CEFS
CENTER for ENVIRONMENTAL FARMING SYSTEMS
NCSU | NCA&TSU | NCDA&CS
www.cefs.ncsu.edu

Soil Quality Considerations for Organic Farmers

by Keith R. Baldwin

In our drive to meet the food and fiber needs of ever-increasing populations, we are taxing the resilience of the planet's natural resources. This fevered quest to pursue ever-increasing crop yields has had devastating impacts: widespread soil erosion, atmospheric pollution, over-grazed forage areas, over-cultivated fields, salinated water supplies, cleared land that is unsuitable for crops, and *desertification*—the loss of agricultural land to desert. The serious degradation of our soil resources has motivated some researchers and farmers to investigate management systems that are less input-intensive and generally more sustainable.

Organic farming is one such system, but it entails much more than simply substituting one set of management practices and inputs for another. Organic farming is a *methodology*—a body of methods and rules—that strives to mimic natural eco-systems in its focus on building soil health. In fact, to fulfill the many requirements for certification of a farm as organic, a farmer must establish a plan to improve soil

Figure 1. A soil scientist assesses the problem of soil erosion on a farm. Photo courtesy of USDA.

Contents

quality or health. The details of the plan on each farm depend somewhat upon how each farmer defines soil quality. A plan's success or failure is determined by changes in measurable *soil quality indicators*.

In this publication, we will discuss how soil quality can be measured and described. The new organic rule stipulates that measuring and managing soil condition is an important component of organic certification. Our discussion, therefore, includes the following topics:

- **Defining soil quality**—Different terms are often used to describe a soil's ability to support crop growth.
- **Soil quality indicators**—These parameters for judging a soil's biological, physical, and chemical properties can be measured as quantities. We will review the importance of organic matter as a biological property that contributes to soil productivity.
- **Qualitative indicators**—The personal descriptions used to describe changes in soil quality can be subjective or exact.
- **Soil quality assessments**—Farmers can use simplified assessments and USDA soil kits to measure changes in soil quality.
- **Interpreting soil quality indicator measurements**—Farmers need to consider other factors when they use indicator measures to evaluate soil health.

DEFINING SOIL QUALITY

The terms *soil quality* and *soil health* are often used interchangeably to describe the soil's ability to support crop growth without becoming degraded or otherwise harming the environment.

Farmers prefer the term *soil health* because it reflects a judgment of the soil as either a robust or ailing resource. The term also portrays the idea of soil as a living, dynamic entity that functions in a *holistic* way—it depends on the condition or state of its interacting parts—rather than as an inanimate entity with a value that depends on its innate characteristics and intended use (Romig et al., 1995).

Soil quality is defined by the interactions of a particular soil's measurable chemical, physical, and microbiological properties. These properties can be managed and adjusted by farmers. Soil quality, therefore, should be distinguished from a soil's *inherent* properties, which cannot be managed or adjusted by farmers. Inherent properties are determined by factors such as climate, topography, vegetation, parent material, and time. From a productivity standpoint, each soil has an innate capacity to function, and some soils will be inherently more productive than others.

In organic farming, a high quality soil is one that provides an environment for optimum root growth, thereby enhancing crop health and productivity. Optimum root growth, however, will also be influenced by the plant species and its genetic potential, environmental conditions imposed by weather, and cultural practices used in the farming system.

A soil that is in balance is said to function within natural or managed ecosystem boundaries, sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. (Doran et al., 1996)

Soil Impacts on Local Ecosystems

A soil's properties determine how effectively it contributes to local ecosystem functions. These functions include:

- Retention and release of nutrients and other chemical constituents.
- Partitioning of rainfall at the soil surface into runoff and infiltration.
- Retention and release of water from the soil to plants, streams, and groundwater tables.
- Resistance to wind and water erosion.
- Buffering against the concentration of potentially toxic materials.

(Larson and Pierce, 1991; Karlen et al., 1997)

SOIL QUALITY INDICATORS

While overall soil health can be measured by the soil's contribution to how well an ecosystem functions, soil quality can be measured by certain parameters or *indicators*. Examples of such indicators are soil water-holding capacity, organic carbon content, and microbial respiration.

