Soil Quality: The Foundation of a Sustainable Agriculture

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Abstract

The various chemical, physical, and biological properties of a soil interact in complex ways that determine its potential fitness or capacity to produce healthy and nutritious food. The integration of these properties and the resulting level of productivity is referred to as "soil quality". Soil quality can be defined as an inherent attribute of a soil that is inferred from its specific characteristics and observations (e,g., compactability, erodibility, and fertility). The term also refers to the soil's structural integrity which imparts resistance to erosion, and to the loss of plant nutrients and soil organic matter, Soil quality is often adversely affected by soil degradative processes such as soil erosion, salinization, and desertification. Indeed, soil degradation can be defined as the time rate of change in soil quality.

There is a growing consensus that the concept of soil quality should not be limited to soil productivity, but should be extended to include the attributes of environmental quality, human and animal health, and food safety and quality. In attempting to characterize soil quality, chemical and physical properties have received much greater emphasis than biological properties because their effects are easier to measure, predict and quantity. In fact, our knowledge of how soil microorganisms affect food quality, environmental quality and human and animal health is rather limited. Future research should seek to identify, and quantify reliable and meaningful biological ecological indicators of soil quality, including total species diversity, or genetic diversity of beneficial soil microorganisms. We need to know how these indicators are affected by management inputs, and how they relate to the sustainability of agricultural systems.

Introduction

Today in the United States, soil erosion by wind and water, the associated decline in soil productivity, and the adverse effects on water quality continue to be our most serious agricultural and environmental problems (Larson *et al*., 1990). Brown and Wolf (1984) reported that worldwide the mean annual loss of topsoil is estimated at 0.7 percent. This is of great concern because the loss of productivity may not easily be restored, even with application of chemical fertilizers. Studies have shown that when the topsoil is removed, or where it has been severely eroded, crop yields are from 20 to 65 percent lower compared with non-eroded soils (Langdale *et al*., 1979; Massee, 1990).

Agricultural productivity depends largely on the topsoil, the uppermost layer, which is about 15 to 20 cm deep for most soils. Topsoil serves many functions. It provides a rooting zone for plants, supplies a balance of plant nutrients, and retains, stores and releases moisture for plant use. It also enhances seed germination and root penetration, and supports a complex community of beneficial microorganisms which decompose organic wastes, recycle plant nutrients, and protect plants from pests. All these functions are essential for maintaining the tilth, fertility and productivity of agricultural soils. Soils with these capabilities are considered by many to be "healthy soils".

Recently, Haberem (1992) introduced the idea of a "Soil Health Index" to characterize a soil's capability for sustainable production of healthy and nutritious crops. He likened this to a "report card" that would document the gains and losses in soil quality as affected by management practices.

The purpose of this paper is to explore the components of soil quality; to discuss how they relate to alternative and sustainable agriculture; and to consider how soil quality might be quantified to indicate the status of soil health and to provide an early warning of soil degradation and the need for remedial measures.

Soil Degradation: A Global Crisis

During the 1980's food grain production per capita declined significantly in some parts of sub-Saharan Africa, the Near East, and Asia. Although part of this decline was due to increased population growth and periodic drought, much of it occurred because of poor management and exploitive farming practices which accelerated the degradation of agricultural lands from wind and water erosion, and the concomitant decline of soil productivity (FAO, 1986; Parr *et al*., l990; Dregne, 1992). Thus, a global crisis has emerged in which decisions must be made concerning the state of the world's soil resource base. There is a strong consensus that we can no longer tolerate the current rate of soil degradation and loss of productivity.

Today soil degradation is the single most destructive force diminishing the world' s soil resource base. Because of this, some countries are already experiencing increased food costs and acute food shortages; however, too few people have related this to the loss of soil quality. Action is needed to sensitize governments in both developed and developing countries to the grim consequences of soil degradation, and to encourage national and regional programs that will conserve and enhance soil quality on a global scale. Browri and Wolf (1984) concluded that the soil erosion crisis must be viewed in a global context because the production, distribution, and consumption of food is part of the global economy. They emphasized that if the loss of topsoil continues unarrested, it will lead to acute economic destabilization worldwide.

