The Concept of Soil Quality: New Perspectives for Nature Farming and Sustainable Agriculture

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Abstract

Many problems which sustainable agriculture attempts to address such as productivity, environmental quality, food quality and farm income are often soil related and can be resolved directly by improving soil quality. Because the soil does more than just produce food. soil scientists and other agriculturists are adopting the concept of soil quality as a way to measure or account for the capacity of the soil to perform multiple functions within an agroecosystem. For agricultural ecosystems three major functions are defined: to sustain productivity, enhance environmental quality, and to support human health and habitation. Many of the problems with current agricultural systems relate to the fact that the multiple functions of the soil have been largely overlooked or ignored, especially those relating to environment and health. Soil quality can be degraded not only by soil erosion but by a number of other processes as well including acidlfication, compaction, crusting, and loss of nutrients, organic matter, and structure.

The most serious degradative processes are management-related and of these tillage, especially excessive tillage is the most destructive. Tillage of any kind results in loss of soil structure and accelerated erosion where the hazard exists. It is becoming well-documented scientifically that continuous no-till, where crop aftermath (i.e., residues) is retained on the soil surface and sowing is done with minimal soil disturbance, is the most effective approach for restoring and improving soil quality. Research and farmer experience indicate that with continuous no-till soil organic matter tends to increase, structure improves and, in time, crop yields can increase substantially due to improved water relations and nutrient availability. A major obstacle that farmers often face with continuous no-till is overcoming yield-limiting factors during the transition years, i.e., the first years of no-till following a history of conventional tillage. These are often poorly understood and may be ecologically-driven and related in very complex ways. Some of the main problems involve managing high residue levels, and increased weed and disease infestations. Farmers switching to continuous no-till must often gain new knowledge and develop new skills and techniques in order to achieve success with this different way of farming.

It would seem that there is considerable potential for nature farming and EM technologies that could help farmers overcome some of the barriers to continuous no-till. For ex-ample, it appears that EM can enhance the decomposition of crop residues. Moreover, research has shown that seed treatment with EM can stimulate germination and seedling emergence. There is also some indication that seed treatment with EM prior to planting either by a) immersing the seed for brief periods using specific EM:water dilutions or b) dusting the seed with finely-ground EM Bokashi, can reduce the incidence of soil-borne diseases and protect seedlings against pathogens. Nature farming experience and philosophy on the judicious use of crop rotations, cover crops, green manures and legumes could be invaluable in developing no-till systems. Research should also be conducted on the use of EM for plant protection against weeds and insects. Answers to these and other questions are urgently needed to provide strategies for promoting soil quality as a way to enhance agricultural sustainability for future generations.

Introduction

Many people fail to fully appreciate or understand the critical importance of a healthy or good quality soil for achieving agricultural sustainability. Sustainable agriculture attempts to address serious problems afflicting many of today’s food production systems such as low water use efficiency, air and water pollution. excessive runoff and soil erosion, poor food quality, and low farm income. All of these problems are soil related, and in many cases can be resolved directly by improving soil quality. Soil quality may also be involved indirectly in other nature farming or sustainability issues, e.g., human and animal health through its effect on food quality. It follows then that soil quality is the “key” to successful nature farming which strives for agricultural sustainability, and that an agricultural system is sustainable only when it maintains or improves soil quality.

The Role of Soil in the Agroecosystem

Agricultural soils have long been regarded by some merely as a means of holding up the plant; consequently, soil science has historically emphasized the productivity aspects of soil management such as quantity of production, high inputs, and maximum yields, but with less concern for crop quality, and little or none for environmental quality. Only in recent years has the scientific community begun to recognize the vital holistic role of soil in performing multiple functions within the agricultural ecosystem, or for that matter, ecosystems in general. In this context the soil is viewed as a complex, living medium, and like humans and animals, its capacity to perform these various functions is diminished if its quality or health deteriorates.

Although crop productivity is an important soil function, the soil does far more for mankind than just produce food. A healthy or good quality soil acts as an environmental filter for cleansing air and water, and as a storage reservoir for water and plant nutrients. Soil can be a major sink for “greenhouse” gases such as carbon dioxide which may affect global warming and the world’s climate. For example, managing the soil to sequester atmospheric carbon dioxide helps to offset emissions from the burning of various fuel sources. Soil is the ultimate receptor and incubation chamber for the detoxification, decomposition, and humification of organic wastes, manures and crop residues, and for the recycling of nutrients from these materials back to plants. If mismanaged, the soil can pollute air and water and in some instances these adverse environmental impacts may be of greater concern to society than a loss in agricultural productivity.