Checklists of physical, chemical, and microbial indicators are commonly assembled in a *minimum data set* (MDS). MDS indicators can be measured *quantitatively* at regular intervals. In other words, these indicators can be defined with specific units of measure, and the measurements can be judged against some common standards or analyzed for improvements over time.

A general minimum data set of quantitative indicators is presented in Table 1. Such a data set may vary from location to location depending on how the land is used, such as for rangeland, wetland, or agricultural land. The relative importance of indicators within a data set is likely to change as land use changes. Comparisons between data sets are usually restricted to sites having similar conditions.

Biological Indicators

Some biological indicators of soil quality that are commonly measured include *soil organic matter*, *respiration*, *microbial biomass* (total, bacterial, fungal, or all of these), *microbial biomass carbon and nitrogen*, and *mineralizable nitrogen*.

Soil Organic Matter. Soil organic matter is that fraction of the soil composed of anything that was once alive. It includes plant and animal remains in various stages of decomposition, cells and tissues of soil organisms, and other organic substances. When the organic substances within the soil and any organic matter that has been added to it, such as compost, decompose, they produce *humus*—organic matter that is *stable* or relatively resistant to further decay. Organic matter is an essential component of soils because it plays such an important role in the physical, chemical, and biological components of soil.

A healthy soil produces a plant that:

- Accumulates nutrients efficiently.
- Competes well with weeds.
- Resists pests.
- Suppresses erosion through an extensive root system.

The key to such a healthy soil is a **sustainable microbial ecology**. A high quality soil is biologically active and contains a balanced population of microorganisms.

Table 1. Proposed minimum data set (MDS) of physical, chemical, and biological indicators for screening soil quality	
Indicator	**Function and Rationale for Measurement** a. Relationship to soil condition and function b. Rationale for measurement
	Biological
Microbial biomass C and N	a. Describes microbial catalytic potential and repository for carbon and nitrogen. b. Provides an early warning of management effects on organic matter.
Potentially mineralizable N	a. Describes soil productivity and nitrogen supplying potential. b. Provides an estimate of biomass.
Soil respiration	a. Defines a level of microbial activity. b. Provides an estimate of biomass activity.
	Chemical
Soil organic matter (OM)	a, b. Defines soil fertility and stability.
pH	a, b. Defines biological and chemical activity thresholds.
Electrical conductivity	a, b. Defines plant and microbial activity thresholds.
Extractable N, P, and K	a. Describes plant-available nutrients and potential for N loss. b. Indicates productivity and environmental quality.
	Physical
Soil texture	a. Indicates how well water and chemicals are retained and transported. b. Provides an estimate of soil erosion and variability.
Soil depth and rooting	a. Indicates productivity potential. b. Evens out landscape and geographic variability.
Infiltration and soil bulk density (SBD)	a. Describes the potential for leaching, productivity, and erosion. b. SBD needed to adjust soil analyses to volumetric basis.
Water holding capacity	a. Describes water retention, transport, and erosion. b. Available water is used to calculate soil bulk density and organic matter.
Sources: Derived from Doran et al. (1996) and Larson and Pierce (1994)	

Soil organic matter improves tilth in the surface horizons of the soil, reduces crusting, increases the rate of water infiltration, helps to control runoff, and facilitates root growth. Generally, organic matter makes soil more friable, less *plastic* or sticky, and easier to work. It stabilizes and holds soil particles together in aggregates, thereby reducing the raindrop splash that can lead to erosion. By improving pore size distribution and decreasing bulk density, organic matter also improves the soil's ability to store and transmit air and water.

Soil organic matter is also critical to plant growth and soil organisms because it provides a reservoir of nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, and various minor elements that become available for plant growth as it decomposes. Management practices common in organic farming systems work to build soil organic matter and humus content over time. These practices include regular applications of compost, manure, and other organic materials; inclusion of cover crops as green manures in cropping systems; rotations that include forage crops; and reductions in tillage.

Cropping systems and soil management also profoundly influence the amount of soil organic matter. For instance, dramatic losses in soil organic matter can take place on farms where soil is inverted or mixed annually through tillage.

As discussed in the composting publication of this series, compost can be an important component of organic farming systems. Because of the *humified nature* of compost, it is relatively resistant to further decomposition. So additions of compost over time can increase soil organic matter and humus content. Organic farmers use composts not so much to provide nutrients as to provide stabilized organic matter, which improves the soil's physical properties.

