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# Introduction

Humankind owes its existence to the thin layer of topsoil that covers much of the earth. Soil takes hundreds of years to form and from it we derive food, fiber, and shelter. Therefore, how we care for and use soil will always be important. This bulletin describes the importance of soil quality and how it may be defined, evaluated, and managed in vegetable and small fruit production. A glossary of terms used to describe and evaluate soil quality is included at the end of the publication. Selected soil quality-related publications and websites are also provided for additional reference.

# Why Soil Quality Is Important, Especially in Agriculture

Soil is a fundamental natural resource with which agriculture meets basic human needs. Soil also supports natural ecosystems as it cycles water and chemical elements, including carbon, nitrogen, and phosphorus, through the biosphere. Soil, air, and water quality contribute equally to the health of our environment. Indeed, appreciation for the diverse functions that soils perform in watersheds and ecosystems continues to grow.

Our recognition that soils, in both agricultural and natural landscapes, are diverse living systems has fueled curiosity about how to measure and manage soil quality, especially its biological components and its role in agricultural production. The fact that it takes hundreds of years for each inch of topsoil to form makes soil preservation a serious issue for everyone, especially in this era of great public concern about the environment and depletion of natural resources.

*Soil cycles nutrients.*

*Soil regulates water flow.*

Soil quality is everyone's concern, but for those who farm, soil quality is essential. In fact, growers may have only two true resources — their know-how and good quality soil. Lacking either jeopardizes the farm's success. Farmers have many opportunities to increase their know-how, but repairing severely degraded soil may be impossible — it is certainly difficult, time-consuming, and costly. Successful farmers recognize that preservation of healthy, high-quality soils is essential to profitable and sustainable crop production.

Soils can provide the physical support, nutrients, water, and gas exchange necessary

**The Dust Bowl phenomenon of the 1930s forced the emigration of thousands and is a striking example of soil degradation due to environmental factors (drought) compounded by soil mismanagement. Erosion removed topsoil and severely reduced soil quality on millions of acres of farmland.**

for crop growth. Soils are also home to many organisms, large and small, which directly or indirectly impact crop growth. Physical, chemical, and biological soil factors determine the need for various inputs, such as water, fertilizer, and pesticides.

*Soil provides food.*

## Defining Soil Quality

Soil quality is defined in various ways. Implicit in most definitions of soil quality is the idea that the most important attributes of a healthy soil vary, depending upon a human value judgment about the primary function of a particular soil in a specific location.

Many define soil quality in terms of a soil's ability to perform its basic functions. These functions include a soil's role in plant growth, hydrology (i.e., the Water Cycle), biological transformations, and degradation of organic materials. All four of these functions are important in both agricultural and ecological contexts.

Soil quality is frequently 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" (USDA - Natural Resources Conservation Service, Soil Science Society of America).

Soil quality may also be defined simply as "fitness for use." Although soil has many functions and uses, this bulletin focuses on the use of soils for production of vegetable and small fruit crops. In this context, farmers often define a soil's quality based on its ability to produce a good crop with minimal inputs.

Evaluation of soils for agricultural and other land uses has been practiced for generations. In modern times, extensive soil surveys completed in the United States and elsewhere classified the suitability of soils for agricultural and other uses. However, classifying soils based on their intrinsic (and, mostly, unalterable) properties is not the same as evaluating soil quality.

Soil quality is not concerned with rating or comparing the suitability of different soil types for a specific use, such as agriculture. Instead, soil quality is concerned with evaluating the condition of a particular soil in relation to its potential capacity. Therefore, the focus of soil quality is on properties or processes impacted by soil management. In considering soil quality, do not ask "Is this soil suitable for farming?" Rather, ask "How will my management affect this soil?"

## Evaluating Soil Quality

### Physical, Chemical, and Biological Indicators of Soil Quality

Soil quality is evaluated using indicators that measure specific physical, chemical, and biological properties. Although it is useful to examine these aspects of soil quality individually, soil should be viewed as an integrated system rather than a collection of separate parts or processes.

Physical and chemical properties are shaped by biological activity, and biological activity is enhanced or limited by chemical and physical conditions. For this reason, specifically categorizing some soil indicators is difficult. For example, cation exchange capacity (CEC) could be classified as either a physical or a chemical property, and organic matter as either a chemical or a biological property. The best and most useful indicators of soil quality integrate the combined effects of several properties or processes.

Important physical indicators of soil quality include those related to water storage and movement, soil structure, and soil or aggregate stability. Important chemical indicators include the presence and amounts of mineral elements and plant growth inhibiting substances. Biological indicators often refer to the amounts, types, and activities of soil organisms. A large, diverse, and active population of soil organisms may be the most important indicator of a healthy, high-quality soil. Yet, soil biological activity may be the most difficult indicator to satisfactorily measure and interpret.