The Concept of Soil Quality

Various physical, chemical, and biological properties interact in complex ways to determine a soil's potential fitness for sustained production of healthy and nutritious crops. The integration of growth-enhancing factors that makes a soil productive has often been referred to as "soil quality". The Soil Science Society of America (1984) defines soil quality as an inherent attribute of a soil which is inferred from soil characteristics or indirect observations (e.g., compactability, erodibility, and fertility). Thus, soil quality has traditionally focused on, and has been equated with, soil productivity.

The Rodale Institute Research Center sponsored a workshop in July 1991 to discuss the attributes of soil quality and whether they could be quantified into meaningful indices that could predict the effects of degradative processes, conservation practices, and management inputs. The workshop concluded that the concept of soil quality should be broadened to include the attributes of environmental quality, human and animal health, and food safety and quality as shown in Figure 1 (Papendick and Parr, 1992; Parr *et al*., 1992). Thus the workshop proposed that soil quality be defined as:

> The capability of a soil to produce safe and nutritious crops in a sustained manner over the long-run, and to enhance human and animal health, without impairing the natural resource base or adversely affecting the environment.

The soil serves as an environmental filter for removing undesirable solid and gaseous constituents from air and water. Almost all recycling of organic materials, and the retention and release of water and nutrients for plants and soil organisms, occurs in the soil and is enhanced by a biologically-active and healthy soil. Although not well understood, soil quality may also play a major role in plant health and in the nutritional quality of the food that is produced.

If properly characterized, soil quality might serve as a measure or indicator of changes in both the soil's capacity to produce optimum levels of safe and nutritious food and in its structural and biological integrity, which in turn is related to the status of certain degradative processes, and to environmental and biological plant stresses. Some believe that good quality soils are essential for producing healthy and nutritious crops that in turn can enhance human and animal health. Figure 1 suggests that such a linkage exists, but research is needed to verify this relationship.

Soil quality can decline for many reasons: not just wind and water erosion but also such degradative processes as nutrient losses from runoff and leaching, depletion of soil organic matter, crusting, compaction, and desertification. It can also decline through the accumulation of toxic substances from excessive use of chemical fertilizers and pesticides, and atmospheric deposition or improper waste disposal (Sampson, 1981; Hornick and Parr, 1987).

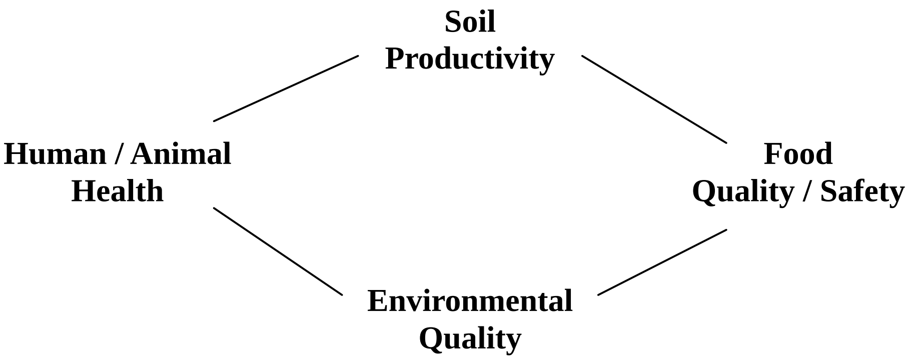

Figure 1. Attributes of soil quality.

The maintenance or restoration of soil quality is highly dependent on organic matter and an array of beneficial macroorganisms and microorganisms that it supports. The proper and regular addition of organic amendments such as animal manures and crop residues can effectively offset many of these degradative processes. It also is the best way to develop a biologically-active soil that requires less energy for producing crops; increases the resistance of plants to pests and diseases; and enhances the decomposition of toxic substances such as residual pesticides (Allison, 1973).

Indicators of Soil Quality

Efforts to characterize soil quality have focused primarily on soil chemical and physical properties because relatively simple and standardized methods of measurement are available. Soil biological properties have been neglected largely because of the difficulty in quantifying and predicting soil biological behavior. Consequently, no single reliable indicator of soil quality has been designated.

