CROPPING SYSTEM EFFECTS ON SOIL QUALITY

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What is Soil Quality?

Soil quality, or soil health, has been 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) or, more simply, the ability of a soil to perform functions that are essential to people and the environment (D. Karlen, personal communication, 2009). Whatever the specific definition, the goal is to manage soils so as to assure long-term productive and environmental sustainability. Soil does this by performing five essential functions: nutrient cycling, water relations, biodiversity and habitat, filtering and buffering, and physical stability and support (Andrews et al., 2004).

People have different ideas of what a quality soil is. For example (USDA-NRCS, 2010b):

- Farmer: sustaining or enhancing productivity, maximizing profits, and maintaining the soil resource
- Consumers: producing plentiful, healthful, and inexpensive food
- Naturalists: soil in harmony with the landscape and its surroundings;
- Environmentalist: soil functioning at its potential in an ecosystem with respect to biodiversity, water quality, nutrient cycling, and biomass production.

These views of soil quality may be too narrowly defined. For example, most farmers recognize the importance of managing soils for conservation and environmental protection, as well as production. But they do point out the different soil functions and individual perspectives on soil quality.

How Can We Assess Soil Quality?

Farmers and others who work with the land often have a personal view of soil quality based on their own experience, for example, the soil is productive, or the soil has "good tilth". Soil scientists in several states have attempted to provide a more systematic approach to experience-based soil quality assessment by developing soil quality score cards. (e.g., the Wisconsin Soil Health Scorecord at http://www.cias.wisc.edu/wp-content/uploads/2008/07/soilhealth_screen.pdf)

For those interested in performing in-field measurements themselves, a Soil Quality Test Kit Guide available from NRCS describes procedures for 12 on-farm tests, an interpretive section for each test, and instructions on how to build your own kit or where to purchase one (USDA-NRCS, 2010c). The UW-Extension Soil Management Team has conducted numerous soil quality field days and demonstrations of the Soil Quality Test Kits in many counties of the state.

Analysis of many soil properties that serve as indicators of soil quality are conducted at a number of university and research labs. Results from selected research studies along with their interpretation for soil quality assessment are summarized in the following sections of this article.

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What Soil Properties Are Indicators of Soil Quality?

Soil quality assessment includes use of standard soil fertility tests for pH and essential nutrients, but it requires a range of other tests to measure physical and biological, as well as chemical, soil properties (Fig. 2).

Chemical (available or harmful)
- pH
- Extractable P, K, other nutrients
- EC (electrical conductivity)
- SAR (sodium adsorption ratio)

Physical – (soil structure, soil strength, water)
- Aggregate stability (water-stable)
- Bulk density, penetration resistance
- Available water capacity
- Water-filled pore space

Biological (biological activity or function)
- Organic matter or total organic carbon
- Active soil carbon
- Potentially mineralizable nitrogen
- Microbial biomass

Figure 1. Typical soil property analyses included in soil quality assessment.

Central to the effects of various cropping systems on soil quality is accumulation of soil organic matter, or soil organic carbon, because it affects many of the other soil properties and processes important for soil quality. Organic matter accumulation can improve soil quality by decreasing bulk density, surface sealing and crust formation, and by increasing aggregate stability, cation exchange capacity, nutrient cycling, and biological activity. Soil organic matter can be affected by the quantity and type of carbon input from crop biomass and manure and by practices such as tillage that affect the decomposition rate and stratification of soil organic matter (Weil and Magdoff, 2004).

How Can We Interpret Soil Property Measurements as Indicators of Soil Quality?

Soil properties can be measured using in-field or laboratory procedures, but soil quality assessment requires quantifiable science-based interpretation. Several soil quality indexes have been developed to interpret individual soil tests and to combine those into an overall soil quality index. Examples are the Soil Conditioning Index (SCI), the Soil Management Assessment Framework (SMAF), and the Cornell Soil Health Assessment.

The Soil Conditioning Index (SCI) is a tool used by the Natural Resources Conservation Service to predict the effect of a particular cropping system and associated practices on change in soil organic matter content (USDA-NRCS, 2010a). An SCI score between -2 and +2 is calculated based on 1) the amount of organic material returned to the soil, 2) the effects of tillage and field operations on soil organic matter decomposition, and 3) predicted erosion. A negative SCI value indicates that a decrease in soil organic matter is expected, whereas a positive value indicates an increase in organic matter over time with that cropping system.