Soil-quality indicators are limited to properties impacted by soil management. For this reason, some soil characteristics are not considered soil-quality indicators although they may influence soil use or productivity. Soil texture, topsoil depth, and slope or topography are examples of fixed soil properties that cannot be altered (except over long time periods or in extreme cases of erosion or sediment deposition). Although these characteristics clearly influence soil use or productivity, they are not used as soil-quality indicators.

Nevertheless, it is important to be knowledgeable about inherent soil properties because they often set limits on the maximum soil quality management practices can achieve. For example, soil texture refers to the relative amounts of primary mineral particles (sand, silt, clay) found in a soil. Coarse-textured sandy soils have proportionately more larger sand particles, while fine-textured clayey soils have proportionately more smaller clay particles. Soil texture is an unalterable soil property which strongly influences many soil-quality indicators, like drainage and water-holding capacity. But soil texture itself is not an indicator of soil-quality.

## Methods and Tools to Evaluate Soil Quality

### Ohio Soil Health Card and USDA Soil Quality Test Kit

Proper evaluations of soil quality require methods to measure indicators and a baseline or standard set of optimum values for comparison. Reliable methods and standard values are available for some properties. Soil chemical properties can be routinely and reliably measured. For example, soil fertility analysis measures certain chemical properties of soil and is widely used in modern agriculture. Decades of research on the responses of different crops to varying pH and nutrient levels on a range of soil types assists growers in knowing how much lime and fertilizer (synthetic or organic) is required to achieve high marketable yield. Soil sampling for fertility analysis is relatively simple for farmers or consultants to do, and many soil testing labs provide accurate and inexpensive lime and fertilizer recommendations.

Physical and biological properties are more difficult or expensive to measure objectively and interpret. Still, there are two tools avail-

**Leading Indicators of Soil Quality**

| Physical | Chemical | Biological |
|---|---|---|
| structure | pH | respiration rate |
| bulk density | cation exchange capacity | earthworms |
| drainage | plant-available nutrients | microbial numbers |
| water infiltration rate | organic matter | microbial biomass |
| water-holding capacity | soluble salts | species diversity |
| soil strength (penetration resistance) | contaminants (metals,toxins) | pathogens (plant and human) |

*Soil Probe*

able to assist farmers in assessing soil quality at the farm or field level — the Ohio Soil Health Card and the USDA Soil Quality Test Kit.

The Ohio Soil Health Card and the USDA Soil Quality Test Kit are useful in assessing soil quality at the farm or field level. The Ohio Soil Health Card evaluates a soil's health or quality using soil and plant indicators identified by farmers. Twelve specific indicators are grouped into four categories — soil tilth, soil life, soil air and water, and plant vigor, which are subjectively rated on a scale of Good, Fair, or Poor. The Card relies heavily on crop growth as an indicator of soil quality, even though it is an indirect indicator.  In this way, the Card integrates physical, chemical, and biological aspects of soil quality.

The Card was developed for farmers by farmers and is a tool to help monitor and improve soil quality based on farmers' field experience and working knowledge of their soils. Regular use allows farmers to record long-term trends and changes in soil quality and to compare the effects of different soil management practices. Because it provides a qualitative assessment of soil quality, the Card is most effective when filled out consistently over time by the same person for each individual field.

The USDA Soil Quality Test Kit is a toolbox with components for taking relatively simple and inexpensive measurements of soil-quality indicators while in the field. In fact, several of the measurements can only be done on intact soil in the field. The test kit was developed by the Agricultural Research Service, refined and expanded by the NRCS Soil Quality Institute, and designed for ease of use by farmers, consultants, Extension and NRCS staff, and other agricultural professionals. Soil properties measured with the Test Kit include:

- Physical indicators — water infiltration, bulk density, water-holding capacity, aggregate stability, soil slaking, and penetration resistance.
- Biological indicators — soil respiration and earthworm numbers.
- Chemical indicators — pH, electrical conductivity (soluble salts), and nitrate-nitrogen.

*Photo courtesy GEMPLER'S, Inc.*

*USDA Soil Quality Test Kit*

The Soil Quality Test Kit Guide carries instructions describing how to complete the tests, worksheets for recording data and calculating results, and suggestions on how to interpret the results of each test. Test kits are available for use in Ohio through Ohio State University Extension District Offices and the organization Innovative Farmers of Ohio (IFO).

**If you could have only one tool to evaluate soil quality, the best choice would be to select a shovel and dig a hole.**

Soil quality is evaluated to assess the extent of soil degradation and maintain or improve the condition of a soil. In agriculture, soil-quality assessment is only meaningful when the results are used to maintain and improve soil quality. In addition to becoming familiar with how to define and evaluate soil quality, farmers and others will benefit by recognizing the common causes for declines in soil quality. This is important in managing soil quality.

