alternative land use conditions with a multi-scale sampling scheme to capture variability within individual wetlands and across the project area.

Determining the Target Soils and Conditions

Studies can be designed to target soils, ecological sites, or land management conditions.

Soils or ecological sites.—Targeting a specific soil(s) or ecological site(s) will determine the extent of the DSP project, where samples and observations might be collected, and where the results should be applied. Approaches for targeting soils include single soil unit, soil system, and ecological site.

Single soil unit.—The smallest unit of the study interest is a map unit component represented by a soil series. Benchmark soils that are representative of other soils in the area and/or represent important resource concerns and ecological processes are selected.

> Example: In an area of Michigan, the organic wetland soil Houghton is the most common soil in restored wetlands. The Adrian soil is very similar taxonomically and occurs in the same landscape positions. Both soils were therefore considered target soils for sampling and comparisons.

Soil system.—A study of a soil system segments the landscape and evaluates appropriate hierarchies in a soil system or catena. Soil components that represent similar portions of the landscape and/or respond similarly to land use and management conditions can be combined for sampling purposes.

> Example: In Renville County, Minnesota, the soil landscape was segmented into three parts based on topography, hydrology, and the reflected taxonomic classes (fig. 9-2). One individual soil component was chosen to represent each of the three groups.

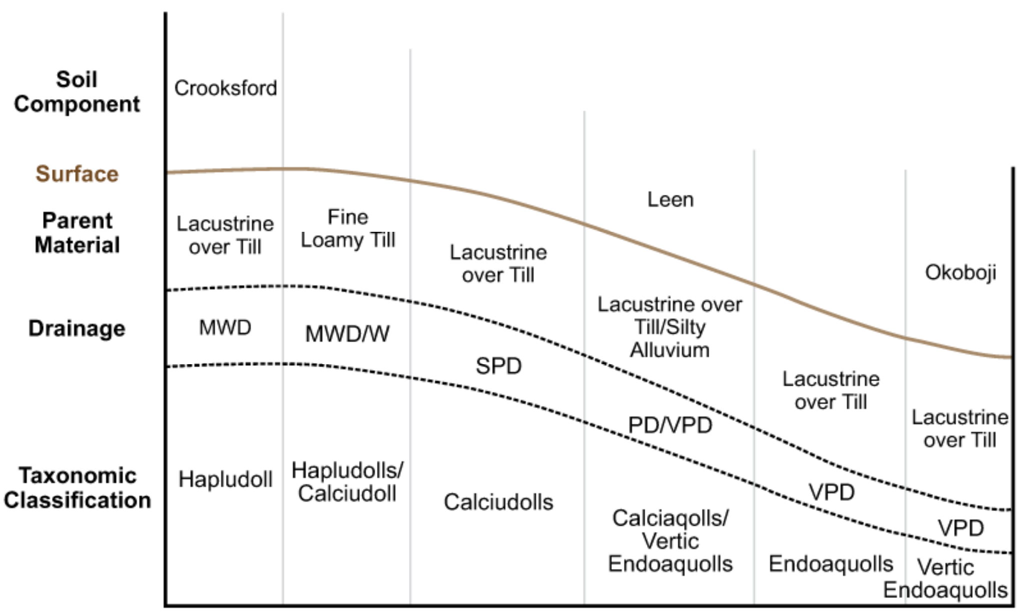
Ecological site.—The study of an ecological site groups soil components into units that are meaningful for ecological processes and land management.

Land management conditions (for reference, baseline, or comparison).—The land management conditions are selected according to the soil and type of project and can include general land cover classes (e.g., rangeland or cropland) or specific management systems (e.g., 3-year burn cycle with moderate grazing or no-till corn with cover crops). For each project, a similar level of variability within the specified land management conditions needs to be maintained. For example, comparing forested conditions within a reference state to a specific cropland management system may be more appropriate than comparing all forested conditions under a specific management system. When trying to document soil change, the chosen conceptual model should partition soil change into discrete frames of reference, conditions that can be put into separate categories (Starfield et al., 1993) and that can be sampled at separate physical locations (using the space-for-time technique). The *Soil Change Guide* (Tugel et al., 2008) recommends using common models of soil disturbance and erosion, such as STIR, RUSLE2, and SCI (Foster, 2005; Hubbs et al., 2002; USDA-NRCS, 2003, 2006). Wills et al. (2016) outlined a potential framework for grouping management systems by primary production groups and types and amount of disturbance.

Example: A DSP planning team in Michigan determined that in order to meet their goals a baseline reference wetland needed to be sampled and documented in addition to two general types of wetland restoration and typical agricultural production.