There is evidence that soil management can have important effects on the nutritional quality of food, but these linkages are often not well understood. The saying goes that a healthy soil will produce an abundance of safe, nutritious food which in turn promotes the health of people whose lives depend on this food. Soil functions that promote food quality include biological processes and conditions that produce a balance of essential plant nutrients, and that produce safe food, i.e., food free of toxic substances.

The Concept of Soil Quality

Because the soil performs so many more important functions than just to produce food, soil scientists and other agriculturists are now adopting a new way of thinking about soil which they refer to as the “concept of soil quality.” This relatively new concept describes the soil in terms of its capacity or capability to perform multiple functions within an ecosystem. For agricultural ecosystems, three major functions are defined: to sustain productivity; to enhance environmental quality; and to support human health and habitation. There are several definitions of soil quality in the literature but the original one that satisfies these three criteria is:

> *“the capability of the soil to produce safe and nutritious food in a sustained manner over the long-term, and to enhance human and animal health, without impairing the natural resource base or harming the environment” (Parr et al., 1992).*

This definition emphasizes that the soil functions in an agroecosystem go beyond those of traditional crop production, and that the term “soil quality” is not synonymous with that of “soil productivity” which historically has been the case. Production agriculture in many places has been under severe criticism for failing to meet many of society’s environmental and resource conservation goals, and to reduce risks to human health. Decades of high erosion rates and organic matter decline resulting from conventional farming practices have reduced soil quality over large areas in both developed and developing countries. Moreover, crop yields in some places can no longer be maintained economically even with vastly increased technological inputs. Many of the problems with agriculture, both past and present, relate to the fact that the multiple functions of the soil have been largely neglected, especially those relating to environmental quality and human health. As a result many current farming systems are not sustainable even with various government interventions intended to protect air and water quality. Soil quality should be the first line of defense against environmental degradation. Managing agroecosystems to protect and enhance soil quality should be a fundamental first step to improve water and air quality, reduce health risks, and sustain high productivity.

Degradation of Soil Quality

Soil quality can be degraded by a number of processes resulting from soil mismanagement due to poor farming practices. Historically, soil erosion has been regarded as the major threat to soil quality, At one time it was commonly accepted that erosion control would correct most soil problems. However, in many cases other processes such as salinization, acidification, compaction and loss of biological activity and organic matter can degrade soil in the total absence of erosion. These degradative processes can result from excessive tillage, inappropriate cropping practices and mismanagement of irrigation, fertilizers, pesticides and other production inputs. Soil quality can also be degraded by accumulation of toxic materials in soil through application of contaminated organic amendments, or atmospheric fallout of industrial pollutants.

Characterizing Soil Quality

Obviously, a number of soil attributes could serve as indicators of soil quality for all three soil functions, but to different degrees. To standardize the procedure it has been proposed that a minimum data set is needed which can be used to assess and monitor soil quality on a field or landscape basis. These would consist of indicators or tests which best measure the soil's capacity to carry out the productivity, environmental and health functions. One such set of indicators was developed by a small working group of USA and Canadian scientists, of which the authors are members, and is reported in Table 1. According to this group, the essential indicators are: pH, organic matter, electrical conductivity, nutrient availability, infiltration rate, water holding capacity, bulk density, mineralizable nitrogen, rooting depth, and soil respiration. The time column in Table 1 indicates temporal sensitivity to change in years, and the X's indicate the function for which the parameter serves as an indicator.

Table 1: Proposed Parameters of Soil Quality Which Best Serve the Functions of Productivity, Environment and Health.

Parameters	**Time (years)**		**Function**	
		Productivity	**Environment**	**Health**
pH	0.1-10	X	X	X
Organic matter	1-10	X	X	X
Electrical conductivity	1-10	X	X	X
Nutrient availability	1-10	X	X	X
Infiltration rate	3-5	X	X	X
Water holding capacity	3-5	X	X	
Bulk density	1-3	X	X	
Mineralizable nitrogen	1-3	X		
Rooting depth	1-10	X	X	
Soil respiration	1-3	X	X	

The X's indicate the function for which a particular parameter best serves as an indicator.