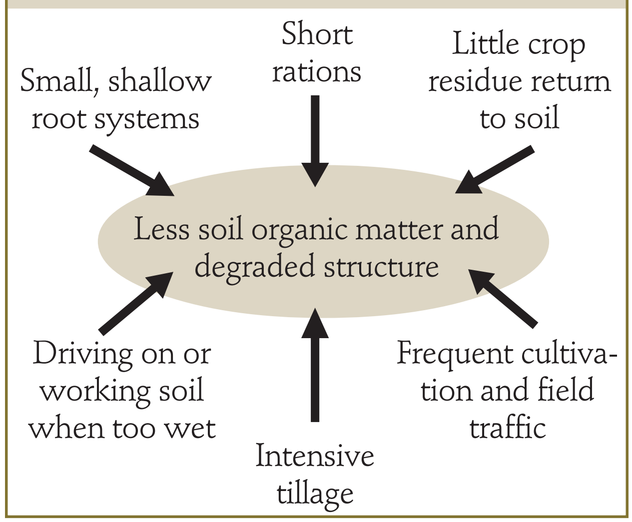
# Managing Soil Quality

## Causes for Decline in Soil Quality in Vegetable and Small Fruit Production

Soil quality is often degraded through a combination of factors that cause a decline in soil organic matter (SOM) and loss of soil structure. The small, shallow root systems of certain crops, in combination with short rotations, intensive tillage, and frequent cultivation and field traffic, create many opportunities to lessen organic matter and destroy soil structure (i.e., increase compaction). Soil degradation is hastened by using crops or practices that return little organic matter to the soil or by driving on or working the soil when it is wet. Many of these practices seem unavoidable (e.g., how to grow and harvest without frequent cultivation and field traffic?).

At first glance then, one may ask what can be done to improve or maintain soil quality. An important step in the process is to recognize that no single management practice or group of practices will ensure that soil quality remains high in all situations, since soils and landscapes are not uniform, and cropping system requirements are highly variable. The best practices for improving and maintaining soil quality will be site- and farming system-specific. However, several generalizations can be made:

**Causes for Declines in Soil Quality in Vegetable Production**




- Organic matter plays a key role in nearly all physical, chemical, and biological soil properties.
- Extensive tillage and cultivation (especially of wet soils) tend to reduce SOM, degrade soil structure, and increase erosion.
- Soil quality must be managed with the same energy and focus as other production issues, like pests and diseases. After all, a farmer's know-how and soil are his or her only true resources.

## The Role of Organic Matter, Rotation, and Tillage

Many factors affect soil quality, but soil organic matter is arguably the most critical. Soil organic matter is an excellent example of a soil component having physical, chemical, and biological properties. Maintaining levels of stable organic matter in the soil is important, but the quantity of organic matter is only part of the story.

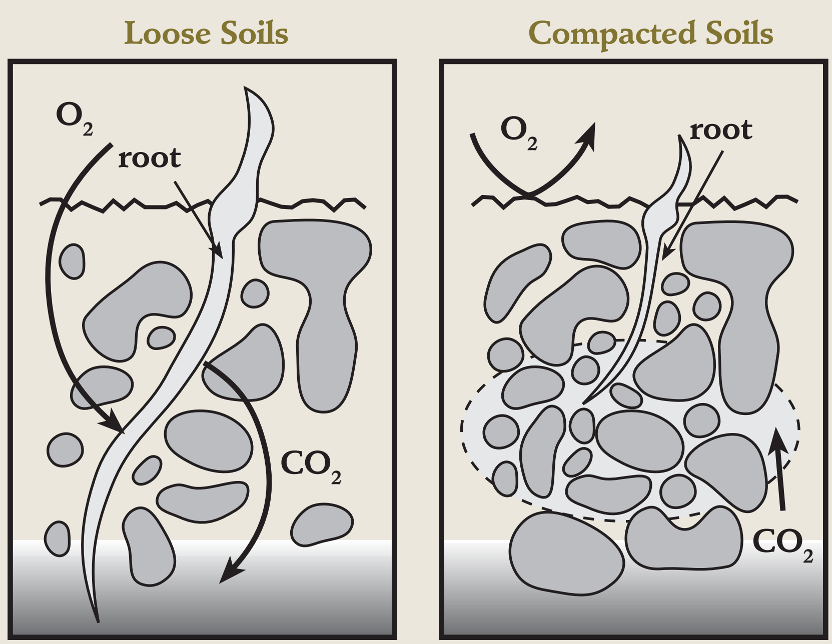
Organic matter is a central component of the soil food web, so soil organisms naturally decompose and deplete it as they grow. More important, the types and activities of soil organisms and the biological processes in which they are involved change with time, climate, rotation, and other factors. This results in different types of organic matter being present in the soil at any one time. Why is this imporant? We are learning that the type of organic matter present is at least as important as the total amount.

Types of organic matter are very difficult to describe objectively. But, for convenience, soil organic matter is often described as belonging to one of three types or "pools:"

- The diverse array of living organisms, including plant roots.
- An "active" pool that is readily turned over or decomposed under favorable conditions (in periods often measured in months).
- Humus, which is relatively stable and resistant to further decomposition (often lasting hundreds of years).

