Soil survey and inventory of dynamic soil properties in the U.S.A.

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Abstract
The U.S. National Cooperative Soil Survey (NCSS) is implementing a program to evaluate dynamic soil properties (DSP) and their response to changes in land use and management for all lands in nation as a new standard protocol. The objective of this paper is to present an overview of this protocol and its design. The design for the DSP inventory is a comparison study that substitutes space for time to infer change. This inventory relies on the assumption that properties of a native soil are sufficiently uniform across the landscape that changes due to land use and management can be detected by data collected from replicate plots in stable land use and management systems. A minimum set of DSP's were selected by analysis of rankings from a panel of experts. Properties selected for sampling were those that have known relationships to soil and ecosystem processes and functions, are relatively insensitive to daily or seasonal fluctuations in environmental conditions, are easy to measure accurately and precisely by different people, and are relatively low cost. The evaluation identified eight properties, organic C, pH, electrical conductivity, bulk density, soil structure, wet aggregate stability, total N, and soil stability.

Key words
Soil function, land use, agricultural management, organic carbon, soil quality, comparison studies

Introduction
Information about how soils change and human impacts on soil function is crucial to sustainable soil management. During the last few decades, the focus of user's needs for soil survey information expanded from erosion control, productivity, land use planning, and infrastructure development to include soil, water and environmental quality, ecosystem sustainability, food-security, biofuel production and soil response to climate change. The need to address these and similar issues demands development of additional knowledge of the state of the soil resource, conditions that can be achieved under specific land uses and management systems, and procedures to predict response to management as an aid to policy makers, land managers, producers, and others who make decisions that protect soil function.

In response to heightened demand for information on soil quality and function, the U.S. NCSS has begun a new standard program to evaluate and inventory disturbance-sensitive DSP for all lands in the U.S. The objective of the DSP inventory is to understand land use and management effects on DSP and soil function for all U.S. soils and to provide tools for land managers and others to better design and implement management systems to maintain and enhance soil quality and ecosystem services. The inventory will focus on soil properties that 1) may change over time scales of decades to centuries, 2) are important for interpreting soil function, 3) reflect management effects as well as soil and vegetation dynamics, 4) identify positive and negative critical management thresholds, and 5) can be documented with measurements recorded at one point in time. The objective of this paper is to present an overview of the protocol developed by the NCSS to produce a scientifically defensible and statistically valid inventory of DSP associated with land use and management.

DSP Protocols
The design selected for the DSP inventory is a comparison study that substitutes space for time to infer change. The basis for the comparisons among land use and management systems is that the variability in an inherent soil property is less than the change in the property induced by differences in land use and management. Thus, differences that are observed in properties of a specific soil under different land use or management conditions reflect changes that can be attributed to the effects of land use or management.
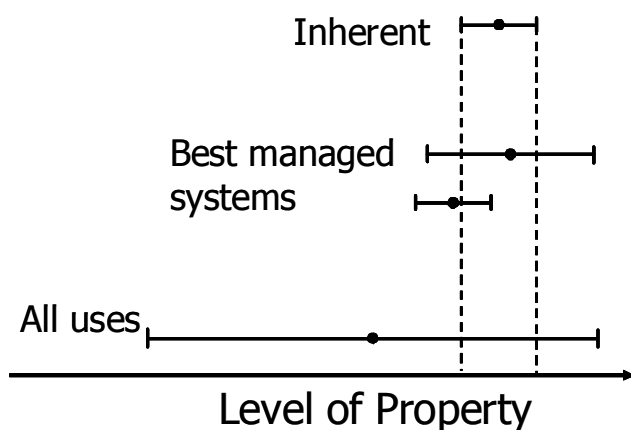
Figure 1. Diagram representing levels of a soil property observed in a non-degraded inherent condition, under best management, and under a range of management conditions.
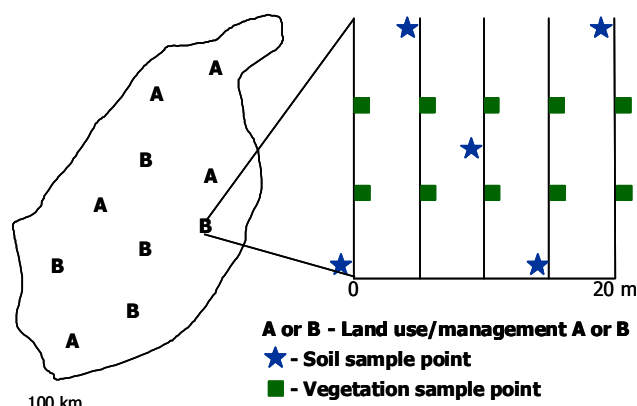

Figure 2. Plot layout for DSP data collection and sampling. The left portion of the figure depicts the geographic extent of Soil X. A and B represent two managements being evaluated for Soil X. The enlargement (right portion of the figure) depicts the sampling layout within each plot for grassland and cropland.

