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SOIL MANAGEMENT AND SOIL QUALITY FOR ORGANIC CROPS

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Specific information on organic vegetable production practices in California is scarce, and growers need sound information to guide their management decisions. The Organic Vegetable Production in California Series is made up of publications written by Farm Advisors and Specialists from the University of California's Division of Agriculture and Natural Resources. Each publication addresses a key aspect of organic production practices applicable to all vegetable crops.

Soil is a fundamental resource base for agricultural production systems. Besides being the main medium for crop growth, soil functions to sustain crop productivity, maintain environmental quality, and provide for plant, animal, and human health. The terms *soil quality* and *soil health* describe the soil's ability to perform these critical functions. Soil quality or health is generally seen as the foundation of successful organic vegetable crop production systems. Sustaining and improving soil quality over the long term are frequently identified by organic farmers as their primary management goals. What follows is a summary of the major factors that contribute to soil quality and the ways a grower can enhance soil quality in an organic production system.

SOIL QUALITY ASSESSMENT

Between 1990 and 2000, our ability to assess soil health and to measure the impacts of management practices aimed at improving it have been the topics of considerable discussion in agricultural circles. Clearly, what is considered good soil quality in one farming context may not be so good in another, and this makes quantitative assessment difficult. There is, however, a growing recognition that much like air or water quality, the quality of soil has a profound impact on the health and productivity of a given agroecosystem and on the ecosystems that interface with it. Fairly definitive standards have been defined for air and water quality, but the definition and assessment of soil quality is more problematic. Soil is not directly consumed by humans and animals, and it is difficult to relate measurable soil quality indicator properties to specific soil functions or management goals.

The assessment of soil quality or health has been likened to a routine medical examination for a human being, when a doctor measures a number of key parameters as basic indicators of overall system function. Because soils perform many simultaneous functions, however, the goal of relating indicator properties to specific functions or processes is very difficult; some would say impossible. Over the last several years, researchers and farmers alike have tried to establish what are now widely called *minimum data sets* of physical, chemical, and biological properties that can be used as quantitative indicators in soil health assessments. Indicator properties that are frequently identified in these sets are listed in Table 1.

Table 1. Soil quality indicator properties

Physical property	Chemical property	Biological property
bulk density	pH	microbial biomass carbon
rooting depth	electrical conductivity	microbial biomass nitrogen
water infiltration rate	cation-exchange capacity	earthworms
water-holding capacity	organic matter	enzymes
aggregate stability	mineralizable nitrogen	disease suppressiveness
	exchangeable potassium	
	exchangeable calcium	

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Characterization of soil health using these indicators can be quite time-consuming and expensive, and is not feasible as a general practice for every farm. In an effort to better enable farmers to conduct ongoing assessments of soil health and to compare management impacts on soil health, the USDA Natural Resources Conservation Service (NRCS) is developing soil quality test kits that provide a relatively inexpensive way to measure a number of these indicator properties. The test kits are now being evaluated at several locations throughout the country and may become useful and accessible tools to help farmers with routine assessments of soil quality. For further information on these kits and their potential usefulness in soil health assessments at your farm, contact your nearest USDA-NRCS field office.

A number of soil health "scorecards" have also been developed as qualitative tools for characterizing soil health. These scorecards are typically available in booklet form, and have been designed as a farmer-based field tool for assessing soil health. A typical scorecard lists several primarily sensory or descriptive indicator properties that a grower can routinely evaluate for a given soil. Their usefulness and validity are being evaluated at a number of cropping system comparison trials throughout the United States. Initial testing has shown that the information they generate may hold promise as a means for monitoring individual descriptive soil quality indicators in the field. Sample scorecards are available through some local University of California Cooperative Extension and USDA-NRCS offices.

Soil organic matter (SOM) content is frequently identified as a primary attribute of soil quality assessment. SOM influences many soil properties including infiltration rate, bulk density, aggregate stability, cation-exchange capacity, and biological activity, all of which are related to a number of key soil functions. SOM serves as a slow-release reservoir for plant macronutrients (especially nitrogen) and also aids in plant micronutrient nutrition. It facilitates the infiltration of water and air into the soil, increases water retention by the soil, and is important in maintaining soil tilth. Over time, increases in SOM can lead to a larger and more diverse population of soil organisms and may thus enhance the biological control of pests and plant diseases. Large quantities of fresh organic matter that are added to the soil, however, may stimulate plant pathogenic organisms and seed and seedling pests such as cabbage maggots and wireworms, which can cause serious losses.

In organic production systems, soil fertility is often augmented through applications of materials such as compost and manure and by the use of cover crops (see *Soil Fertility Management for Organic Crops,* ANR Publication 7249). Organically managed soils that routinely receive these deliberate inputs typically differ substantively in fertility as well as a number of other soil quality properties when compared to conventionally managed soils.

