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Soil Quality Physical Indicators: Selecting Dynamic Soil Properties to Assess Soil Function

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Soil Quality Physical Indicators: Selecting Dynamic Soil Properties to Assess Soil Function

What is soil quality?

Soil quality is defined as the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Karlen et al. 1997).

The quality of a soil, or its capacity to function, is a reflection of its inherent and dynamic properties. Inherent, or use-invariant, soil properties change very little or not at all with management. Inherent soil properties form over thousands of years and result primarily from the soil-forming factors: climate, topography, parent material, biota, and time. Examples of inherent properties are soil texture, type of clay, depth to bedrock, and drainage class. Many inherent soil properties are evaluated by the National Cooperative Soil Survey. They are used for taxonomic classification and to develop localized soil suitability interpretations and limitations. An evaluation of these properties can be used to suggest how well soil will function for septic systems, building support, road fill, agricultural production, or other uses.

In contrast, dynamic, or management dependent, soil properties are affected by human management and natural disturbances over the human time scale. Land uses as varied as crop and livestock production or buildings and roads change soils. There are many dynamic soil properties. A few examples are organic matter content, biological activity, aggregate stability, infiltration, soil fertility, and soil reaction.

Changes in dynamic properties may be limited by a soil's inherent properties, most notably soil texture, and/or by another dynamic soil property, most notably organic matter content. For example, the potential to build organic matter in a silt loam soil may be greater than for a loamy sand soil since a silt loam soil has higher available water capacity to support plant growth and produce plant biomass. If soil organic matter increases other dynamic properties, such as aggregation and aggregate stability, infiltration, and bulk density, are improved.

While several dynamic soil properties are evaluated by soil survey, the effect of management on the properties has not been adequately captured. The properties are typically recorded as point-in-time values with the resulting data insufficient for management practice or land use comparisons. Significant changes in dynamic soil properties can occur in a single year or growing season. Intensified evaluation of dynamic soil properties, particularly in soil survey areas where once-over mapping is complete and review activities are taking place, will strengthen the value of soil survey for making management and land use decisions. A baseline from which to measure subsequent human-induced changes in soil function will also result.

Soil quality indicators describe soil function

Dynamic soil properties can help determine how well a soil performs ecological services or functions essential to people and the environment.

Soil functions to (modified from Seybold et al. 1998):

- sustain biological diversity, activity, and productivity
- regulate and partition water and solute flow
- filter and buffer, degrade, immobilize, and detoxify organic and inorganic materials, including industrial and municipal by-products and atmospheric deposition
- store and cycle nutrients and carbon within the Earth's biosphere
- provide physical stability and support for plants or socioeconomic structures or protection for archeological treasures associated with human habitation

Referenced in the National Soil Survey Handbook, Part 624 and Guidelines for Soil Quality Assessment in Conservation Planning, this definition and list of soil functions guides USDA Natural Resources Conservation Service soil quality investigation and conservation planning activities.

Soil function and environmental quality

Soil quality affects environmental quality and is analogous to air and water quality (even though environmental standards for soil quality generally do not exist). High functioning soils are needed for optimum plant growth, nutrient cycling, buffering and filtering, and water partitioning and storage, each function directly influencing environmental quality. Since air and water quality are also affected by the condition of soil resources, environmental quality is further affected by soil quality (fig.1). Soil particles blown through the air by wind diminish air quality, while sediment in water bodies negatively affects water quality.

The soil in figure 2 is functioning poorly for maintaining air quality. Repeated mechanical cultivation of this walnut orchard destroys ground cover, prevents buildup of organic matter and destabilizes the soil. Soil particles dislodged by cultivation are subject to wind transport and they adversely affect air quality.

Soil function to regulate water flow can be described by how long it takes for water to enter the soil (fig. 3). Water must enter the soil for it to be available for plant growth. The more water that enters this soil the less runs off of it. Reduced runoff results in reduced erosion and sediment transport, and water quality is maintained or enhanced.