The breakdown of "active" organic residues produces long polysaccharides (sugars) that are gummy and bind soil particles into stable aggregates that resist compaction and erosion. Aggregation is also promoted by networks of filaments (hyphae) from fungi growing through the soil, the binding action of plant roots, and root exudates. Aggregation and the activity of earthworms, burrowing insects, and plant roots create channels that aid water infiltration, aeration, and drainage.

In quick-draining sandy soils, organic matter increases soil water-holding capacity. Assimilation by living plants, microbes, and other soil organisms retains nutrients, preventing them from leaching. Later, breakdown of "active" and stable types of organic matter releases nutrients essential for the growth of plants and soil organisms. Stable organic matter (humus) also buffers soil pH (making soil more resistant to changes in pH) and retains nutrients through its contribution to CEC. A plentiful amount and diverse range of organic matter provides food and energy for soil organisms, and the resulting biological diversity and competition can significantly suppress some plant pests.




***Nutrient and water uptake and air exchange occur by means of roots, especially small root hairs. The size and arrangement of soil particles must allow for easy movement of nutrients, water, and air to and from roots. Loose, friable soils, depicted at left, permit free exchange and promote root growth. Compacted soils restrict exchange and prevent root growth and penetration. As a result, crops grown in compacted soils are weaker, less stress tolerant, and require greater inputs.***

Organic matter levels have declined 30% to 50% in many areas since the introduction of agriculture, primarily based on short rotations and aggressive tillage and cultivation. However, many soil- and crop-management practices can increase SOM, stimulate biological activity, improve soil structure, and reduce erosion. These practices include:

• Reducing tillage. This slows decomposition of crop residue and limits erosion of organic-matter-rich topsoil.

• Avoiding the urge to work soil when it is wet, common in springtime planting preparation. Working wet soil compacts it. Working wet soil leads to a cascade of events, resulting in severely degraded soil structure and weak, input-demanding, low-yielding crops.

• Diversifying and lengthening rotations. Include legumes and deep-rooted and high-residue crops to add nitrogen, recycle nutrients from the subsoil, disrupt plow pans, and stimulate soil biological diversity.

• Adopting a "no bare soil" philosophy. Plant cover crops to increase organic matter inputs, recycle nutrients, reduce runoff and erosion, suppress weeds (which may limit the need for cultivation), and add nitrogen (if they include legumes). Practices such as intercropping, double-cropping, and using living or plant-residue mulches increase the time the soil is covered and provide many of the same benefits as cover crops.

• Applying organic soil amendments, such as manures, composts, biosolids (sewage sludge), food waste and processing effluent, leaves, wood chips, sawdust, grass clippings, and other high-carbon residues and wastes, to stimulate biological activity and add organic matter and nutrients. Be careful to avoid crop nitrogen deficiency when applying material with a high carbon:nitrogen ratio (above 30:1). Time applications to permit significant decomposition before planting and adjust fertilizer nitrogen to maximize the benefits of organic amendments.

## Specific Tips for Vegetable Production

Maintaining soil organic matter is a significant challenge in the production of annual vegetable crops. There are two reasons for this:

- Many vegetables are short-season, low-residue crops that return small amounts of organic material to the soil after harvest.
- Vegetable cropping systems often involve intensive tillage and cultivation which promote rapid depletion of soil organic matter.

Carrots and onions are prime examples of low-residue crops that leave little organic matter to replenish the soil after harvest. Potatoes produce high amounts of organic matter per acre, but most is removed in the tubers. Radishes and leafy crops like lettuce and spinach have short growing seasons and return little residue even with multi-cropping. To compound the challenge of maintaining SOM, frequent and intense cultivation are generally used in the production of these crops.

Methods discussed in the previous section for increasing SOM — reducing tillage, improving soil structure, and recycling excess plant nutrients — are all suitable for vegetable crops. Application of manures, composts, biosolids, and other organic wastes are good ways to add organic matter. If biosolids are used, they should be low trace-metal, "clean" sludges that can be applied to food crops with no restrictions.

Soil preparation and management operations such as preparing seedbeds, controlling and cultivating weeds, burying crop residue (e.g., for disease control), and building raised beds are important in vegetable production. These operations improve certain soil conditions that otherwise limit crop growth and development. However, each operation also accelerates the loss of SOM by mixing and aerating the soil. And excessive tillage severely degrades soil structure. Loss of structure makes soil prone to compaction and related problems like reduced water infiltration and poor root growth. Tillage operations should be selected carefully, because in some situations growers must weigh short-term benefits to the current crop against long-term reductions in soil quality.

Growing cover crops and preceding vegetables with high-residue rotation crops, such as small grains and forages, can increase SOM. In addition, many cover crops suppress weeds; legume cover crops add nitrogen; and cereals and other grasses scavenge residual nutrients and keep them from moving off-site. Buckwheat, sorghum-sudangrass, millets, and annual ryegrass are useful summer cover crops that can follow early-season vegetables or precede fall crops.

