Sustainable Agriculture Farming Systems Project

University of California, Davis

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Evaluating Soil Quality in Organic, Low-Input, and Conventional Farming Systems

Soil quality is an evolving concept intended to aid farmers, land managers, researchers, public decision-makers, and others in the management of soil resources. The central question of soil quality assessment is “how does a soil function?” and a variety of physical, chemical, and biological indicators can be used to address it. This question, however, is complicated by the interdependencies between soil characteristics which often lead to trade-offs. Moreover, societal demands on soil resources are diverse and often contradictory, making soil quality a controversial topic. Nevertheless, examination of soil quality indicators can result in a better understanding of the effects of management activities on soil processes and the interactions among these processes. In this article we summarize current soil quality research at the Sustainable Agriculture Farming Systems (SAFS) project at UC Davis. We examine a variety of soil quality indicators and discuss their meaning within the context of sustainability (Table 1).

Table 1. Response of chemical, biological, and physical soil quality indicators to low-input and organic management at the SAFS site.

Chemical	Response
pH	+
cation exchange capacity	0
electrical conductivity	0
total carbon	+
total nitrogen	+
soluble phosphorus	+
exchangeable potassium	+
potentially mineralizable nitrogen	+
mineral nitrogen	-
Biological	
microbial biomass	+
microbial diversity	0
bacterial feeding nematode abundance	+
fungal-feeding nematode abundance	-
omnivore/predator nematode	0
plant-parasitic nematode abundance	0
nematode species richness and diversity	0
ground beetle abundance	+
ground beetle species richness	+
Physical	
water infiltration	+
water holding capacity	+
aggregate stability	0
bulk density	0

+, -, and 0 denotes increase, decrease, and no change respectively

The SAFS Project

The SAFS project, which began in 1989, is a comparison of four farming system treatments which differ in crop rotation and use of external inputs (Table 2). These include four-year rotations under conventional, low-input, and organic management and a conventionally-two-year rotation. All three, 4-year rotations include processing tomato, safflower, bean, and corn. In the 4-year conventional treatment, beans are double-cropped with winter wheat, while in the low-input and organic treatments, beans follow a biculture of oats and vetch which is either harvested for seed, cut as hay, or incorporated as green manure. The 2-year conventional treatment is a tomato and wheat rotation. All farming systems use “best farmer management practices” which are determined through consultation with area farmers and University of California Cooperative Extension Farm Advisors participating on the project (Table 2). The conventional treatments are managed with practices typical of the surrounding area. In the low-input system, synthetic fertilizer and pesticide inputs are reduced primarily by using cover crops to improve soil fertility and mechanical cultivation for weed management. Manure was applied in the low-input system during the first rotation cycle but discontinued after 1992.

Table 2. Farming system treatments comprising the Sustainable Agriculture Farming Systems Project at the University of California, Davis.

Farming System	Crop Rotation	Description
Organic	Tomato safflower corn oats/vetch; bean	Four-year, five-crop rotation relying on composted and aged animal manures, legume and grass cover crops, and some organic supplements; no synthetic pesticides or fertilizers are used.
Low-input	Tomato safflower corn oats/vetch; bean	Four-year, five-crop rotation relying on legume and grass cover crops and synthetic fertilizer applied at about one-half the recommended rate; pesticide use is reduced through cultivation and some hand hoeing.
Conventional 4-year	Tomato safflower corn wheat; bean	Four-year, five-crop rotation relying on synthetic fertilizer and pesticides used at conventionally-recommended rates
Conventional 2-year	Tomato wheat	Two-year, two-crop rotation relying on synthetic fertilizer and pesticides used at conventionally-recommended rates

managed,

The organic treatment is managed according to the regulations of California Certified Organic Farmers (CCOF). Management includes the use of legume and grass cover crops and mixtures, aged and composted animal manure, mechanical cultivation, and limited use of CCOF-approved products.

A wide array of physical, chemical, and biological soil properties have been measured and studied over the nine years of the project. Such information is useful in understanding the changes in soil quality resulting from the transition to low-input and organic farming practices. The results of this research are briefly described below.