While soil provides physical stability and support for plants, it also serves as an engineering medium to support buildings and roads. Figure 4 shows several practices used to maintain soil quality in an urban setting. Temporary cover and mulching on level land (foreground) and seeded erosion control mats on steeply sloping land (background) protect the soil from water erosion and maintain a stable foundation for the roadbed and future structures in this neighborhood.

Figure 2 Soil quality affects air quality

Figure 3 Soil quality affects water movement into and through soil, water storage and water quality

Figure 1 Soil function affects environmental quality (after Andrews et al. 2002)

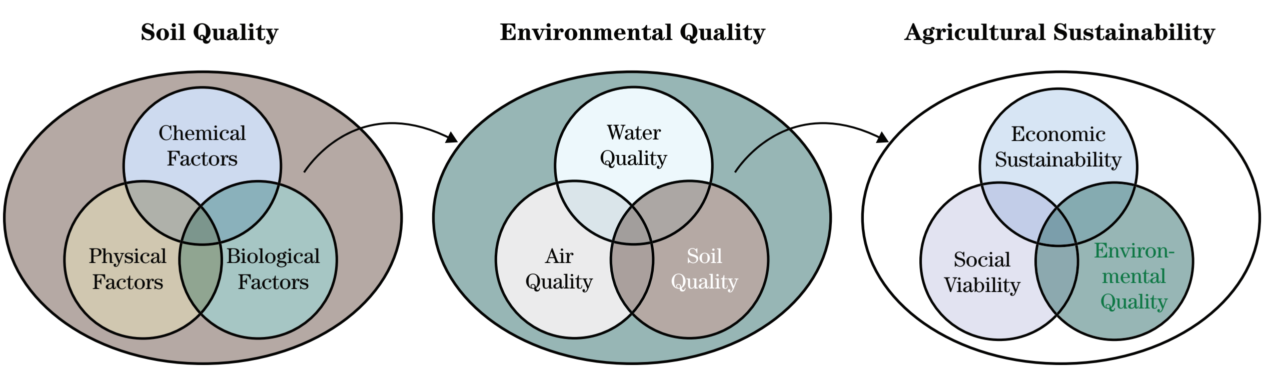

Figure 4 Soil supports plant growth and socioeconomic structures

Assessment indicators are physical, chemical, or biological

Soil quality is assessed indirectly by measuring dynamic soil properties. These properties serve as indicators of soil function since it is difficult to measure function directly and observations may be subjective.

Doran and Parkin (1996) suggested that ideal indicators should:

- correlate well with ecosystem processes
- integrate soil physical, chemical, and biological properties and processes
- be relatively easy to use and assessable by many users, both specialists and producers
- be sensitive to management and climate
- be components of existing databases

Soil indicators are often divided into physical, chemical, and biological categories depending on how they affect soil function. However, these categories are not always clearly designated since a soil property or indicator can affect multiple soil functions. For example, soil sodium content serves as a chemical indicator of soil function based on plant toxicity and water uptake effects while also serving as a physical indicator based on its effect on soil dispersion, crusting, and erosion. Organic matter, or more specifically soil carbon, transcends all three indicator categories and has the most widely recognized influence on soil quality. Organic matter affects other indicators, such as aggregate stability (physical), nutrient retention and availability (chemical), and nutrient cycling (biological), and is itself an indicator of soil quality. Historically though, soil test labs focus on chemical fertility indicators, missing many important functions and processes of soils.

Focus on physical indicators

Soil quality indicators of physical condition provide information related to aeration and hydrologic status of soil, such as water entry into soil and capacity of soil to hold water in the root zone. Since soil physical properties influence rooting depth and volume, they also affect nutrient availability and plant growth. Physical properties also provide information related to the soil's ability to withstand physical forces associated with splashing raindrops or rapid water entry into soil that contribute to aggregate breakdown, soil dispersion, and erosion.

Physical indicators commonly used to assess soil function and quality include:

- aggregate stability
- available water capacity
- bulk density
- infiltration
- slaking
- soil crusts
- soil structure and macropores

Selecting soil quality indicators

A soil function-indicator matrix can be used by soil scientists and conservationists to select appropriate indicators for assessing a particular soil function. Additionally, if an indicator is already being measured, a matrix reveals the indicator's relationship to other soil functions, thus maximizing the usefulness of the data that is collected.