Less Crop Residue = Less Organic Carbon

Generally, practices that reduce the amount of residue left in the field after harvest deplete soil organic carbon. These practices include:

- Replacing perennial vegetation with short-season vegetation.
- Replacing mixed vegetation with monoculture crops.
- Introducing more aggressive but less productive species.
- Using cultivars with high harvest indices (ratio of harvested biomass to total biomass).
- Increasing the use of bare fallow (fallow periods provide little in the way of biomass additions while allowing mineralization of organic matter in soil to continue).

Factors that increase the mineralization rate of organic matter also deplete soil organic carbon (such as frequent tillage, drainage of wet soils, and application of fertilizers, especially nitrogen).

Soil Respiration. Soil respiration is the creation of carbon dioxide (CO_2) as organic matter decomposes in the soil. It provides a gauge of the activity of living organisms in the soil. Microbial respiration and activity are influenced by such elements as moisture, temperature, availability and degradability of organic residues, and toxic effects of various agricultural chemicals.

Respiration generally increases as organic matter is added to the soil, indicating that increased biological activity is taking place. Decreased respiration rates in times of heavy rains might reflect flooded soils that have problems with partitioning water as they should. A rise in respiration rates in cases of environmental contamination in soils might indicate that living microbes are at work to decompose pollutants.

Organic Carbon. Soil organic carbon, in particular *labile* (easily decomposed) organic carbon, has an overwhelming effect on soil microbial activity (Hajek et al., 1990). Labile organic carbon makes up approximately 10 to 14 percent of total soil carbon. It is the heterogeneous mix of living and dead organic materials that are readily circulated through soil *biological pools,* groups of interacting organisms. This carbon is the basis for a major soil nutrient reservoir.

Microbial Activity. Microbial activity in the soil can be assessed in a number of ways. Farmers can measure the status of either the total community of micro organisms or specific members of that community. Of these two assessments, the latter is perhaps the most useful. For example, populations of predatory nematodes are good indicators of soil quality. These microscopic worm-like organisms play numerous important roles in the soil, with both negative and positive effects. Some act as *primary consumers* of plants—in other words, they are pests. Others act as *secondary predators* of bacterial and fungal feeders—they serve as *beneficials* in the soil. Thus, an analysis of nematode communities is one way to determine the health and balance of a soil.

Earthworms. Earthworms are also good bioindicators of soil quality. Earthworm populations can tell a researcher a great deal about the structural, microclimatic, nutritive, and toxic status of soils (Christensen, 1988). Large, vertically-burrowing earthworms play an important role in conserving and improving soil structure, recycling soil nutrients, promoting the gradual mixing of the soil layers, and creating an aeration and drainage system in the soil.

How Organisms Help To Build Soil Quality

Soil organisms contribute to the maintenance of soil quality because they control many of the key processes that occur in healthy soil, including these:

- Decomposition of plant residue and organic material.
- Mediation of availability of phosphorous (P), manganese (Mn), iron (Fe), zinc (Zn), and copper (Cu) via microbial-mediated processes, including symbiotic mycorrhizal associations.
- Production of organic chelating agents.
- Solubilization of phosphate.
- Fixation of biological N.
- Biological control of plant diseases, nematodes, insects, and weeds.
- Biodegradation of synthetic pesticides or other contaminants.
- Enhancement of a plant's drought tolerance.
- Improvements in soil particle aggregation.

(Kennedy and Papendick, 1995)

Farmers must be cautious in attempting to judge soil quality by interpreting biological indicator measurements. For instance, an increase in soil microbial biomass or activity cannot automatically be equated with an increase in soil quality. After a farmer incorporates organic matter into the soil, microbial biomass and respiration usually increase. This is because the increased food supply in the soil will support a higher population of decomposer organisms. Whether or not respiration and biomass remain elevated will depend on whether additional organic matter is added or not.

Tillage also stimulates microbial activity and respiration by increasing the amount of oxygen available to soil microbes. It is important to remember this: The microbial activity that will be stimulated is associated with decomposing soil organic matter, a soil quality parameter that we want to increase. Soils that have been in conventional tillage for many years may have lost much of their organic matter content in this manner. Therefore, it takes a dedicated effort by farmers to increase soil organic matter content. Conventional tillage systems require annual additions of organic matter.