Rye and millet produce large amounts of vegetative growth, adding potentially large amounts of organic matter. It is important to fertilize rye cover crops or the subsequent cash crop adequately to avoid nitrogen tie-up during decomposition. Common winter cover crops include small grains, such as cereal rye, wheat, and oats. Oats often winter-kill and produce much less dry matter but are a good cover crop for wet soils because they are less likely to delay field operations in the spring. Hairy vetch and red clover are common legume cover crops. They can be grown alone or in grass/legume mixtures.

Many vegetable crops have relatively shallow, sparse root systems but are well fertilized because of their high value. This combination of small root systems and high fertilizer rates may lead to another potential soil-quality problem — the possible movement of excess nutrients to surface water or groundwater. Following a good soil-testing program, banding fertilizer, splitting nitrogen applications, using fertigation, and avoiding excess irrigation can minimize unwanted nutrient movement.

**Loss of prime farmland to non-agricultural use is a major concern in many areas. As the amount of land available for crop production and rotation is reduced by development, it is even more important to maintain our remaining agricultural soils at their highest possible level of quality and productive capacity.**

No-till alternatives have not received as much attention in vegetable crops as in agronomic crops, especially in temperate climates with cold winters. Yet, cover crops are used in successful no-till vegetable systems. Transplanting into killed cover crops (e.g., tomato into hairy vetch) has produced the best results to date. Various practices to overcome the challenges of no-till vegetable production are being tested. For example, seeding or transplanting into living mulches like short life-cycle medics may allow for more timely planting and still offer the benefits of reduced tillage. These and other practices may soon become viable alternatives, especially in northern growing regions.

## Specific Tips for Small Fruit Production

Managing and maintaining soil organic matter is important in small fruit production, as in vegetable crops. Managing properties that affect soil-water relations and root growth may be the primary challenge in sustaining soil quality during production of perennial small fruit crops. Small fruit crops require adequate available soil moisture for high total and marketable yields. However, the roots of small fruits such as strawberry, raspberry, blackberry, and blueberry are extremely sensitive to even short-term periods of saturated soil, so good drainage is also essential. Waterlogged soil restricts aeration, thereby damaging roots and promoting the growth of root pathogens.

Soils with optimum structure provide a balance of air and water in the plant-root zone. Soil structure refers to how soil particles are grouped and arranged. Well-structured soils contain voids or pore spaces of different sizes between soil particles. Small pores hold and store water that is readily available to plant roots. Large pores allow free air exchange with the atmosphere and rapid movement and drainage of excess water. While little can be done to alter soil texture (the size of soil particles), soil structure is strongly impacted by management.

Knowledge of soil structure is important because the perennial nature of small fruit production dictates that special care be taken in selecting a site for small fruit production. For example, some fields are prone to early spring flooding due to high seasonal water tables or poorly drained low spots; these fields are unsuitable for perennial small fruit crops. At the least, such fields will require costly and extensive modification before planting.

Small fruit are least tolerant of water-saturated conditions in the spring and fall when rapid root growth requires good aeration. Flooding during winter dormancy can break and damage roots by increasing soil heaving. While annual crops allow an opportunity for fertilizers and lime to be incorporated into the soil, this is difficult or impossible with small fruit. Small fruit growers must carefully consider soil management needs both before planting and during every phase after plant establishment.

Improvements in soil quality for small fruit production are easier to accomplish prior to planting, rather than after establishment. Ideally, soil preparation begins one to two years before planting is scheduled to occur as poor conditions are not easily changed after planting and are likely to result in crop failure.

Organic matter additions before planting from manures, other organic wastes, high-residue rotation crops, cover crops, and other sources can increase soil aggregation and improve soil structure. These same practices may also improve root penetration, water infiltration, permeability, and available water-holding capacity. Subsoiling can break up impermeable soil layers, increase rooting depth, and create passages for air and water movement.

Conservation tillage in the years before small fruit planting and between rows or beds of established small fruit maintains surface residue, limits crusting of the soil surface, improves infiltration, decreases runoff, and increases earthworm populations by providing a stable habitat. The channeling activity of earthworms and other soil organisms increases soil tilth and porosity.

Crop rotation before small fruit plantings can help control nematodes, weeds, and root diseases. Strawberries, raspberries, and blackberries are all susceptible to Verticillium wilt, which can be suppressed by avoiding the planting of Solanaceous vegetables before establishing small fruit crops. Some plant pathogenic nematodes are suppressed by cover crops of marigold, oat, Brassicas (mustards) like oilseed radish and forage turnip, rye, sudangrass, and sorghum-sudangrass hybrids. Plant residue also contributes SOM as it slowly decomposes.

Small fruit production on raised beds is increasingly common. Raised beds improve natural drainage and aeration and speed soil warming and early spring root growth. Building raised beds provides an opportunity to modify the soil environment by incorporating organic soil amendments, fertilizer, and lime during their construction. Raised beds dry out faster than plantings on flat ground, but this can be counteracted by applying organic mulches on the bed surface to increase water infiltration, reduce evaporation, and conserve water.