Example: In Dodge County, Nebraska, two agricultural management systems were chosen as the target conditions. The reference condition was the highest functioning agricultural land use.

Figure 9-2



A generalized cross-section of a soil landscape near Olivia, Minnesota. A DSP project was designed to capture the effect of land use change on the soil system. Crooksford components represented relatively well drained Hapludolls, Leen components represented Calciudolls and Calciaquolls on depression rims, and Okoboji components represented Endoaquolls in depressions and lake plains. (Drainage class abbreviations: MDW—moderately well drained, W—well drained, SPD—somewhat poorly drained, PD—poorly drained, and VPD—very poorly drained.)

Data Collection Plan

A written plan serves as both a tool for organizing work and a record of how the project was conducted for future data use.

Formalizing Project Objectives

Planning decisions are recorded. The project goals and the geographic and conditional constraints are clearly defined. This information includes identification of which soils and land management conditions will or will not be acceptable for sampling.

Gathering Existing Data

Relevant data in soil survey and laboratory databases can be located by querying for the target soil taxa or spatial joins or by other means. Relevant information may also be located in journal publications, extension publications, or graduate student work through nearby universities, colleges, or other groups.

Additional Data Collection

All DSP projects need to include a protocol for data collection across multiple scales. Sites (independent locations commonly sampled as plots) should capture the full range of soils and land management conditions of interest. Within each site, a minimum of three pedons should be located in a standard layout or in a random fashion. Methods, field forms, and equipment for field data collection are discussed in appendix 3 of the *Soil Change Guide* (Tugel et al., 2008). All information should be provided as general metadata about how the project was designed and executed.

Determining Sources, Types, and Amount of Variability

Expert knowledge of the system and existing data are used to identify sources of variability. Tools such as the Multi-Scale Sampling Requirement Evaluation Tool (Tugel et al., 2008) can be used, or estimates can be made for the number of sites (independent location) and pedons per site needed to meet project objectives.

Designing a Sampling Scheme

The best arrangement of pedons within sites can be determined using the information about expected variability. The sampling scheme should include multiple sites or locations across the spatial extent of the study. The design should not under- or over-represent landscapes (e.g., hummocks or depressions) or microfeatures (e.g., trails or tree-throw) within a site. Figure 9-3 shows a sampling scheme.

Locating Sites for Data Collection

Field sites should represent both the central concept and the typical range of properties for the target soil and land management conditions. Care is needed to avoid bias in location selection. GIS techniques, such as conditioned Latin hypercube sampling, or other statistical sampling techniques can be used. Alternate locations should be chosen in case a site cannot be accessed or must be rejected. Brungard and Johanson (2015) describe a rigorous plan for substitution.