The use of comparison studies to evaluate DSP meets NCSS needs because of their efficiency and simplicity, both of which are necessary for a large nationwide inventory. Space for time comparison studies overcome many of the constraints associated with long-term monitoring including land use and management changes that may occur on private land over the monitoring period. It is recognized that comparison studies may fail to differentiate natural variability from that resulting from differences in land use and management history (Pickett 1989), that the underlying assumption that all locations were initially equal is difficult, if not impossible, to verify, and that the "management legacy" is difficult to assess since the complete history of any site is seldom known (Foster *et al.* 2003). These limitations can be minimized by restricting sampling to a well-defined soil and replicating data collection at multiple spatial scales. Use of a conceptual model that describes expected changes in properties with deviation from the native condition will also help to separate land use and management effects from natural variability and will permit identification of critical management thresholds useful to land resource managers.

The NCSS DSP inventory focuses on land use and management systems that have been in place for sufficient time, such that the functionally important properties are at relative steady-state. It also focuses on understanding properties under two conditions; 1) a reference management system which is either non-degraded native conditions or where such conditions no longer exist, a well-managed alternative system and 2) an attainable condition that represents the soil under best management (Figure 1). The requirement for steady-state conditions is necessary to gain meaningful data from a one-time evaluation of soil conditions related to a specific disturbance regime and to relate management systems to optimal soil functional levels. The steady-state restriction, however, limits information gained concerning rates of change which is better obtained through long-term monitoring (Richter *et al.* 2007). The DSP effort will yield information on how the soil functions under differing land use and management and how the soil can be expected to function if best management is imposed over its aerial extent.

A hypothetical distribution of plots and the standard plot layout for collecting statistically valid data within operational conditions necessary for a nationwide effort are illustrated in Figure 2. Two levels of stratification are imposed in site selection; all plots occur on a single soil (confirmed in the field) and the land use and/or management has been in place for sufficient time to achieve steady state (derived from local knowledge). An additional requirement is that, if possible, plots sites extend over the full extent of the soil's occurrence in order to capture variability due to environmental gradients. In the absence of variance data to develop more precise sampling requirements, a minimum of five replicate plots and five systematically located soil replicates per plot are sampled (Figure 2). The plot design also accommodates collection of functionally important plant

community features including foliar cover, species composition, site indices, and productivity data. The numbers of plots per soil and plot replicates will be evaluated and modified as data are collected.

Properties evaluated
Although soil function cannot be measured directly, certain soil properties that reflect complex processes and functions can be measured and used to represent soil functions (Karlen and Stott 1994). For the NCSS DSP program, a functionally important difference in DSP is considered to be a difference sufficiently large to reflect or cause an important difference in soil or ecosystem function. Minor differences in management systems are expected to translate to minor differences in DSP. Thus, procedures have been or are being developed to group land use and management systems into categories expected to cause functionally important differences in soil properties.

For a nationwide inventory of DSP, it is not possible to evaluate all properties that may change in response to differences in land use and management. Those evaluated must fit within the constraints of the large project including availability of laboratory resources, the requirement that the data and samples must be collected in a single visit to the site, and the expertise and availability of soil scientists collecting the data and samples. Properties that fit within these constraints and that satisfy the objectives of the effort were selected with a multi-step process that employed expert knowledge. The steps in the process included 1) developing criteria for rating soil properties, 2) selecting properties reported to change with disturbance across a wide range of soils, 3) having experts rank the properties in order of importance and according to the rating criteria, 4) prioritizing the properties statistically, and 5) reviewing the rankings for potential bias due to evaluators area of expertise (Wills *et al.* in review).

The criteria used to select and rank properties are as follows (Wills *et al.* in review):
1. The property is sensitive to disturbances or management.
2. The property clearly reflects the status of processes that are important for a number of soil or ecosystem services and functions or is a key indicator of one particularly important service or function. The relationships between the property and the processes, functions or services it reflects have been quantified for a wide range of soils.
3. The property is relatively insensitive to daily or seasonal fluctuations in environmental conditions of moisture, temperature, and light, or such fluctuations are well-understood and can be quantitatively predicted.
4. The property is easy to measure accurately and at the necessary level of precision by different people or by the same person at different times.
5. The cost, including field and laboratory expenses and time, necessary to obtain the required number of measurements is low.