## Practices to Help Maintain or Improve Soil Quality

- *Reduce tillage and minimize cultivation*
- *Do not drive on or work wet soil*
- *Diversify and lengthen rotations*
- *Grow cover crops*
- *Use living and plant residue mulches*
- *Apply organic amendments*
- *Use a controlled-traffic system*

# Summary

Soil quality is "the capacity of a soil to function." It is defined based on the intended use of a soil and evaluated by comparing the condition of a particular soil to its potential capacity. Farmers want to ensure that a soil supports ideal crop growth with minimal inputs, season after season. To do so, growers should be familiar with the physical, chemical, and biological aspects of soil quality and soil-management practices that maintain or improve it.

Preventing erosion, sustaining or increasing soil organic matter levels, and encouraging a large, diverse, and active population of soil organisms may be the most important steps growers can take in managing soil quality. Practices such as lengthening and diversifying rotations, minimizing tillage and cultivation, and growing cover crops are useful in accomplishing soil-quality goals. Exercising restraint and not working soil when it is wet (a common urge in springtime planting preparation) helps maintain soil structure, an important aspect of soil quality.

Production of annual vegetables often returns small amounts of crop residue to the soil and involves intense tillage and cultivation and large amounts of fertilizer. Therefore, soil-quality management for vegetables should emphasize the conservation or buildup of organic matter, maintenance of soil structure, fertilizer application based on soil analysis, and scavenging and recycling of residual nutrients. Steps to manage soil quality may be taken at all stages of vegetable production.

Perennial small fruits require a balance between air and water in the root zone and do not grow well in either very dry or water-saturated conditions. The root systems of small fruits are extremely sensitive to compaction, which limits air exchange, water movement, and root penetration. Therefore, soil management for small fruits should emphasize maintenance of soil structure, tilth, and related properties such as internal drainage, porosity, and permeability. Steps to manage soil quality in small fruit production are especially important before planting.

# Glossary of Soil-Quality Terminology

**Aeration (gas exchange) —** The process of replacing air in the soil with air from the atmosphere. In well-aerated soil, air in the soil is similar in composition to air above the soil. Poorly aerated soils contain a higher content of carbon dioxide and a lower content of oxygen than the atmosphere above the soil. Aeration is important because plant roots and aerobic soil organisms consume oxygen and release carbon dioxide during respiration.

**Aggregation —** The process whereby primary soil particles (sand, silt, clay) are bound together into large particles by physical and chemical forces and substances derived from root exudates and microbial activity. Soil aggregates are the building blocks of soil structure.

**Bulk Density** — The weight of dry soil of a given volume. Bulk density is determined by the texture of the soil, which is inherent, and by soil structure and the amount of soil pore space, which can be changed by management. Compaction increases bulk density by reducing soil pore space.

**Carbon Cycle** — The sequence of transformations in which carbon dioxide is converted to organic forms by plants through photosynthesis, organic carbon is recycled through a series of living organisms, and carbon is ultimately returned to its original state (gaseous $CO_2$) through organic matter decomposition and biological respiration. Living organisms use carbon compounds as energy sources (respiration) and as building blocks for biological molecules essential for their bodies and life functions. The carbon cycle is also important because plant nutrients follow carbon through the organic phases of this cycle, so the carbon cycle overlaps and interacts with many nutrient cycles.

**Cation Exchange Capacity (CEC)** — The surfaces of clay minerals and organic matter have negative electrical charges that attract positively charged elements or molecules (cations), which are exchangeable with other cations in the soil solution. The net negative charge of a given weight of soil is equivalent to the cation exchange capacity. CEC is especially important for the essential plant nutrients potassium, calcium, and magnesium. When held in exchangeable form on particle surfaces, these nutrients are protected from leaching and are a reserve nutrient supply that can replenish ions taken up by plant roots. Another important function of CEC is the exchange of hydrogen and aluminum cations between particle surfaces and the soil solution, which helps buffer soil pH (i.e., pH remains more stable because of the ability to exchange acidic cations).

**Compaction** — An increase in bulk density and soil strength and a decrease in soil porosity by the application of mechanical forces to the soil. Wheel traffic, the action of tillage implements, and similar physical forces crush soil aggregates and push soil particles closer together, especially under wet soil conditions. Compacted soils or soil layers restrict root growth, water movement, and air exchange.

**Crust** — A dense, cemented layer at the soil surface, usually only a few tenths of an inch thick, that is very hard when dry and inhibits water infiltration and seedling emergence. Crusting is most common on fine-textured soils (high in silt and clay) and is often caused by the impact of raindrops on soil that has been extensively tilled to produce a very fine seedbed.

**Drainage** — Loss of water from soils, either by percolation through the soil or by surface flow across the soil. Adequate drainage is necessary for good soil aeration, but soils that drain too well have low soil water content and may dry too quickly for good crop growth without irrigation.

**Erosion** — The detachment and movement of soil by water, wind, ice, or gravity. Loss of topsoil by erosion is probably the most common cause of soil-quality degradation, so management practices to control erosion are critical to sustaining soil quality.