Improved soil quality is generally indicated by increased infiltration, macropores, aggregate size and stability, soil organic matter, and aeration, and by decreased soil resistance to tillage and root penetration, and decreased runoff and erosion (Granatstein, 1990). More attention should be given to soil biological properties because their relationships with soil chemical and physical properties, plant health, and food quality are obviously important, but poorly understood. Plant health and nutritional quality may prove to be useful and reliable indicators of soil quality (Hornick, 1992).

Soil microorganisms and invertebrates play a vital role in the decomposition of organic matter and nutrient cycling, and could be important indicators of soil quality. The various species, numbers, and functions of these organisms often are sensitive to environmental stresses and changes in soil properties associated with tillage and cropping practices. Changes in biodiversity of soil organisms (microorganisms, insects, and earthworms) may provide indications of soil degradation or rehabilitation (Stork and Eggleton, 1992; Visser and Parkinson, 1992).

Soil Quality Index

While some of the indicators of soil quality may be sensitive to change, others may be more subtle. The overlying question is whether we can measure and quantify these indicators and develop them into a Soil Quality Index that can be used reliably to monitor and predict the impact of farming systems and management practices on soil productivity, environmental quality, food safety and quality, and human and animal health. Moreover, can these indices provide an early indication of soil degradation and the need for remedial measures, and characterize changes in soil properties that would reflect the extent of rehabilitation or regeneration of degraded soils?

The ultimate goal is to develop a mathematical relationship or model that could quantify the various attributes of soil quality, and from it derive one or more indexes for simulation and prediction.

Such a relationship could take the following form:

Soil Quality Index = f(SP, P, E, H, ER, BD, FQ, MI)

where SP = Soil Properties
P = Potential Productivity
E = Environmental Factors
H = Health (Human/Animal)
ER = Erodibility
BD = Biological Diversity
FQ = Food Quality/Safety
MI = Management Inputs

We would have to determine the interaction of these indicators and the relative weight of each. Much valuable information is already available from research on benchmark soils and long-term tillage and fertility trials. We can also speculate on how soil quality indices might be used, including the following:

- Assess the impact of management practices on soil degradation and soil conservation.
- Assess the accrued benefits on highly erodible lands under the Conservation Reserve Program that was authorized by the 1985 Farm Bill.
- Provide a basis for conservation compliance.
- Establish the loan value and price of land.
- Establish a more realistic base for tax assessment and tax credit.
- Assess the impact of management practices on human and animal health.
- Assess the impact of management practices on food safety and quality.
- Assess the impact of management practices on water quality.
- Provide information for simulating and predicting environmental change.
- Provide an improved basis for land capability classification.

Relationship of Soil Quality to Alternative Agriculture and Sustainable Agriculture

Alternative Agriculture: The Strategy

The National Research Council (1989) defined alternative agriculture as a system of food and fiber production that applies management skills and information to reduce costs, improve efficiency, and maintain production levels through such practices and principles as:

- Crop rotations instead of monocultures
- Integrated crop/livestock systems
- Nitrogen fixing legumes
- Integrated pest management
- Conservation tillage
- Integrated nutrient management

Recycling of on-farm wastes as soil conditioners and biofertilizers

A U.S. House of Representatives Report (1988) considered low-input or alternative agricultural practices as promising strategies for preventing groundwater pollution and lowering farmer's production costs. The report implied that these goals could be achieved by reducing, or largely excluding, the use of chemical fertilizers and pesticides.

Sustainable Agriculture: The Goal

Sustainable agriculture is increasingly viewed as a long-term goal that seeks to overcome problems and constraints that confront the economic viability, environmental soundness, and social acceptance of agricultural production systems both in the U.S. and worldwide. Although there are many definitions of sustainable agriculture, most of them encompass the same elements: productivity, profitability, conservation, health, safety, and the environment. They differ mainly in emphasis.