This data set is regarded as tentative and its usefulness will change with the agroecosystem cropping mix, soil type, and management system and may be location or site specific. It should be emphasized that the soil quality concept accounts for the diversity among soils, and that ultimately soil quality will probably be best expressed by a unique set of characteristics for each different soil. Another paper in this Proceedings by Smith and Halvorson discusses how a set of indicators can be integrated into a single index of soil quality.

Improving Soil Quality for More Sustainable Agriculture

Just as soil quality can be degraded by inappropriate management, it can be improved and restored by best crop and soil management practices. Change in the soil organic matter content is probably the best single indicator of long-term change in soil quality. The key to improving soil quality lies in stabilizing or increasing the soil organic matter content. Soil organic matter improves soil structure, nutrient cycling and soil water relations as well as other indicators of soil quality.

Effects of Tillage on Soil Organic Matter

Of all management practices used in crop production tillage by far has the most destructive effect on soil organic matter. There is a vast amount of scientific data reporting the depletion of organic matter after soils in their native grassland condition are subject to cultivation. An exception to this may be desert soils with a very low organic matter content when converted to irrigated cropland. In this case, high production inputs and return of crop residues can lead to an increase in the soil organic matter content (Sampson, 1981). In the USA and in other countries worldwide, agricultural soils continue to lose organic matter with conventional intensive tillage even where crop yields are high and all of the crop residues are returned to the soil. Carlos Crovetto Lamarca, a farmer in Chile who is a practitioner and strong advocate of continuous no-till farming, writes in his book "Stubble over the Soil," that the three worst enemies of the soil are tillage, the match and the axe (Lamarca, 1996), Scientific evidence would indicate that tillage is by far the worst of the three because of its widespread use and devastating effects in accelerating soil erosion and organic matter loss.

In the USA Reicosky and Lindstrom (1993), working at a field site having a long history of cultivation, measured carbon dioxide evolution from plots with a portable canopy cover and gas chromatograph. The treatments consisted of untilled wheat (*Triticum aestivum*) stubble which was either moldboard plowed, chisel plowed, or disked. They found that after 19 days, carbon dioxide evolution (reported as oxidized carbon) was greatest from the moldboard plowed plots. More carbon was lost from this treatment during this time than was contained in tops and roots of the entire wheat biomass. Less carbon was lost from the other two tillage treatments than from moldboard plowing; however, the loss was considerably higher than from the untilled treatment. These results indicate that tillage, which incorporates residues and aerates the soil, can rapidly generate high microbial populations which, in turn, can greatly accelerate the decomposition of crop residues and soil organic matter.

Though the benefits of continuous no-till systems are becoming well-documented scientifically, relatively few farmers have adopted the practice mainly because of various risks during the transition from conventional tillage to no-till. Most of these uncertainties appear to be related to ecological changes that occur in the soil and plant environment, and the inability to manage them until a new equilibrium is established. For example, when soil is no longer tilled the organic matter content slowly increases in the upper-most layers where residues decompose and/or are incorporated by soil insects and animals (Wood and Edwards, 1992). Under many conditions the macrofauna (e.g., earthwonns) tend to increase which alters the soil macroporosity by creating larger pore spaces (Norton and Schroeder, 1987). Undisturbed plant roots also create natural channels as they decompose. The loose but friable structure that is formed by the macro- and microfauna in the absence of mechanical tillage increases the soil's water holding capacity, improves mixing of soil air, and increases nutrient availability (Reganold et al., 1990). However, these physical, chemical and biological changes take time to achieve a true equilibrium, e.g., up to 5 to 10 years or more depending on soil, climate and cropping conditions. One tillage operation can completely destroy a no-till soil structure and the rebuilding must start all over again.