Two major projects are currently comparing soil quality indicator properties under different management systems, including organic. These projects, the Sustainable Agriculture Farming Systems (SAFS) Project (Davis, California) and the Biologically Integrated Farming Systems (BIFS) Project (Five Points, California), have found that organic soil management can result in fundamental differences in a number of soil health indicator properties including water infiltration rate, microbial biomass carbon and nitrogen, and disease suppressiveness in the case of the SAFS comparison, and SOM and microbial biomass carbon and nitrogen in several BIFS comparisons. Determination of the practical significance of these management-induced differences is the focus of intense ongoing research. Preliminary analyses from the SAFS comparison project, however, suggest that while organic systems might be "leakier" in terms of nitrogen losses during the transition period when relatively high nitrogen loading is common, these systems may eventually cycle nitrogen more efficiently and thereby result in greater nutrient conservation.

PROVIDING FOR SOIL HEALTH

Growers use a wide variety of practices to maintain or improve soil health in organic vegetable production systems in California. These practices generally are part of long-term, site-specific management programs that aim at developing fertile and biologically active soils that readily capture and store water and nutrients, have good tilth, and suppress plant disease. Deliberate and routine carbon inputs are essential to achieving this goal in organic production environments. Special care is needed to select organic carbon sources that will ensure short-term productivity while building long-term soil quality.

Rotations

Judicious crop rotation may be a useful strategy for increasing short-term SOM and for establishing healthy, fertile and productive soils. Amounts of postharvest crop residues in California organic vegetable production systems vary widely depending on the crop and the intensity with which it is harvested. Rotations that include small grain crops such as wheat, barley, oats, rye, or triticale that are harvested for seed typically add 8,000 to 10,000 pounds of dry matter per acre to the soil after harvest. By including these crops in a vegetable rotation, a grower can also lessen the incidence of several potentially devastating vegetable crop soil diseases and help with nematode problems (See *Integrated Pest Management for Small Grains,* ANR Publication 3333). Field residues from broccoli harvest may typically provide nearly 7,000 pounds dry matter per acre, and residues from other vegetables such as tomato, lettuce, onions, and garlic may respectively add on average 2,500, 1,200, 700, and 500 pounds of dry matter per acre.

Organic Amendments

While composts and manures are frequently considered to be mainstays of fertility management programs in organic systems, these amendments often vary widely in nutritive value and thus are increasingly being applied as a basic carbon source to enhance overall and long-term soil health. The carbon content of these materials is also quite variable, though it generally ranges from 20 to 40 percent on a dry-weight basis. Annual applications of composts and manures at rates of 3 to 5 tons per acre are common in organic vegetable systems in California. Such organic amendments add significant amounts of carbon to the soil and are generally associated with improved tilth, lower bulk density, and increased water infiltration. Very few studies, however, have been conducted to monitor changes in key soil quality indicator properties or processes that may result from the application of these amendments over the diverse range of organic vegetable systems in California.

Cover Crops

Cover cropping (also called *green manuring*) is widely seen as an important part of soil quality management in organic production systems in California. Cover crops can provide a practical and economical means for supplying organic matter, enhancing soil fertility, suppressing weed growth, attracting beneficial insects, spiders, and predatory mites, and reducing nitrate leaching losses to the groundwater during periods between crops. Cover crops also may seriously limit a grower's options for planting and harvesting alternative main cash crops, and, depending on the specific cropping situation, the use of cover crops may also result in potentially adverse consequences such as soil moisture depletion, temporary immobilization of plant nutrients, increased pest problems, and increased management and associated costs.

While cover cropping has not been an integral component of many annual crop production systems in California over recent decades, there is now growing interest in the use of cover crops to store carbon and improve resource use efficiencies in these systems. Recent research in the Sacramento Valley suggests that cover crop–based production systems may exert a more favorable influence on annual water balances than has previously been thought. Intensifying concerns about increasing atmospheric CO_2 levels, global warming, and the potential roles that carbon sequestration in plants and the soil may play in mitigating the greenhouse effect also may result in more widespread use of cover crops. The key to the effective and profitable use of cover crops lies in the creative design of management options to take advantage of those windows of opportunity when they can be grown to maximum advantage within vegetable crop rotations without missing opportunities for income as a result of not utilizing the land for cash crops.

A considerable body of information currently exists within California's main organic vegetable production regions on how to select, grow, and work in cover crops. This information is readily available through UC Cooperative Extension county farm advisors and can be used as a point of departure for establishing small-scale on-farm evaluations of cover crops for achieving particular management goals (see *Cover Crops for California Agriculture,* ANR Publication 21471). While much of this information has been developed for winter cover crop species, several recent studies have also evaluated late summer or other nonconventional cover crop growing windows. For example, while October-planted, March-incorporated rye and vetch cover crops respectively produce about 9,000 and 5,000 pounds of dry matter per acre in the Central Valley, an August-planted, November-incorporated Sudangrass crop may provide twice the biomass per acre.