The U.S. Congress (1990) in drafting the “Food, Agriculture, Conservation, and Trade Act of

1990”-PL 101-624 (better known as the 1990 Farm Bill) defined sustainable agriculture as an integrated system of plant and animal production practices, having site-specific application, that over the long-run will do the following:

- Satisfy human food and fiber needs
- Enhance environmental quality and the natural resource base
- Make efficient use of nonrenewable resources
- Utilize natural biological cycles and controls
- Improve the economic viability of farming systems
- Enhance the quality of life for farmers and society as a whole.

Soil Quality: The Linkage

As mentioned earlier, soil quality is now considered in a broader context to include attributes of environmental quality, human and animal health, and food safety and quality. It follows then that the best means to improve or maintain soil quality are alternative agricultural practices such as crop rotations, recycling of crop residues and animal manures, reduced input of chemical fertilizers and pesticides, and increased use of cover crops and green manure crops, including nitrogen-fixing legumes. These help to maintain a high level of soil organic matter that enhances soil tilth, fertility, and productivity, while protecting the soil from erosion and nutrient runoff. Effective implementation of these alternative agricultural practices using a holistic or systems approach requires skilled management and innovativeness by the farmer.

A conceptual diagram of how the attributes of soil quality link the strategy of alternative agriculture to the ultimate goal of sustainable agriculture is shown in Figure 2. Soil quality occupies a pivotal position in this concept and many would agree that soil quality is the "key" to agricultural sustainability.

Kyusei Nature Farming, the subject of this Second International Conference, also proposes a similar strategy (i.e., the five requirements stated earlier) for achieving a more sustainable agriculture. It is noteworthy that the practice of Kyusei Nature Farming focuses directly on ways and means of improving soil quality which Mokichi Okada recognized as the "key" to sustainable agriculture in 1935.

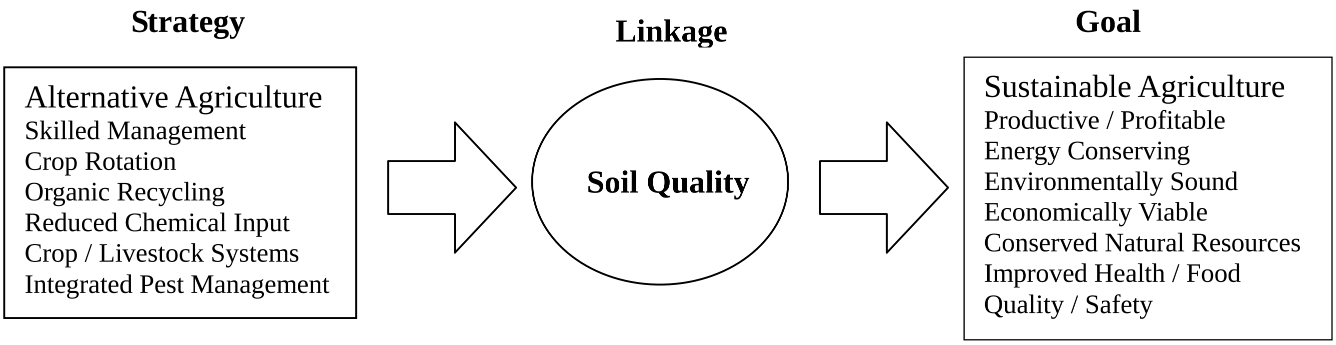

Figure 2. A conceptual diagram that illustrates how the attributes of soil quality provide a link between the strategy of alternative agriculture and the ultimate goal of sustainable agriculture.

Research Needs and Priorities

There is a strong consensus that the establishment of a global network for monitoring, assessing, improving, and restoring the quality of degraded soils is a logical and appropriate goal. Research is needed to quantify the indicators or attributes of soil quality into indexes that can accurately and reliably characterize the relative state of soil quality as affected by management practices and environmental stresses. The best indicator of soil quality probably will differ according to agroecological zones, agroclimatic factors, and farming systems. It is likely that soil quality indicators would be quite different for paddy rice compared with crops grown in well-drained soils. A high priority for future research is to identify and quantify reliable and meaningful biological/ecological indicators of soil quality, including total species diversity and genetic diversity of beneficial soil microorganisms. We need to know how these indicators are affected by management practices, and how they relate to the productivity, stability and sustainability of farming systems.

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