In the early years of conversion to continuous no-till the various physical, chemical and biological changes that occur may not always be beneficial for growth of crop plants but may become favorable later on. For example, Ismail et al. (1994) showed that the yield of no-till corn (*Zea mays*) was about 90 percent of that from tilled corn during the first few years of transition to no-till, but increased to about 110 percent after 20 years. This yield increase is a typical experience of no-till farmers who have maintained a continuous no-till system, especially on soils that have been degraded by erosion or other degradative processes. Lamarca (1996) reported dramatic increases in crop yields with continuous no-till farming on soils that were once severely eroded. Grain yields in 1978-79 when he switched a corn-wheat rotation from conventional tillage to continuous no-till were 2.2 t/ha for wheat and 4.6 t/ha for corn. In the following years, he experienced a progressive increase in yields with no-till, reaching a maximum of 7.5 t/ha for wheat in 1991 and 13.7 t/ha for corn in 1994. On Mr. Lamarca's farm wheat is produced under rainfed conditions and corn with supplemental irrigation. He credits the yield increases largely to overall improved agronomic management (e.g., improved pest control, better crop varieties, and timeliness of farm operations) and to regenerated physical, chemical, and biological soil conditions promoted by continuous no-till.

Among the problems that farmers encounter during the transition to continuous no-till are excessive crop residues which interfere with sowing and which can also cause inhibitory effects (e.g., allelopathy) on plant growth. They may also experience increased weeds and diseases, and may require new, costly equipment for sowing, and fertilizing, and additional expenses for controlling crop pests. The change-over may also require farmers to gain new knowledge and skills to be successful in this different way of farming.

Overcoming Problems During the Transition to No-Till and Maintaining Soil Quality

Most successful no-till farmers indicate that crop rotations which include a diversity of crops are essential for reducing risks to economic production, especially during the transition years. Many farmers use soil building crops sequenced in the rotation, including cover crops and green manures, which are controlled either with chemicals or naturally by weather (e.g., killed by frost, or drought during a dry season). Cover crops are not only a source of organic matter for return to the soil but also can reduce the leaching loss of nutrients where this is a problem. The additional carbon source and retention of nutrients by cover crops can increase soil microbial activity and induce soil aggregation at the surface where it is important for increasing infiltration and reducing soil crusting. For maximum benefits with the use of these crops it is important to keep the residues on the surface and avoid tillage that would incorporate them into the soil.

Starting the no-till conversion with the proper cropping sequence is important for minimizing production risks. However, the scientific principles for this first step are neither well-established nor often understood. For example, in the USA Pacific Northwest, no-till has helped to overcome the problems of rotating bluegrass (*Poa pratensis*) seed fields back into grain crops. This is best achieved when the grass is killed in the spring and the first crop is spring wheat or field pea (*Pisum sativum*) direct-drilled into the dead sod (Elliott and Papendick, 1983). Later, farmer experience showed that lentil (*Lens culinaris*) is also an excellent first crop. Winter wheat does poorly as the first crop because of heavy grass weed growth in the late summer or early fall before sowing, and toxicity to seedlings from decomposition of the sod during cool weather.

The Potential Role of EM in Improving Soil Quality for More Sustainable Agriculture

It would appear that EM and nature farmiing technologies may have considerable potential for helping farmers make the transition from conventional tillage to continuous no-till. For example nature farming has a wealth of experience with crop rotations and the use of cover and green manure crops and legumes for a range of cropping systems. Cropping management could be especially useful for controlling and breaking pest cycles during the transition years and as the farming system equilibrates. Where excessive surface residues are a problem EM may have the potential to accelerate straw decomposition so that farmers can avoid burning or using costly measures to mechanically remove the residues. This would be especially useful with wheat production in the USA Pacific North-west, where fanners who are attempting to use continuous no-till are seeking alternative practices that do not require tillage to reduce surface residues to manageable levels. Can EM be used economically to hasten residue decomposition enough to help them overcome this problem?

Another problem farmers frequently encounter in the first years of no-till is poor emergence and early growth of seedlings with sowings made into moderate to heavy surface residues. These may be related to buildup of soil-borne plant pathogens or microbially-mediated phytotoxic effects from decomposing crop residues during the transition period when complex biological and other changes are occurring in the soil. Can EM be applied as a seed coat or as granular formulations with the seed that would protect both seeds while germinating and seedlings during the early stages of plant growth in the transition years and beyond? Some experienced no-till fanners indicate that plant diseases and weeds become less of a problem as the rotations pass through several sequences and the no-till system matures and stabilizes. The same questions may be asked of EM as an aid for controlling weeds and insect pests as with crop diseases during the transition years and even beyond. It would appear that answers to these and other questions are urgently needed as part of an overall strategy to promote farming systems that enhance soil quality as the “key” to achieving a more sustainable agriculture.

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