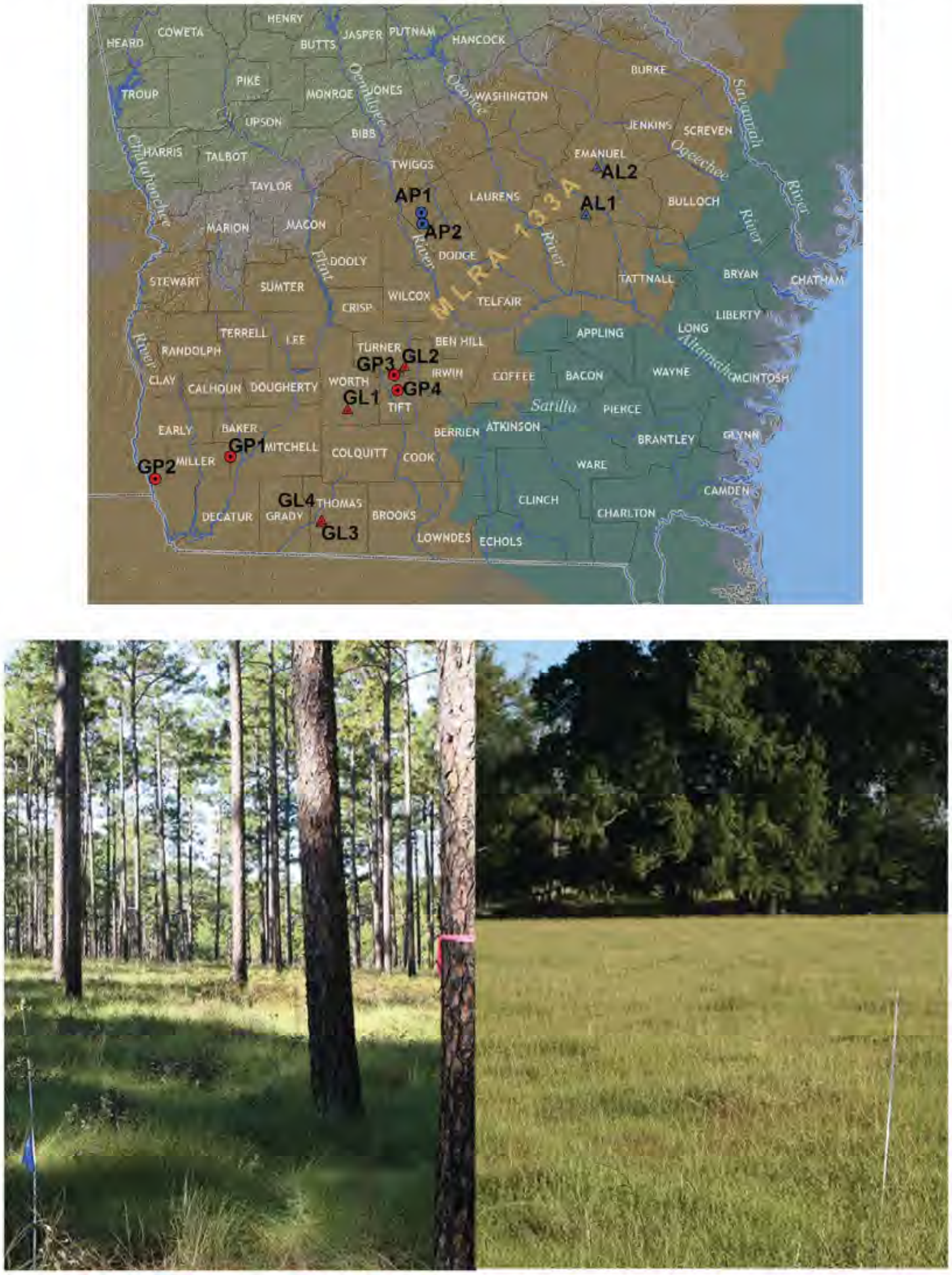
Developing data collection and sampling plan.—The protocols and procedures for DSP project sampling need to be planned. The data elements and terminology used must be compatible with the soil system. The top image in figure 9-3 shows how sites can be distributed across a region. Figure 9-4 shows pedon distribution within a paired site in Dodge County, Nebraska. In this project, sites were located as pairs (with both target land management conditions present) to limit soil variability and improve condition comparisons.

Guidelines for accepting or rejecting a site for sampling.—For most soil survey applications, soils and conditions should be verified in the field to ensure that sampling will meet project objectives. Guidelines should outline the ranges of soils, features, and land management conditions that are acceptable for inclusion in the project.

List of data elements for site information.—Management and vegetation data are typically collected at the site scale. All data elements to be measured or recorded at each site (location or plot) should be identified. They may include vegetative cover, residue, site index, or other metrics of vegetation or management. Common collection schemes for ecological site data in the project area can be used as a starting point. Table 9-1 is an example of elements that might be collected at each site, location, or plot.