**Humus** — Well-decomposed organic compounds in soil that are very resistant to further degradation. Humus has high water-holding and cation-exchange capacity, binds soil particles, and improves soil structure.

**Infiltration** — The entry of water into the soil profile through openings in the soil surface. Infiltration capacity, or rate, determines how much water runs off and how much soaks in during rainfall, although after soil pores become filled, the permeability of soil layers below the surface may control water entry.

**Leaching** — The movement of soluble materials from one soil zone to another by water movement in the soil profile. Excessive leaching of agrochemicals like nitrate fertilizer and herbicides can be an environmental problem.

**Mulch** — Any material such as straw, wood chips, sawdust, leaves, plastic film, loose soil, etc., that is spread or formed upon the soil surface to protect the soil and/or plant roots from the effects of raindrops (crusting), wind or flowing water (erosion), temperature extremes (cold or hot), evaporation, etc. Mulches are also used primarily to control weeds, conserve soil moisture, or alter soil temperature.

**Nutrient** — Chemical elements or compounds that are essential raw materials for the growth and development of plants and/or soil organisms. Nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, boron, chlorine, copper, iron, manganese, molybdenum, and zinc are absorbed by roots from the soil and are necessary for completion of the normal life cycle of all plants.

**Nutrient Cycle** — The sequence of biochemical changes undergone by an essential plant nutrient where it is taken up by plant roots or soil microbes, used by a series of living organisms, and transformed to its original state upon the death and decomposition of the organism (at which time the cycle can start again). Chemical and physical changes (such as ammonia volatilization) are also parts of some nutrient cycles.

**Permeability** — The ease with which gases, liquids, or plant roots penetrate or pass through the soil or a layer of soil. Permeability is determined by soil texture, structure, and porosity.

**pH** — A measure of soil acidity or alkalinity; the hydrogen ion activity of a solution in equilibrium with the solid phase of a soil.

**Porosity** — The non-solid portion of a volume of soil, consisting of air- or water-filled pore space. Soil porosity, both the total amount of pore space and the distribution of pore sizes, controls soil water content, air movement, and water movement. The rates of air exchange and water movement depend on both the volume and continuity of pore spaces within the soil.

**Raised Bed** — A slightly dome-shaped or flat-topped ridge of soil. Raised beds are generally a series of parallel ridges formed by cultivation with shallow furrows in between. Bed size depends on the crop grown and the number of plant rows per bed but is usually in the range of four- to eight-inches high and two- to four-feet wide, with one to three rows per bed. Advantages of raised beds include improved soil drainage, earlier soil warming, and easier picking of some crops. But beds also dry out more quickly and make irrigation a more critical requirement for many crops.

**Residue** — Leaves, stems, stalks, stubble, and other plant parts that are left on the soil surface after the harvested portion of a crop is removed. Crop residue protects the soil surface, improves water infiltration, and reduces crusting, erosion, and evaporation. But large amounts of residue also can keep soil excessively cool and wet early in the growing season.

**Respiration Rate** — The rate of carbon dioxide release (or oxygen consumption) by biological respiration. Soil respiration rate is a measure of the size and activity of the overall population of soil organisms. Soil microbes generally make the largest contribution to soil respiration, although measurements in the field can include significant contributions from larger organisms and plant roots. Soil temperature, moisture, aeration, and food supply all have major effects on biological activity, and therefore respiration rate, so these factors must be taken into account when interpreting and comparing respiration measurements.

**Soil Organic Matter (SOM)** — The organic fraction of the soil. The broadest definition includes undecayed plant or animal residues, living soil organisms, and plant roots as categories of soil organic matter. Many definitions restrict the term to humus and organic materials that are at least partially decomposed, and whose origin (plant stems, leaves, animal remains) is no longer recognizable. Organic matter that bacteria, fungi, earthworms, and other soil organisms can decompose is a critical component of the soil food web, which is important in nutrient cycling and all other soil biological processes.

**Soil Strength (penetration resistance, cone index)** — The hardness, or resistance to a physical force, of a soil layer, zone, or specific point in the soil. Soil strength is often defined in terms of a measurement of resistance to penetration with an instrument such as a cone penetrometer. Measurements may be difficult to interpret, because they are strongly affected by differences in soil water content. Penetration resistance is also determined by soil texture and many properties related to soil aggregation and structure. Soil zones with very high soil strength, such as clay pans, plow pans, and other types of hardpans, restrict root growth, water movement, and air exchange.

**Soil Structure** — The combination or arrangement of primary soil particles (sand, silt, clay) into larger, aggregated particles with pore spaces between them. Soil with "good" structure is about 50% solids and 50% pore space, with the pore space evenly distributed between large, air-filled pores and smaller, water-holding pores.

**Soil Texture** — The relative proportions of primary soil particles (sand, silt, clay) in a soil, which determine a soil's "textural class" (loamy sand, loam, silty clay, etc.). Texture is not a measure of soil quality, because it is an intrinsic soil property that cannot be changed. But texture is an important soil characteristic that affects most soil management decisions.