The Soil Management Assessment Framework (SMAF) is a tool for assessing the impact of management practices on soil functions associated with management goals of crop productivity, waste recycling, or environmental protection (Andrews et al., 2004). Specific soil properties, or indicators, are transformed via scoring algorithms into unitless scores (0 to 1) that reflect the level of function of that indicator, with 1 representing the highest potential. The nonlinear scoring algorithms take one of three general shapes—more-is-better, less-is-better, or midpoint optimum (Fig. 2). The SMAF user is directed to select between four and eight indicators, representing physical, chemical, and biological properties.

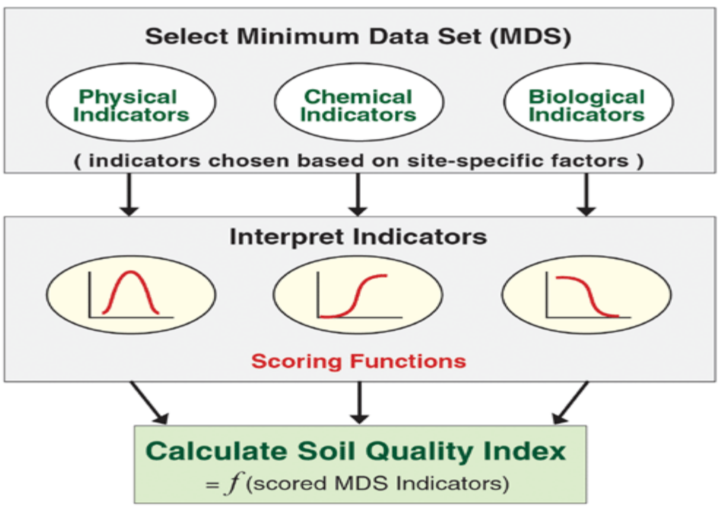

Figure 2. Conceptual framework for the Soil Management Assessment Framework (SMAF; Andrews et al., 2004; D. Karlen, personal communication, 2009).

The Cornell Soil Health Test is a program established in 2007 that includes testing soils for a range of chemical, physical, and biological indicators (particle size distribution and texture, wet aggregate stability, available water capacity, soil hardness, or penetration resistance, organic matter, active carbon, and a standard fertility test) and a comprehensive soil health assessment (Idowu et al., 2009; http://soilhealth.cals.cornell.edu/extension/test.htm).

How Do Different Cropping Systems Affect Soil Quality?

Cropping systems can affect a range of soil properties depending on the specific crop rotation, nutrient amendments, and tillage practices employed. Over time this can result in soil quality degrading, improving, or being maintained. Midwest cropping systems include a variety of crops and crop rotations -- continuous corn, short rotations of corn with soybean or other annual grains, or longer rotations that include multiple years of perennial forages. Karlen et al. (2006) evaluated crop rotations at three locations in Iowa and Wisconsin and found that longer rotations with at least three years of perennial forage and, in some cases, manure application generally had more total organic C, water-stable aggregates, and microbial biomass C than shorter corn-based cropping systems, resulting in higher SMAF soil quality indexes. They found that total organic C was the most sensitive indicator for detecting soil quality differences among cropping systems. In a regional study, Wienhold et al. (2006) found that combining more diverse crop rotations with reduced tillage and less frequent fallow periods improved soil function at several sites throughout the Great Plains.

Two recent studies in Wisconsin evaluated a range of physical, chemical, and microbial soil properties in two separate field experiments – a 4-year trial with various cover/companion crops in no-till silage corn (Jokela et al., 2009) and the long-term (18-year) Wisconsin Integrated Cropping Systems Trial (WICST; Posner et al., 2008; Jokela et al., 2010). Extractable P and K, pH, total organic C, total N, active soil C, potentially mineralizable N, water-stable aggregates, bulk density, penetrometer resistance, and total microbial biomass were measured, and the SMAF soil quality index was calculated.

Corn silage is an integral part of most dairy cattle rations, but removal of both grain and stover for silage increases the risk of soil degradation because of the limited amount of biomass returned to the soil and the lack of crop residue to protect the soil from erosion and runoff. Cover, or companion, crops may be one option to improve the sustainability of silage production. In the no-till silage corn trial referred to above soil samples were collected from treatments of silage corn grown with a living mulch of kura clover, interseeded red clover or Italian ryegrass, September-seeded winter rye, and no cover crop, all with spring-applied liquid dairy manure (Jokela et al., 2009). Use of companion/cover crops in silage corn resulted in more microbial biomass and in improvement in physical conditions, as reflected by more large water-stable macroaggregates and lower bulk density, especially in the surface 2-inch soil layer. Cover crop treatments had more active soil carbon and a nonsignificant trend for greater soil organic matter. These effects on soil quality indicators produced higher SMAF soil quality indexes from most companion/cover crop treatments, especially in the upper soil layer.