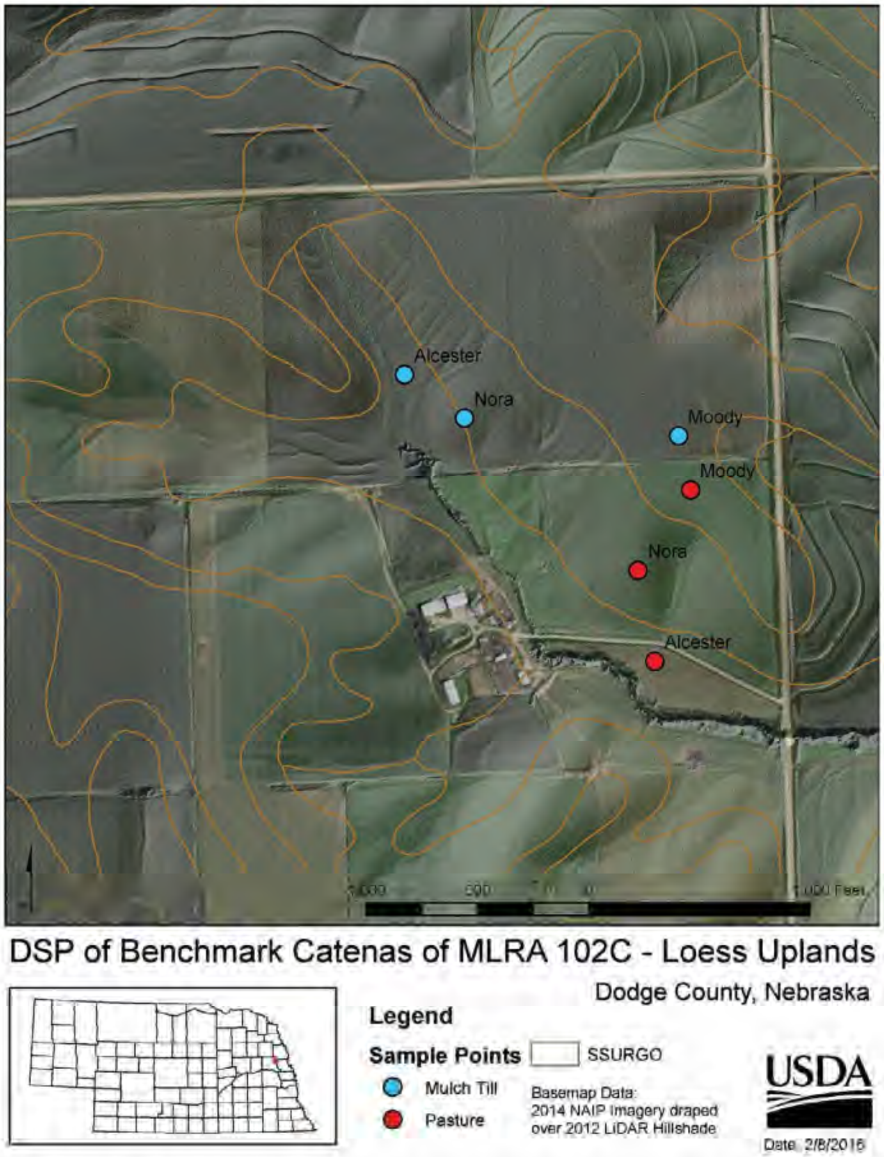
Instructions for locating individual pedons and measurements.—A clear plan is needed to explain how pedons will be located within each site as well as where and how any associated surface properties will be measured. It may include a standard plot layout (fig. 9-5), randomly positioned pedons within a plot area, or transects (fig. 9-4) with pedons positioned at regular intervals along a catena contour. A plan for measuring infiltration, hydraulic conductivity, and surface features (such as residue, pattern class, and soil crust) before pedons are disturbed improves data integrity.

Figure 9-3



Documentation from the Georgia Longleaf Pine Dynamic Soil Property project (unpublished data). Care was taken to include both target land use conditions across the study area. Top: Distribution of plots across the major land resource area (MLRA) 133A. Plots were labeled to designate them as being on the A (Atlantic) or G (Gulf) side of the region and as P (pasture) or L (longleaf pine). Bottom left: A longleaf pine plot. Bottom right: A pasture plot with a transect tape (for vegetative cover measures). County names and boundaries are shown on the map. (Photo courtesy of Dan Wallace)

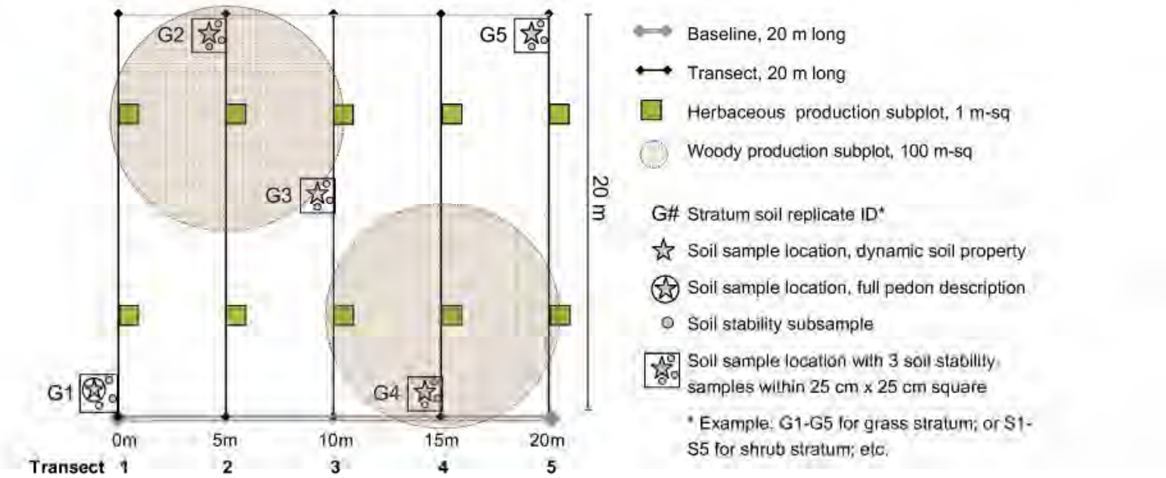
Figure 9-4



Example of pedon placement for a paired site in Dodge County, Nebraska. Each site has both target land management conditions (pasture and corn-soybeans with mulch tillage). The soil system was captured with three target soils. The central pedon location is represented on the map and labeled with the soil name. Two additional satellite pedons located along the contour are not shown on the map.