Chemical Indicators

Farmers who want to achieve the high crop yields expected of modern agriculture will have to provide nutrients in large quantities. Farmers increase and alter the pool of available nutrients by adding fertilizers, incorporating cover crops, and using other organic materials, such as manures and composts. The types and proportions of amendments—and how they contribute to soil quality—largely depend on each farmer's management principles and philosophy. In any case, soil chemistry, with its influence on the availability of nutrients to plants, plays a key role in soil quality.

Acidity. Soil acidity (pH) is one of the principal factors affecting nutrient availability to plants. The major nutrients (nitrogen, potassium and phosphorous) can't effectively promote high crop yields if the soil pH is not correct. Decreasing soil pH increases the solubility of elements such as aluminum, zinc, copper, and iron. At pH values less than approximately 5.5, toxic levels of these elements may even be present in the soil. Applying lime will help to increase soil pH and thus decrease the solubility of these elements in the soil.

Liming has other benefits as well. It tends to produce favorable conditions for microbial activity in soil, with such related benefits as enhanced nitrogen fixation and, in some cases, improved soil structure.

Physical Indicators

A soil's physical properties affect crop performance in many ways. Plant health and growth are heavily influenced by the soil's *texture*, *bulk density* (a measure of compaction), *porosity*, *water-holding capacity*, and the presence or absence of *hard pans*. These properties are all improved through additions of organic matter to soils.

Soil physical properties also influence soil-water and plant-water relationships. The partitioning of water at the soil surface is important because it determines both the quantity and the quality of surface and groundwater, as well as the amount of water that will be available for plant growth. Water running over the surface, rather than infiltrating it, can carry sediment and other pollutants (Karlen et al., 1997). This run-off can result in negative impacts on water quality in surface waters, such as rivers, ponds, and lakes.

QUALITATIVE INDICATORS OF SOIL QUALITY

Qualitative descriptions of soil quality are usually personal assessments of short-term changes in soil quality. For example, a farmer using such a description may tell a visiting Extension agent, "There seemed to be more earthworm activity this year."

Alternatively, the personal assessment may be a thoughtful conclusion based on recollections of how things were "way back when" compared to how they are today. We might hear a farmer make a longer-term assessment by saying, "All that compost I added since I bought the place 10 years ago sure has improved my soil; why, the color's changed from brick red to burnt sienna."

Unfortunately, these kinds of field observations may be influenced by wishful thinking or *subjective impressions*—observations that are colored by one's personal views, experience, or background. When making qualitative assessments of soil quality, it is important to rely upon a set of well-defined *qualitative indicators* (see Table 2). Although these qualitative indicators cannot be gauged in units of measure, each one can be assessed based on the specific observations noted in Table 2.

ASSESSING SOIL QUALITY

A Simplified Assessment

Farmers can use a simple set of qualitative and quantitative assessments to track changes in soil quality over time (see Table 3). This simplified assessment includes a guided visual check of crop conditions, surface residue, living organisms, surface structure, and soil erosion using the qualitative indicators in Table 2. Included are evaluations of compaction, subsurface structure, soil pH, and humic matter content. The last two components of this assessment are quantitative indicators that require a soil test.

These simplified assessments are relatively easy to make. To perform the assessment, first turn over a shovelful of soil about 6 to 8 inches deep. On the assessment sheet, rate each indicator by marking an *X* or shading out the box that best represents the value for that indicator. Assessments are most effective when filled out by the same user over time and under similar soil moisture levels. The assessments are qualitative; therefore evaluation scores do not represent any absolute measure. Assessing soil in more than one spot per field will provide more accurate results.

USDA Soil Quality Kits

As its name implies, a soil quality kit can help a farmer to assess and manage soil quality. Farmers can inquire about the availability of testing kits at their local USDA office. The USDA soil testing kit was designed as an instructional tool and data collection device for those interested in monitoring changes in soil quality. Specifically, the handbook and kit are designed to do the following:

- Define and demonstrate the use of indicators of soil quality and degradation.
- Explain how land use practices may enhance or degrade soil quality.
- Provide simple field tests of soil quality indicators.
- Provide a list of resources for further exploration of soil quality issues.