Chemical Indicators

Significant differences have been found in a number of soil chemical properties, including total carbon (C), total nitrogen (N), electrical conductivity (EC), pH, phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca). Most of the observed changes in soil chemical properties were predicted based upon nutrient budgets. Inputs of C, P, K, Ca, and Mg are higher in the organic and low-input systems as a result of manure applications and cover crop incorporations. After four years of production, soils in the organic and low-input systems had higher total C, soluble P, exchangeable K, and pH. However, discontinuation of manure applications in the low-input system after 1992 resulted in detectable declines in total C, soluble P, and exchangeable K in that system. Differences in crop rotation have also had a significant effect on C levels, as the 3, four-year rotations have substantially higher C inputs due to greater crop residues (Fig. 1). Relative differences in total N among treatments are similar to those of total C (Fig. 2).

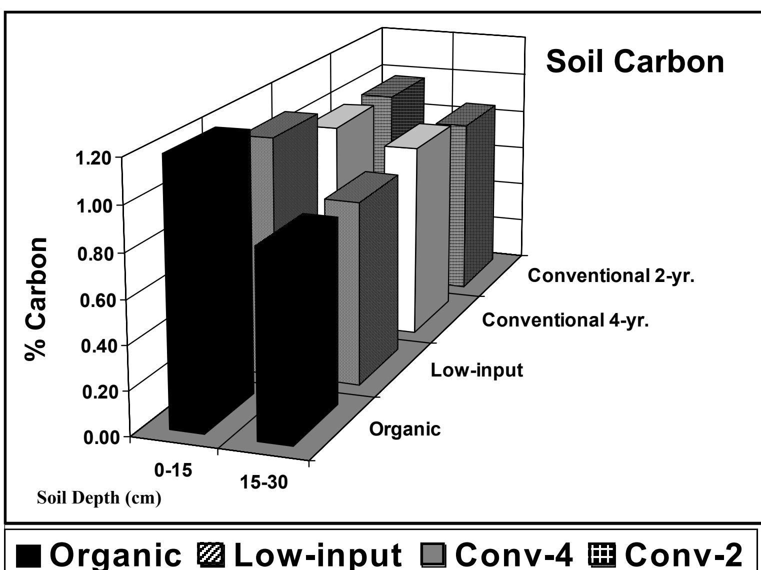

Figure 1: Comparison of soil carbon (%) in the four farming systems of the SAFS Project, 1996

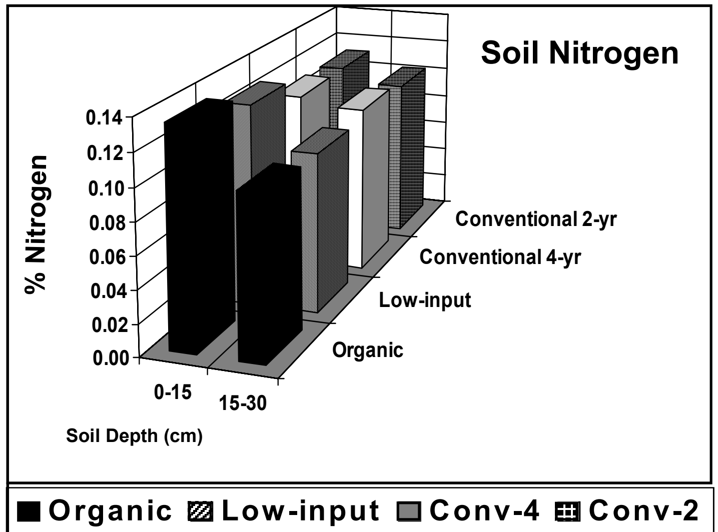

Figure 2: Comparison of soil nitrogen (%) in the four farming systems of the SAFS Project, 1996

Soil monitoring indicates that much of the N applied to the organic system is incorporated into microbial biomass and stored in the soil as organic matter. Thus, potentially-mineralizable N is highest in the organic, intermediate in the low-input, and lowest in the conventional systems. However, mineral N levels are sometimes less than optimal in the organic system, particularly early in the growing season, and can result in N limitations to crops with high N demands.

Biological Indicators

Soil biology research at the SAFS site has included studies on the microbial community, soil nematodes, and ground beetles (Table 1). Soil microbial biomass levels have been higher in the organic and low-input than conventional tomato systems. Levels of microbial activity have also been correspondingly higher in the organic and low-input systems. To provide an indication of the structure and diversity of the microbial community in these soils, phospholipid fatty acids (PLFA) were extracted from tomato soil samples and analyzed by gas chromatography. PLFA profiles from organic and conventional systems differed substantially from one another throughout the season and profiles from the low-input system were intermediate between organic and conventional systems. However, diversity indices, using several approaches, suggested little difference in the PLFA diversity among the conventional, low-input and organic farming systems. This indicated that the differences in the PLFA profiles among the farming systems were due more to differences in the relative abundances of the same group of species rather than to differences in the species composition in the farming systems.