Instructions for pedon sampling and description.—Descriptions of pedons to a predetermined depth should follow standard procedures (see page 8-2 of Schoeneberger et al., 2012). It is suggested that one pedon per site be observed, one pedon per condition be sampled to a depth necessary for soil series confirmation, and detailed high-quality information, such as bulk density and water retention analysis, be collected for those pedons (table 9-2).

Figure 9-5



Instructions: The baseline should be positioned obliquely to the slope and 5 transects should be positioned at approximately 90° from the baseline parallel to one another. The individual placing the flags will fill out the “Sample Locations and ID” portion of the “Plot Master” field form while identifying and flagging the soil sample locations. The flags will be pre-labeled with the Stratum-soil replicate ID (e.g., G1-G5). At each soil sample location, stability samples, penetrometer readings, bulk density samples, and soil samples for laboratory analysis will be collected. Line-point intercept and GAP will be completed 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 1 Pedoderm and Pattern Classes form for each plot (Tugel et al., 2008).

Example of detailed plot sampling instructions for a rangeland DSP project in Utah. Because the project involved both soil scientists and range scientists, a highly detailed plan was developed for sampling. From the Soil Change Guide *(Tugel et al., 2008).*

Table 9-1

DSP Project Data Elements Collected at Site (Across Plot) Scales

Type of data	Property/measurement
Management information	Crop rotation
	Tillage system
	General description
	Tillage operations (frequency and timing)
	Applications and other operations and treatments
	Grazing management
	Forestry management

Type of data	Property/measurement
Vegetation information (as appropriate)	Plant biomass or production
	Composition
	Understory
	Overstory
	Line-point intercept
	Canopy and basal gap
	Site index
Forest floor (when present in any part of study)	Woody debris
	Visual disturbance classes*
	Soil surface displacement, compaction, litter thickness, crust cover, etc.
Surface properties	Residue cover/bare soil
	Pedoderm and pattern class+

* Page-Dumroese et al., 2012
\+ Burkett et al., 2011

Table 9-2

DSP Project Data Elements Collected at Pedons; Multiple Locations per Site/Plot

Type of data	Property/measurement
Surface properties	Aggregate or soil stability
	Infiltration
	Single ring
	Double ring
	Crust description (when present)
	Pedoderm and pattern class
	Relevant microtopography
	Soil surface temperature
	Cover/bare soil
Pedon properties	Pedon description
	Horizon depths, colors, textures, fragment estimates

Table 9-2.—continued	
Type of data	**Property/measurement**
Pedon properties	Agronomic feature (furrow, wheel-track, etc. at pedon location)
	Soil horizon/depth increment
	Temperature
	Cover/bare soil
	Saturated hydraulic conductivity

Instructions for sample collection.—Collecting a sample from a predetermined depth (e.g., 0–5 cm) near the surface helps in making comparisons between conditions. The kind of near surface horizon of the sample should be noted (see chapter 3). This sample can be treated as a subsample of the first horizon or described as a separate horizon. All other samples should be collected by genetic horizon to capture the most variability within the profile and allow comparisons between horizons. Because many DSPs are sensitive to disturbance, walking or using heavy equipment on sampling areas should be avoided. A plan for labeling samples is needed to keep track of soil, condition, site, and pedon replication as well as information on horizons and layers.

Instructions for sample handling.—Many of the properties measured in DSP studies are the same as those measured in standard soil survey procedures. The emphasis is on targeting, tracking, and replicating certain conditions. However, some measures are of particular interest for DSP sampling, such as bulk density, aggregate stability, and soil biology measures (e.g., enzyme activity). The samples should be handled carefully and not exposed to crushing or warming. Samples should be air dried as soon as possible if they are to be shipped and/or stored for more than 24 hours.

Desired minimal dataset for laboratory samples.—The dataset should have information on standard inherent properties to allow for correlation and comparisons between soils and sites. It may include standard pedon description information (such as horizon thickness, texture, and coarse fragments) and laboratory data (such as particle-size determination). At minimum, the DSP dataset should include carbon (organic and inorganic), pH, EC, bulk density, aggregate stability, biological enzymes (β-glucosidase is recommended), particulate organic matter, and nutrients (N, P, K, etc., as appropriate). Table 9-3 provides a potential list of properties to measure. The Kellogg Soil Survey Laboratory currently analyzes standard interpretive and dynamic properties.