The soil quality kit describes a set of measurements, a minimum data set (MDS). These measurements can be taken in the field to assess the *holistic* nature of soil health in agricultural systems. By holistic, we mean that the measurements interweave the physical, chemical, and biological components of soil and the resulting interactions. A farmer should use the kits as a screening tool to show the general trend or direction of soil quality; for instance, whether current management systems are maintaining, enhancing or degrading the soil.

The soil quality kit can also be used to make side-by-side comparisons of different soil management systems and determine their relative effects on soil quality. It can be used to take measurements on the same field at different times, which will help farmers to monitor trends in soil quality as affected by soil use and management. It is also handy for comparing problem areas in a field to nonproblem areas.

Table 2. Qualitative Soil Quality Indicators

Indicator	Poor	Medium	Good
Earthworms	0-1 worms in shovelful of top foot of soil. No casts or holes.	2-10 in shovelful. Few casts, holes, or worms.	10+ in top foot of soil. Lots of casts and holes in tilled clods. Birds behind tillage.
Organic matter (OM) color	Topsoil color similar to subsoil color.	Surface color closer to subsoil color	Topsoil clearly defined, darker than subsoil
Roots/residue/(OM)	No visible residue or roots.	Some residue, few roots.	Noticeable roots and residue
Subsurface compaction	Wire breaks or bends when inserting surveyor's flag.	Have to push hard, need fist to push flag in.	Flag goes in easily with fingers to twice the depth of plow layer.
Soil tilth, mellowness, and friability	Looks dead. Like brick or concrete, cloddy. Either blows apart or hard to pull drill through.	Somewhat cloddy, balls up, rough pulling seedbed.	Soil crumbles well, can slice through, like cutting butter. Spongy when you walk on it.
Erosion	Large gullies over 2 inches deep joined to others, thin or no topsoil, rapid run-off the color of the soil.	Few rills or gullies, gullies up to two inches deep. Some swift runoff, colored water	No gullies or rills. Clear or no runoff
Water holding capacity	Plant stress two days after a good rain.	Water stress after a week	Holds water for a long period of time without puddling.
Drainage, infiltration	Water lays for a long time, evaporates more than drains, always very wet ground	Water lays for short period of time, eventually drains	No ponding, no runoff, water moves through soil steadily. Soil not too wet, not too dry.
Crop condition	Problem growing throughout season, poor growth, yellow or purple color.	Fair growth, spots in field different, medium green color.	Normal, healthy dark green color, excellent growth all season, across field.
pH	Hard to correct for desired crop.		Proper pH for crop.
Nutrient holding capacity	Soil test values dropping with more fertilizer applied than crops use.	Little or slow change	Soil tests trending up in relation to fertilizer applied and crop harvested.

Source: Maryland Quality Assessment Book, Natural Resource Conservation Service

Table 3. Simplified Assessment of Soil Quality

ASSESSMENT SHEET									
Date				**Crop**					
Farm / Field ID									
	Poor			**Medium**			**Good**		
Soil Quality indicators	1	2	3	4	5	6	7	8	9
Earthworms									
Organic matter color									
Organic matter roots/residue									
Subsurface compaction									
Tilth/friability mellowness									
Erosion									
Water holding capacity									
Drainage infiltration									
Crop condition									
pH									
Nutrient holding capacity									
Other (write in)									

INTERPRETING SOIL QUALITY INDICATOR MEASUREMENTS

Farmers should always remember that field conditions vary widely depending on the landscape, region, climate, and other factors. Therefore, the relative importance of soil quality measurements will vary accordingly. Any interpretation of results, particularly comparisons between fields, needs to reflect these differences. It is important that each site evaluated is characterized by soil series, signs of erosion, management history, landscape position, location of field and sampling site, climatic condition, and location of environmentally sensitive areas.