In the WICST experiment (Jokela et al., 2010) soil was sampled in the fall following the corn year of three grain-based systems, after both corn and alfalfa in two forage-based systems, and in a grass-legume pasture (Fig. 3). Results showed that different long-term cropping systems had significant effects on most chemical, physical, and microbial soil properties (soil quality indicators), primarily the effect of crop type and rotation, manure addition, and intensity of tillage (primary/secondary tillage and mechanical weed control). In particular, the intensively managed grass-legume pasture was higher in most soil quality indicators (microbial biomass, organic carbon, total nitrogen, readily available nitrogen and carbon, and aggregate stability) than all other corn or forage-based systems and had a significantly higher SMAF soil quality index. The alfalfa-based systems had higher levels of the carbon, nitrogen, and water-stable aggregate variables, but also higher bulk density, in one or both depths than did the grain-based systems. There were only small, nonsignificant differences in soil quality index values. These results suggest that, while there were differences in most soil quality indicators, when well managed, all of the cropping systems maintained acceptable soil quality on these productive, high organic matter, prairie-derived soils.

In summary, results of several Midwest cropping system trials showed that soil organic matter and various other soil properties are affected by the specific management practices and crop rotations of each cropping system. Mixed grass-legume pasture or, in most cases, incorporation of companion/cover crops or perennial forage crops into a grain-based rotation improved soil properties and overall soil quality, as measured by a soil quality index. The management level and inherent soil characteristics are important factors and can affect the sensitivity of soil quality to cropping systems.

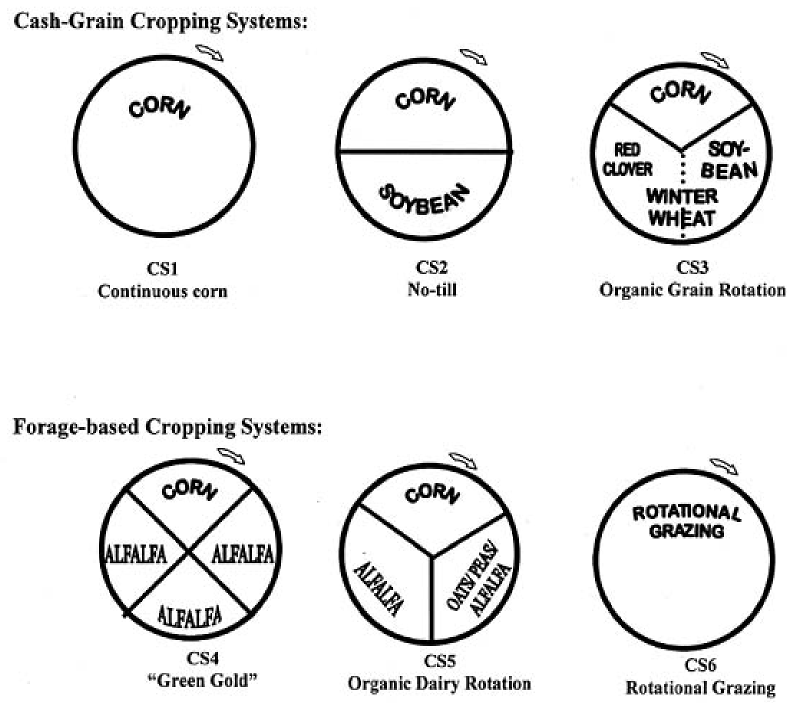

Figure 3. Schematic diagram of the WICST cropping systems (Hedtcke and Posner, 2010).

Management Strategies to Maintain or Improve Soil Quality

Based on practical experience and the results of research trials such as those reported here, several management strategies have been proposed to improve soil productivity, environmental protection, and overall soil quality (USDA-NRCS, 2010b; Magdoff and van Es, 2009).

- Enhance organic matter by adding diverse sources of organic materials to the soil
- Avoid excessive tillage
- Manage soil fertility to maintain optimum pH and nutrient availability
- Prevent soil compaction and maintain good soil structure
- Maintain good ground cover with crop residue, cover crops, or perennial forage rotations
- Diversify cropping systems

The specific practices within each of these management components will vary with the soils, climate, and farming system of a particular situation, but the principles apply to all cropping systems.

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