A rating tool that included 19 properties meeting criteria 1 (Figure 3) was developed and sent to 41 scientists with expertise in soil survey (25), soil biology (7), agronomy (6), forestry, range science, and hydrology (1 each). Each expert ranked the properties in order of importance and rated each property relative to its fit to each of the ranking criteria 2 thru 5. From these data, a weighted average score was calculated for each property (Figure 3), and the eight highest ranked properties; organic C, pH, electrical conductivity, bulk density, soil structure, wet aggregate stability, total N, and soil stability; were selected as the minimum dataset for each DSP project. In addition to these eight properties, additional properties that are easily measured, e.g. plant available P, or are potentially diagnostic of soil degradation or aggregation, e.g. active C, will be evaluated in selected projects and may be added to the minimum dataset. Local soil scientists and cooperators involved in data collection are encouraged to collect additional data at the sites for evaluation of locally important questions.

Conclusions
The U.S. NCSS is initiating a standard protocol to produce a nationwide inventory of dynamic soil properties subject to change in response to changes in land use, agricultural and silvicultural management, and other disturbances. The inventory is based on comparison of major management systems in optimal condition, each reflecting a specific disturbance regime, through substitution of space for time. Resources available preclude

evaluation of all soils, land uses, and management systems that occur in the U.S. Thus, initial efforts target Benchmark and other important soils and broad land use and management groups to build a dataset that can be used to represent other similar soils. These data and that collected over the longer term will provide the information needed to encourage and implement wise land management practices and policies to sustain important soil functions. The full protocol the NCSS DSP program is available in Tugel *et al.* 2008.
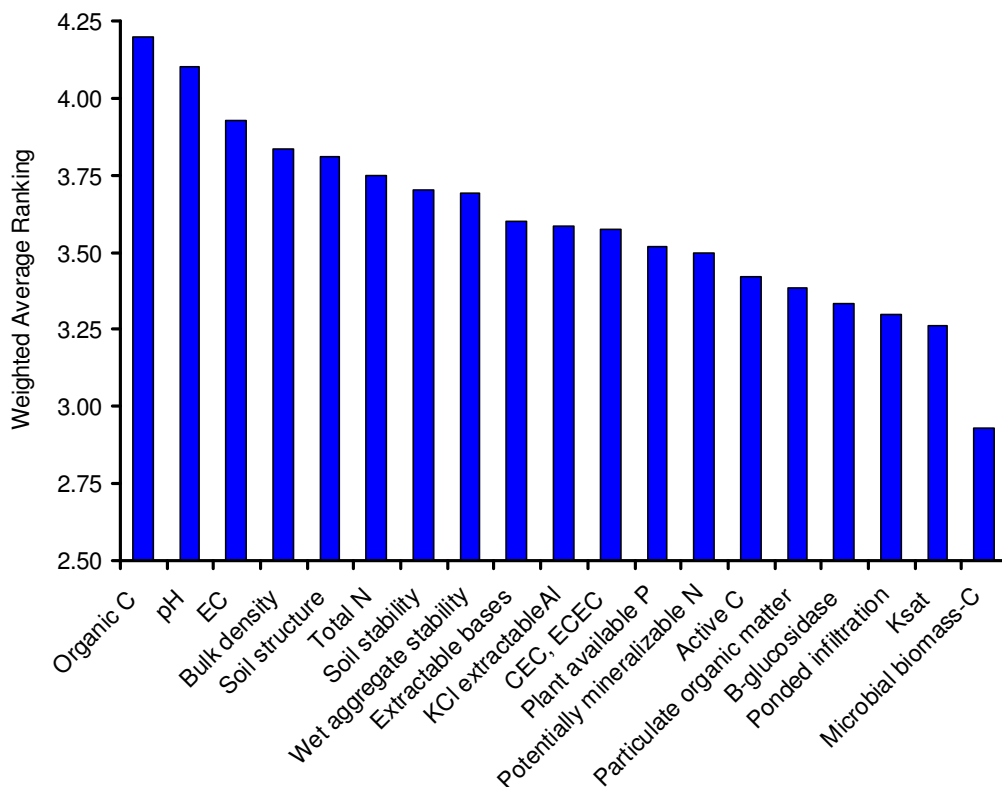

Figure 3. Weighted average ranking for properties considered in DSP.

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