Because soil quality parameters vary widely, sampling at the same site, at sites with similar management operations (tillage, for example), and at the same time of year is important. Within a given field, consideration should be given to the following:

- row versus inter-row areas
- differences in soil type
- differences in management
- tracked versus nontracked areas
- salt-affected versus non-salt-affected areas
- eroded versus noneroded areas
- drainage

Generally, when collecting soil for an assessment, a farmer should select sites representative of the field or trouble spots within the field. A minimum of three samples or measurements should be collected on any one soil type and management combination. The greater the variability of the field, the greater the number of measurements that are needed to get a representative value at the field scale.

Initial measurements of all soil quality indicators should be made in high and low productivity areas to establish a range of values that are site specific. This allows for the assessment of changes occurring through time with different management systems.

A farmer's ability to interpret changes in indicators of soil quality normally improves over time. It takes some experience to know what kind of change and how much change in an indicator is actually meaningful. Farmers will need to recognize that local, random changes in field conditions—caused by such elements as weather and human activity—can radically influence indicator values at any particular point in time. Natural cycles will also influence indicator values.

Farmers can expect to see regular changes in values that result from seasonal weather variations, crop growth stage effects, fluctuation of groundwater tables, and other natural cycles. For example, the amount of plant available nitrogen (PAN) in the soil depends on the decomposition and mineralization of cover crop biomass through microbial activity. Microbial activity is a commonly measured soil quality parameter. However, mineralization rates vary with the season and with management practices. A farmer would need to recognize such variations when making any comparisons of available nitrogen.

As a second example, let's say a farmer measures a change in soil pH from 5.9 to 6.0. Is this a meaningful change? A pH change of 0.1 units would not normally be enough to make a difference in crop production, whereas a pH change from 5.0 to 5.8 over a two-year period certainly would be.

New Organic Rule: Managing Soil Fertility

Regarding soil fertility, the USDA Organic Rule states the following:

- Farmers must manage soil fertility, including tillage and cultivation practices, in a manner that maintains or improves the physical, chemical, and biological condition of the soil and minimizes soil erosion.
- Farmers are responsible for identifying measurable indicators that can be used to evaluate how well they are achieving the objectives of the operation.
- The specific indicators used to evaluate a given organic system plan will be determined by the farmer or handler in consultation with the certifying agent.
- If the organic system plan calls for improvements in soil organic matter content in a particular field, it should include provisions for analyzing soil organic matter levels at periodic intervals.

Changes in measured soil quality parameters over an extended period of time are referred to as *trend changes*. Ideally, the trend is positive. That is, soil quality improves, albeit often slowly, over time. Note that trend changes can be negative as well. For example, soil humus content may decrease because of extensive tillage to control weeds. This decline would represent a *depletive* management system. Trends are usually gauged over a relatively long period of time, such as 10 years.

Unfortunately, trend changes don't provide an immediate assessment of soil quality. They require measurements of indicators over an extended period. Within that extended period, farmers should recognize changes between any two points in time that are definitive, important, and rapid enough that management can be altered (if necessary) to influence trends.

Another drawback to gauging changes in soil quality by trends is that a trend line may essentially be flat. For instance, measurement of a quality parameter, such as soil microbial biomass, in year 1 may be equal to the measurement in year 10. A farmer interpreting this information must consider the possibility that the soil may be functioning at its highest attainable level and cannot improve, or it may be functioning at its lowest level and cannot go lower (Seybold et al., 1997).

RECOMMENDED READING

References Cited

Much of the information contained in this section is summarized from *The Soil Quality Concept,* a United States Department of Agriculture, Natural Resources Conservation Service publication edited by The Soil Quality Institute.

Christensen, O. 1988. The direct effects of earthworms on nitrogen turnover in cultivated soils. Ecology Bulletin. 39:41-44.

Doran. J.W., M. Sarrantonio, and M.A. Liebig. 1996. Soil health and sustainability. Advances in Agronomy. 56:1-54.

Hajek, B.F., D.L. Karlen, B. Lowery, J.F. Power, T.E. Schumaker, E.L. Skidmore, and R.E. Sojka. 1990. Erosion and soil properties. In W.E. Larson, G.R. Foster, R.R. Allmaras, and C.M. Smith (Eds.) *Research Issues in Soil Erosion Productivity*. pp. 23-40. University of Minnesota. St. Paul, MN.

Karlen, D.L., M.J. Mausbach, J.W. Doran, R.G. Cline, R.F. Harris, and G.E. Schuman. 1997. Soil quality: A concept, definition, and framework for evaluation. Soil Science Society of America Journal. 61:4-10.