**Tilth** — The physical condition of soil, generally described in terms of its ease of tillage (workability), fitness as a seedbed, and its resistance to seedling emergence and root penetration. Soil tilth is closely related to soil structure, but structure is usually described in physical terms and tilth is usually evaluated in relation to a crop response or soil management operation.

**Topsoil (surface soil, plow layer, Ap horizon)** — The uppermost part of the soil, ranging in depth from three to 10 inches, and generally containing higher amounts of organic matter and plant nutrients than the soil below. Topsoil is often functionally defined as the soil layer moved in primary tillage or the equivalent depth in uncultivated soils. This definition is rather arbitrary in deep, untilled soils with no clear indication of where topsoil ends and the next soil layer begins.

**Water (hydrologic) Cycle** — The fate of water from the time it leaves the atmosphere as precipitation until the water has been returned to the atmosphere by evaporation or plant transpiration. Soil plays a very important role in the water cycle, because a substantial portion of the precipitation reaching the earth falls on soil. The condition or quality of the soil determines such things as how much water runs off to rivers or lakes, how much enters the soil and can be taken up by plants or evaporated, and the rate and the amount of water that moves through the soil to groundwater.

**Water-Holding Capacity (field capacity)** — The amount of water soil can hold against the downward force of gravity. Soil texture, structure, porosity, and organic-matter content determine soil water-holding capacity. Some soil water is held too tightly to be taken up by plant roots, either in thin films on particle surfaces or in very small soil pores. Plant-available water-holding capacity is the portion of the total amount of water a soil can hold that can be taken up by plant roots. Available water in a soil can vary by crop, because roots of some plants can absorb water at lower soil water contents (held more strongly by the soil) than other types of plants.

# For More Information

## Publications

*Building Soils for Better Crops.* 2nd Ed. 2000. F. Magdoff and H. van Es. Sustainable Agriculture Network. Handbook Series. Book 4. 240 pp.

*Conservation Tillage for Vegetables.* 2000. Proceedings of the Workshop, presented at the 1998 meetings of the American Society for Horticultural Science, July 11–16, 1998, Charlotte, N.C. *HortTechnol* 9:349-393.

*Managing Cover Crops Profitably.* 2nd Ed. 1998. Sustainable Agriculture Network. Handbook Series. Book 3. 212 pp.

*Methods for Assessing Soil Quality.* 1996. J. Doran and A. Jones, Eds. Soil Science Society of America. SSSA Special Publication No. 49.

*Nutrient Cycling and Maintaining Soil Fertility.* 2000. P. Bierman. The Ohio State University Centers at Piketon. SWR-3. 15 pp.

Ohio Soil Health Card. 1999. P. Bierman, N. Widman, and R. Gehring, Eds. The Ohio State University Centers at Piketon. SWR-1. 4 pp.

*Soil Biology Primer.* 1999. Soil Quality Institute, USDA-Natural Resources Conservation Service. Bulletin PA-1637. 50 pp.

*Soil Management.* 1997. Ontario Ministry of Agriculture, Food, and Rural Affairs; Agriculture and Agri-Food Canada; Ontario Federation of Agriculture. Best Management Practices Series. 68 pp.

Soil Quality Information Sheets. National Soil Survey Center in cooperation with the Soil Quality Institute, USDA-Natural Resources Conservation Service and the National Soil Tilth Laboratory, USDA-Agricultural Research Service.

*Soil Quality — Introduction* (1996)

*Indicators for Soil Quality Evaluation: Organic Matter* (1996), *Aggregate Stability* (1996), *Soil Crusts* (1996), *pH* (1998), *Infiltration* (1998).

*Soil Quality Resource Concerns: Soil Erosion* (1996), *Compaction* (1996), *Sediment Deposition on Cropland* (1996), *Salinization* (1998), *Pesticides* (1998), *Available Water Capacity* (1998), *Soil Biodiversity* (1998).

*The Soil Management Series.* 2000. Minnesota Institute for Sustainable Agriculture; Soil Quality Institute, USDA-Natural Resources Conservation Service; University of Minnesota Extension Service. PC-7398-S (complete series).

*Soil Management* (BU-7399). 21 pp.

*Compaction* (BU-7400). 17 pp.

*Manure Management* (BU-7401). 17 pp.

*Organic Matter Management* (BU-7402). 17 pp.

*Soil Biology and Soil Management* (BU-7403). 17 pp.

## Websites

A slide set related to this bulletin is located at: **http://www.oardc.ohio-state.edu/kleinhenz/**

Soil and Water Resources Program, The Ohio State University Centers at Piketon: **http://www.ag.ohio-state.edu/~prec/soil/**

NRCS Soil Quality Institute: **http://www.statlab.iastate.edu/survey/SQI/**

Soil Health Slide Show, Northeast Region Sustainable Agriculture Research and Education Program: **http://www.uvm.edu/~nesare/slide.html**



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