Cover crop species mixtures are gaining wider adoption throughout California because they may provide multiple benefits to a production system and may serve as insurance against conditions that are unfavorable to a single species. Recent research conducted by the Sustainable Agriculture Farming Systems Project in Davis, California, suggests that legume cover crops may be particularly important factors in the development of key humic acid fractions that typically distinguish organic soils from conventionally managed soils and that may be significant indices of soil quality improvement.

CONSERVATION TILLAGE

Although increasing SOM is widely recognized as a primary goal of soil management programs for organic vegetable producers, tillage has a negative effect on SOM. While moderate tillage may provide more favorable soil conditions for crop growth and development and weed control over the short term, intensive tillage of agricultural soils has historically led to substantial losses of soil carbon, ranging from 30 to 50 percent.

Conventional tillage practices disrupt soil aggregates, exposing more organic matter to microbial degradation and oxidation, and are among the primary causes of tilth deterioration over the long term. Micro and macro channels within the soil, created by natural processes such as the decay of roots and worm activity, may also be destroyed by tillage. Deep tillage, a customary "soil preparation operation," is also costly and requires high energy and increased subsequent efforts to prepare seed beds. A recent survey documented a 40 percent decline in SOM since intensive tillage practices began in the Salinas Valley. This survey confirms the conclusion drawn from other long-term crop rotation studies as the Morrow Plots at the University of Illinois, the Sanborn Field Plots in Columbia, Missouri, and the Columbia Plateau Plots near Pendleton, Oregon: that intensive tillage typically leads to decreased soil carbon in virtually all crop production systems.

Recent studies involving a variety of tillage methods indicate that there are major gaseous losses of carbon immediately following tillage, but point to the potential to reduce soil carbon losses and enhance soil carbon management through the use of conservation tillage (CT) crop production practices. Though these practices have been developed over the past several decades primarily for erosion control in other parts of the United States, recent concerns regarding the need to sustain soil quality in areas such as California (where CT is virtually nonexistent) as well as potential global climate changes have reemphasized the importance of CT and its potential for implementation on a broader scale to help reduce soil carbon losses, improve soil quality, and sustain agricultural productivity.

The term *conservation tillage* describes production systems in which at least 30 percent of the soil surface is covered by residues from previous crops. Traditionally, organic farmers have avoided production systems that leave a lot of surface residues because such systems make mechanical weed control difficult. As Dr. Ronald Morse, a Professor of Horticulture at Virginia Tech and a long-time no-till vegetable pioneer, has pointed out, this creates a true paradox for organic growers: primary tillage and weed cultivation as used extensively on organic farms incorporate surface residues, excessively aerate the soil, and reduce soil organic matter content and soil quality, the very opposite of the goals organic vegetable producers want to achieve. The development of high-residue CT systems that enable adequate weed control is a challenge facing innovative organic vegetable producers.

Studies are underway in California on reduced-tillage crop production systems. The basic feature of these systems is the use of surface organic mulches that are derived from cover crops grown in the off season. Winter annual cover crops such as rye and vetch, for example, have been used successfully both as cover crops and as mulches in a variety of CT systems. As cover crops, these species recycle nutrients, reduce soil erosion, add organic matter to the soil, and (in the case of vetch or other legumes) fix nitrogen. When mowed and converted to a mulch, they reduce weed emergence, lower soil temperatures during the hot summer months, reduce water loss from the soil, and act as a slow-release fertilizer. There may be problems associated with using cover crops in this way: the cover-cropped land is put out of production, the land's soil moisture may be depleted more by the cover crop than it would be by a winter fallow, early summer soil temperatures may be cooler with a surface mulch than bare soil, and cover crops used as surface mulches may not release nutrients until incorporated into the soil. There may also be problems related to the management of cover crops and cover crop residues that can be phytotoxic to certain crops that follow a green manure mulch.

A major limitation to conservation tillage and cover crop mulch systems in organic crop production is the need to manage the cover crop so that it does not compete with or reduce the growth of the cash crop that is planted into it. Various management options to ensure this condition are currently under evaluation. Timing the growth of the cover crop so it will reach maturity and complete its life cycle at the time it is scheduled to be mowed, rolled, or planted into may be a useful strategy in certain contexts. This has been done successfully with rye. However, this approach generally assumes that the vegetable crop will not be planted or transplanted into the cover crop mulch until late in the spring. A grower can also use irrigation cut-off or rely on increasing temperatures to kill off certain cover crops to an extent that prevents them from effectively competing with the vegetable crop. Given the immense array of cover crop species available for use as surface mulches, it is likely that rapid progress can be made in further refining the economic and ecological benefits of conservation tillage production systems for organic vegetable producers.

OTHER PUBLICATIONS IN THIS SERIES

Organic Certification, Farm Production Planning, and Marketing, UC ANR Publication 7247

Soil Fertility Management for Organic Crops, UC ANR Publication 7249

Weed Management for Organic Crops, UC ANR Publication 7250

Insect Pest Management for Organic Crops, UC ANR Publication 7251

Plant Disease Management for Organic Crops, UC ANR Publication 7252

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