Table 9-3

Measurements of Dynamic Soil Properties on Individual Samples

Type	Property/measurement
Standard interpretive	Standard laboratory characterization
	Particle-size determination
	Other properties *in lieu* of particle size
	Minerology (clay or other as appropriate)
	CEC
Standard dynamic	Organic carbon
	Derived from total and inorganic carbon
	Inorganic carbon
	Derived from calcium carbonate equivalent
	pH
	EC
	Bulk density
	Aggregate stability
	Water stable aggregates
	Total N
	P (Mehlich or other as appropriate)
	Water retention
	Extractable bases
	Extractable acidity
	ECEC
	Permanganate extractable carbon (POX-C or Active C)
	Soil enzymes
	β-glucosidase
	Particulate organic matter (POM)
Supplemental as needed and available	SAR
	Plant available P
	Dry sieve aggregates
	Potentially mineralizable N

Table 9-3.—continued	
Type	**Property/measurement**
Field lab	pH
	Active C (kit for permanganate extractable C)
	Aggregate stability
	Advanced soil structure and pore analysis
	CO_2 burst and respiration tests

Analyzing Dynamic Soil Property Data

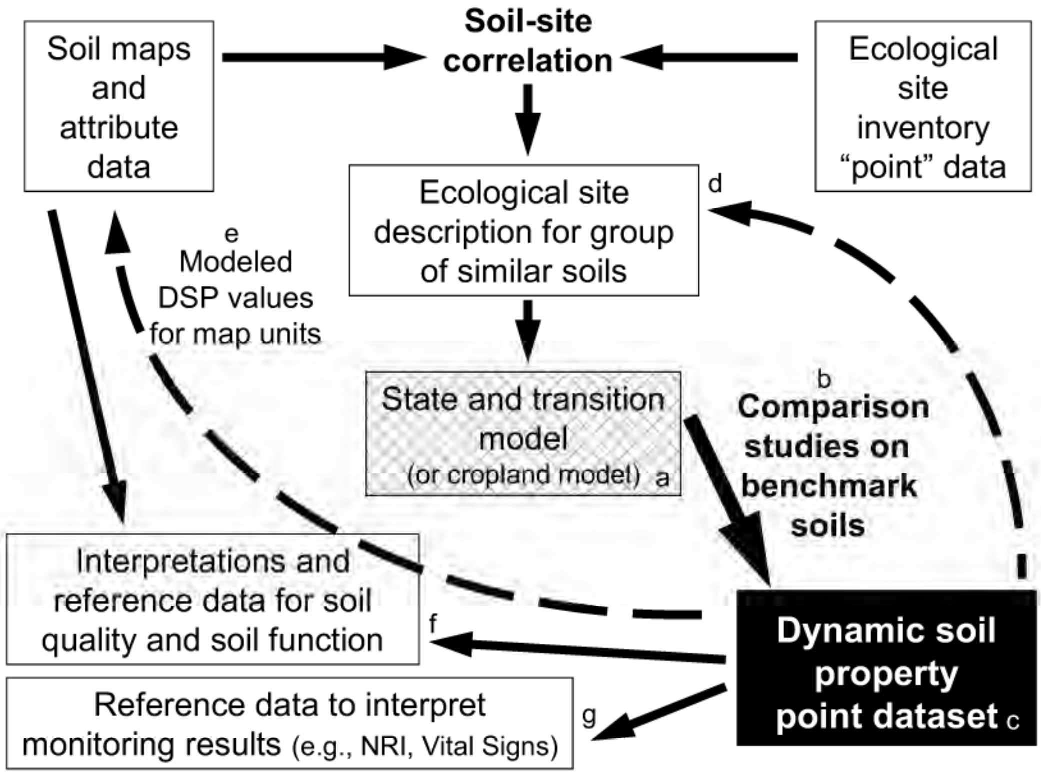
DSP data can be used for many purposes, some directly related to soil survey and many others that are indirectly related (fig. 9-6). The first and most long-lasting outcome of a DSP project is the collection and documentation of soil and vegetation data under various land use and management scenarios. This is an immediate product that can serve as input for many other products, such as conservation effects modeling and general geospatial analysis.