Soil biology research has also focused on the nematode community. Comparisons of the organic and conventional tomato systems revealed that bacterial-feeding nematodes are most abundant in the organic system while fungal-feeding nematodes are more common in the conventional system. However, differences in species richness and species diversity were not found. Field and laboratory studies are being used to quantify the role of bacterial-feeding nematodes (and soil biota in general) in N mineralization and evaluate the effectiveness of using summer cover crops and fall irrigation to enhance bacterial-feeding nematode abundance and mineral N levels in the following spring. Results show that summer cover crops and fall irrigations promote bacterial-feeding nematode abundance and N mineralization which leads to higher tomato yields.

These nematodes may be a marker/indicator of soil biological activity in general and future research will be expanded to include micro-arthropods such as mites and springtails. In addition, a pilot project to monitor ground beetles, an important group of predators, was initiated in 1997 and results show greater abundance and species richness in the organic compared to the conventional tomato system. This project will be expanded in 1998 to include the low-input farming system.

Physical Indicators

Soil physical properties, including water dynamics and structural characteristics, have been studied at the SAFS site in recent years (Table 1). Important differences have surfaced with respect to irrigation management and water relations within the farming systems. Infrared aerial photos taken in 1994 revealed water stress in conventional corn plots during grain fill. Intensive soil water monitoring in 1995 further revealed that water penetration decreased as the season progressed in the conventional system, however, differences in bulk density were not found. Because of the importance of water in the irrigated, semi-arid cropping systems of California's Central Valley, and because of uncertainties with respect to overall water relations of alternative cropping systems in this region, in 1997 a comprehensive investigation was aimed at characterizing key aspects of soil-plant water relations.

Water storage capacity and infiltration rates were found to be greater in the low-input and organic soils compared to conventional soil. Results of ring infiltrometers taken in the three corn systems near the time of planting indicated greater infiltration rates in the organic and low-input systems than in the conventional system. Blocked-furrow infiltrometer measurements taken in August indicated similar treatment effects. However, the soil water content of the conventional system was somewhat greater than the low-input and organic systems, making interpretation of these results difficult. A recirculating infiltrometer system will be used in 1998 to clarify the 1997 infiltrometer results. Finally, soil water holding capacity was measured in October, and again the organic and low-input systems showed somewhat greater water holding capacity than the conventional system.

Field and laboratory studies have also been used to study soil aggregate stabilization at the SAFS site over the last several years. Aggregate stability at the site varied during the 1994, 1995, and 1997 growing seasons, with the percentage of water stable aggregates (WSA) highest during the peak growing season and lowest prior to planting and following harvest. WSA in the farming systems varied significantly by treatment in fall and spring of 1994 and 1995 but not during the peak growing season. Little variation in WSA among treatments was observed in 1997. Microbial biomass carbon (MBC) in the top 15 cm correlated significantly to aggregate stability in 1994, but preliminary results for MBC in 1997 do not indicate strong correlation with WSA.

A root-microorganism interaction may be responsible for the higher WSA during the growing season. Microbial polysaccharides are considered important in the formation of stable aggregates and microbial abundance (as measured by MBC) appears to partially account observed patterns. However, the general lack of consistent differences among treatments may be due to a systematic error in the method used and a more robust measurement of aggregate stability may be needed. Differences in water budgets, microbial activity, and organic C inputs among treatments should result in differences in aggregate stability but results do not reflect observed differences in infiltration rates between SAFS organic and conventional plots. Future research will compare polysaccharides occuring in these systems and use synthetic aggregates to model observed differences.

Conclusions

Soil quality research to date at the SAFS site demonstrates that an array of changes in chemical, biological, and physical soil properties result from the transition to low-input and organic farming practices in California's Sacramento Valley. Many of the changes observed were expected while other findings provided new and interesting insights into soil processes. In general, changes resulting from low-input and organic farming methods have had postive, long-term effects on soil quality, including increased storage of plant nutrients and C, greater biological activity, and improved water infiltration. However, other changes present new management challenges, such as the slow or unpredictable N mineralization processes in systems depending on cover crops and/or organic amendments for N fertility. Current and future research at the site is aimed at addressing N availability problems in organic and low-input systems by finding means of monitoring and managing the soil biota. In addition, future work will continue to examine the interactions between soil processes such as the effects of bacterial-feeding nematode population dynamics on N

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