Larson, W.E., and F.J. Pierce. 1994. The dynamics of soil quality as a measure of sustainable management. In J.W. Doran, D.C. Coleman, D.F. Bezdicek, and B.A. Stewart (Eds.) *Defining Soil Quality for a Sustainable Environment*. SSSA Spec. Pub. No. 35. ASA, CSSA, and SSSA, Madison, WI.

Larson, W.E., and F.J. Pierce. 1991. Conservation and enhancement of soil quality. In *Evaluation for Sustainable Land Management in the Developing World*. pp 175-203. Int. Board for Soil Res. and Management. Bangkok, Thailand.

Romig, D.E., M.J. Garlynd, R.F. Harris, and K. McSweeney. 1995. How farmers assess soil health and quality. Journal of Soil and Water Conservation. 50:229-236.

Seybold, C.A., M.J. Mausbach, D.L. Karlen, and H.H. Rogers. 1997. Quantification of soil quality. In B.A. Stewart and R. Lal (Eds.) *Advances in Agronomy. Proceedings from an International Symposium on Carbon Sequestration in Soil*. Lewis Publishing.

Additional Reading

Cavigelli, M.A., S.R. Deming, L.K. Probyn, and R.R. Harwood (Eds.) 1998. Managing biological processes for productivity and environmental quality. *Michigan Field Crop Ecology*. Michigan State University Extension Bulletin E-2646.

Doran, J.W., D.C. Coleman, D.F. Bezdicek, and B.A. Stewart (Eds.) 1994. *Defining Soil Quality for a Sustainable Environment*. American Society of Agronomy Special Publication No. 35. Madison, WI.

Follett, R.F., J.W.B. Stewart, and C.V. Cole. 1987. *Soil Fertility and Organic Matter as Critical Components of Production Systems*. SSSA Special Publication Number 19. Soil Science Society of America, Inc. Madison, WI.

Gershuny, G., and J. Smillie. 1986. *The Soul of Soil: A Guide to Ecological Soil Management.* 2nd Ed. 1986. Gaia Services. St. Johnsbury, Quebec.

Magdoff, F. 1992. *Building Soils for Better Crops: Organic Matter Management*. University of Nebraska Press. Lincoln.

National Organic Program. 2000. *The Final Rule*. Online: http://www.ams.usda.gov/nop/nop2000/nop/finalrulepages/finalrulemap.htm.

NRCS (National Resource Conservation Service). 1997. *Maryland Soil Quality Assessment Book*. USDA. Washington, DC.

Parnes, R. 1990. *Fertile Soil: A Grower's Guide to Organic & Inorganic Fertilizers*. agAccess. Davis.

Sanders, D.W. 1992. International activities in assessing and monitoring soil degradation. American Journal of Alternative Agriculture. 7:17-24.

Sullivan, P.G., D. Doel, and C. Rugen. 1995. *Sustainable Soil Management*. Sustainable Agriculture Fundamental Series. ATTRA. Fayetteville, AK.

U.S. Department of Agriculture. 1998. *Soil Quality Test Kit Guide*. United States Department of Agriculture. Agricultural Research Service. Natural Resources Conservation Service. Soil Quality Institute. Washington, DC.

U.S. Department of Agriculture. 1980. *Report and Recommendations on Organic Farming*. U.S. Govt. Printing Office. Washington, DC.

The *Organic Production* publication series was developed
by the Center for Environmental Farming Systems,

a cooperative effort between North Carolina State University,
North Carolina A&T State University, and the
North Carolina Department of Agriculture and Consumer Services.

The USDA Southern Region Sustainable Agriculture Research and Education Program
and the USDA Initiative for Future Agriculture and Food Systems Program
provided funding in support of the *Organic Production* publication series.
David Zodrow and Karen Van Epen of ATTRA
contributed to the technical writing, editing, and formatting of these publications.

Prepared by
Keith R. Baldwin, Program Leader, ANR/CRD
Extension Specialist—Horticulture
North Carolina A&T State University

Published by
NORTH CAROLINA COOPERATIVE EXTENSION SERVICE

AG-659W-04

07/2006—BS
E06-45788