Initial steps for DSP data analysis are the same as those for any aggregation of soil survey data. The data compilation is complicated by replication across sites and pedons. Good recordkeeping and labeling throughout the process help ensure reliable results. To allow for improvement over time, all data aggregation should be documented through written records, program scripts, and public databases. The following outline describes several important steps and considerations in analyzing DSP data.

DSP Data Handling

1. **Maintain the project's data collection plan.** The data collection plan serves as the metadata for the project and will explain to future data users how and why the data was collected.
2. **Enter and check data for errors.** Enter data into required programs and databases and examine it for errors. This data includes information about the sites, pedons, samples collected, and land management systems. Some information (such as infiltration rate) may be collected in the field and recorded later in a database or other file structure.

Figure 9-6



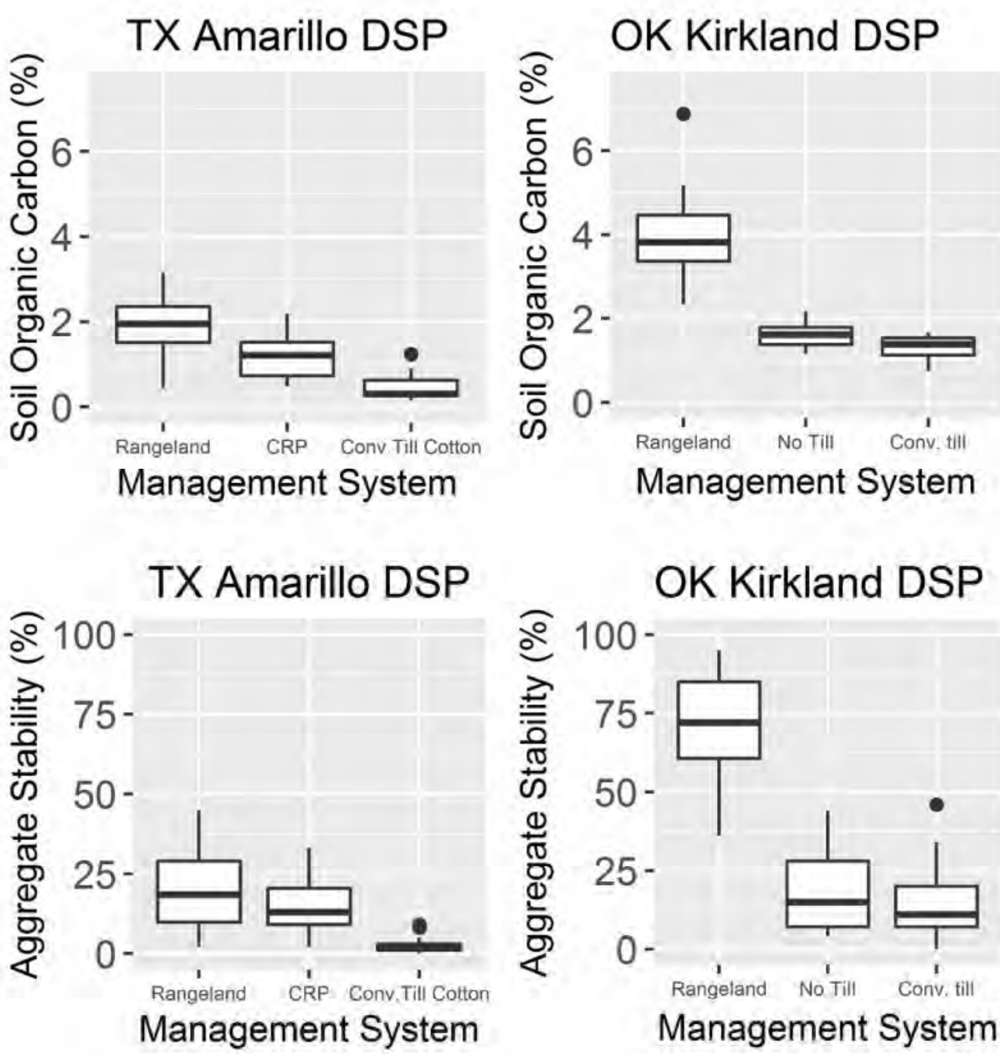
Dynamic soil property data in relation to ecological sites, soil interpretations, and monitoring data. A simple conceptual model (a) is used to design comparison studies (b). Dynamic soil property data derived from these studies are used to populate a point dataset (c). The point data are then available 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). From Tugel et al., 2008.

3. **Compile or link data across common scales.** Link and label DSP data, as appropriate, to include site and observation information (e.g., vegetation and individual pedons from the same site are labeled with the same plot ID). A robust database should allow for the association of data elements across conditions and locations.
4. **Generalize horizons and other units of measure.** Data collected by samples that are individually labeled, such as by genetic horizon, must be grouped into common units so that properties can be analyzed and compared. Add other data elements (such as comparable layer; Tugel et al., 2008) that

group all possible horizons in the project. Keep scripts and rules as part of the project metadata and documentation.