The matrix provided in table 1 is specific to physical indicators of soil function. Each physical indicator listed in the matrix is hyperlinked to an information sheet. The information sheets:

- define the physical indicator
- relate the physical indicator to soil function
- discuss inherent and dynamic factors influencing the soil property
- suggest management practices to improve the soil property so as to improve soil function and address resource concerns
- provide a reference for an assessment method

Table 1 Soil function – physical indicator matrix: when a direct relationship exists between the function and indicator, increasing reliability and ease of use of the associated assessment method is shown with increasing stars

Physical indicator / Soil function	Sustain biological diversity, activity, and productivity "D"	Regulate and partition water and solute flow "W"	Filter, buffer, degrade, detoxify… organic and inorganic materials "F"	Store and cycle nutrients and carbon "N"	Physical stability and support for plants and… structures associated with human habitation… "S"
Aggregate stability[a,c,f]	☆☆	☆☆	—	☆☆	☆☆½
Available water capacity[a,g]	☆☆☆	☆☆½	—	☆☆	—
Bulk density[a,h]	☆☆½	☆☆☆	—	☆	☆☆☆
Infiltration[b,e,i]	—	☆☆	☆	—	—
Slaking[b,e,i,j]	☆	☆☆½	—	—	—
Soil crusts[b,d]	—	☆☆½	—	—	—
Soil structure and macropores[b,d]	☆½	☆½	☆	☆	☆☆

[a] laboratory/office method
[b] field method
[c] time consuming
[d] simple visual observation
[e] variability requires large sample number
[f] perhaps the most informative physical indicator
[g] important for drought prone areas
[h] important for weight to volume conversions, small sampling errors result in significant interpretation problems
[i] effective educational method
[j] qualitative

Additionally, code blocks are displayed in the upper right of the hyperlinked information sheets to distinguish between Physical, Chemical or Biological indicators, Field or Laboratory/Office test method, and related soil function(s) of most significance, where:

- D = sustain biological diversity, activity, and productivity
- W = regulate water and solute flow
- F = filter, buffer, degrade organic and inorganic materials
- N = store and cycle nutrients and carbon
- S = provide physical stability and support

When a physical indicator is directly related to a soil function, the reliability and ease of use of the associated assessment method is shown with one to three stars, with three stars the highest rating. In many cases, several methods, from simple in-field to complex laboratory assessments, are available to assess a particular physical indicator. The methods referenced in the information sheets are generally those that can be performed in the field or a laboratory/office setting without the need for specialized equipment or extensive training. Footnotes to table 1 provide considerations for using each indicator and/or assessment method.

Using the soil function – physical indicator matrix: an example

A soil scientist is interested in assessing a cropland soil's ability to allow soil water and dissolved nutrients to move through the soil profile. A plow pan or other compacted layer may be slowing water movement through the profile and causing surface ponding as a result. From the matrix, it appears that bulk density is the best physical indicator to assess this soil function.

Bulk density measurements can be taken for various layers through the profile to establish a trend and compare the measurements to reference values based on soil texture. The matrix reveals that bulk density also provides useful information related to two other soil functions to further characterize the soil. They are: sustaining biological diversity, activity and productivity, and providing physical stability and support for plants (in the cropland context). As an added benefit, bulk density can be used for weight and volume conversions to improve reliability and usefulness of other soil quality measurements, such as nutrient load. A linked sheet provides further information about the bulk density indicator: its uses, importance, and effects of management.

Summary

As a definition for soil quality, "fitness for use" (Pierce and Larson 1993) succinctly aligns soil quality assessment with soil function. To assess soil quality, the intended soil or land use should be determined to draw meaningful conclusions regarding its capacity to function. Various soil properties can be measured to evaluate function, and thus make statements regarding soil quality. The set of properties needed to characterize soil quality will undoubtedly include one or more of the physical indicators referenced here. A soil function – physical indicator matrix reveals the important relationship that exists between physical soil properties and soil function, particularly for water flow and biological productivity.

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