5. **Aggregate individual observations and measurements.** From the smallest individual data element (sample values) to the broadest level of interest (soil and land use or management system), select meaningful comparisons between conditions. Aggregate horizons, pedons, and sites to make comparisons.
    a. Create separate data elements for surface samples (0–5 cm) and comparable layers, such as all A horizons or all B horizons or other combinations outlined in the *Soil Change Guide* (Tugel et al., 2008).
    b. Use weighted averages by depth to combine horizons into pedon values.
    c. Compute statistical measures for plots or sites.
    d. Compute statistical measures for land use or management.
6. **Analyze data.**
    a. Perform data evaluation and graphical comparisons. Preliminary data is evaluated to gauge general trends, identify errors, and locate any outliers. Graphs should include box plots by comparable layers, pedons, and sites and depth functions within pedons. Figure 9-7 shows a summary of two surface layer DSPs for two separate DSP projects. Data visualization can be used to explore, examine, and share general conclusions about the project.
    b. Calculate descriptive statistics across soil groups. Initial summary statistics include central tendencies (mean, median, and mode) as well as measure of dispersion and variability (range, standard deviation, etc.).
    c. Calculate descriptive statistics for individual land management conditions (as appropriate). Calculate measures of central tendencies, dispersion, and variability. Use site averages or a mixed model to accurately reflect any autocorrelation between observations taken at the same site.
    d. Conduct statistical comparison and ascertain meaningful differences. Evaluate statistical differences between land management conditions.
        i. Use T and F tests for differences. Mixed models optimize use of fixed (condition) and random (plot replication) factors.

Figure 9-7



Dynamic soil properties of 0–2 cm samples for two DSP projects (Amarillo and Kirkland soils) for: a) soil organic carbon (%) measured as total carbon and b) water stable aggregates (%). Box plots represent the 25th and 75th percentiles. Note that rangeland was used as a reference condition for both projects but that different alternate land management systems were used for comparison. The soils also have different reference levels of these two DSPs.

ii. Examine literature to determine if described differences are meaningful to soil function.
iii. Evaluate sampling sufficiency (e.g., were enough samples collected to detect a difference if one exists?). If properties are more variable than originally anticipated, the sampling design

may not have the power to detect anything other than a very large difference. Additional sites can be chosen and samples collected so that meaningful statistical comparisons can be made to detect smaller (but important) differences in DSP values.

7. **Make inferences about soil variability, land management conditions, and soil change.** A final report should summarize the project goals, the target soils and land management conditions, the data collection process, and the methods of data aggregation and analysis. Final conclusions should include the most specific level of evaluation and the expected area of inference (i.e., other areas where the results might apply). This report serves to document the process and support any conclusions.
8. **Populate soil survey databases (such as information for soil map unit components) as appropriate.** Depending on the nature of the project, report results for the entire extent of the soil (or soil group) or report results as being limited to certain conditions.

Care should be taken when incorporating DSP project data into standard data aggregation. Consider the distribution and representativeness of data when populating general component information, such as representative values (RV). If differing management conditions have statistically different DSPs, compare the distribution of the conditions assessed to the number of pedons available for aggregating. You may need to aggregate by land management condition and then weight the conditions by spatial prevalence to arrive at an overall value.

Summary of DSPs in Soil Survey

Dynamic soil properties enhance soil survey by providing information about soil properties that change with land use and management. Information about DSPs improves the ability to document, explain, and predict the effects of land use and management on soil and ecosystem function. DSP data can be collected as general information or as projects designed to detect statistical differences between management and land use types. In both approaches, DSPs are collected in a way that documents both soil properties and classifications and land use and management information. Careful planning, sampling, and analysis ensure that DSP data enhances soil survey projects and allows for additional use of soil information.

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RE: #T3-2022-16220 - Submittal for OAN May 15 2025

Joseph Schaefer <joseph.schaefer@jordanramis.com>
To: LUP Hearings <lup-hearings@multco.us>

Mon, May 19, 2025 at 11:26 AM

Good morning. On Friday, an email was sent with one pdf for submittal as per the email below. Confirmation has not been received. In the event the submittal was too large (24 MB), it is being resent as two separate pdfs, with the largest being 19 MB.

Please confirm receipt.

Thanks

Joseph

[Quoted text hidden]

Submittal 2 for OAN May 15 2025.pdf
3085K