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Concept, Components, and Strategies of Soil Health in Agroecosystems[1]

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Abstract: The terms ''soil health'' or ''soil quality'' as applied to agroecosystems refer to the ability of soil to support and sustain crop growth while maintaining environmental quality. High-quality soils have the following characteristics: (i) a sufficient, but not excess, supply of nutrients; (ii) good structure (tilth); (iii) sufficient depth for rooting and drainage; (iv) good internal drainage; (v) low populations of plant disease and parasitic organisms; (vi) high populations of organisms that promote plant growth; (vii) low weed pressure; (viii) no chemicals that might harm the plant; (ix) resistance to being degraded; and (x) resilience following an episode of degradation. Management intended to improve soil health involves creatively combining a number of practices that enhance the soil's biological, chemical, and physical suitability for crop production. The most important general strategy is to add plentiful quantities of organic matter—including crop and cover crop residues, manures, and composts. Other important strategies include better crop rotations, reducing tillage and keeping the soil surface covered with living and dead residue, reducing compaction by decreasing heavy equipment traffic, and using best nutrient management practices. Practices that enhance soil quality frequently reduce plant pest pressures.
Key words: soil health, soil organic matter, soil quality.

''Soil health'' is a term gaining use among farmers to refer to the condition of their soil as it relates to growing crops. The concept of soil health is similar to that of human health. Human characteristics such as body temperature and blood sugar content must be within certain ranges for an individual to be healthy, and soil characteristics such as water and nutrient contents must be within certain ranges for plants to grow normally. All the various components of a healthy person such as internal organs must perform sufficiently for the person to grow and function normally while essential biological, chemical, and physical soil components must be present and functioning to permit the growth of healthy and high-yielding crops. Finally, as human health is partially defined by the absence of infectious diseases and parasites, low levels of organisms that might interfere with plant growth—parasites and weeds—are characteristic of healthy soils. The U.S. Department of Agriculture's Natural Resource and Conservation Service (NRCS) has been helping farmers and scientists develop ''soil health cards'' that are appropriate for local conditions (USDA, 1997). These cards are to be used on a field-by-field basis to assess the effects of management practices on soils and to help suggest whether changes in management are needed. Simple observations and measurements of soil properties are used to evaluate soil health.

While the concept of ''soil quality''—a term generally used by scientists—is similar to that of soil health, there are some significant differences. The term ''quality'' is used to acknowledge that soils provide many uses and functions for humans. Characteristics that are good for one purpose are frequently good for another, as when a well-drained soil is desirable for both growing crops and installing septic tank seepage fields. However, some very good agricultural soils may not provide the mechanical stability needed for structures in earthquake-prone regions. In reference to agriculture, soil quality has been defined as ''the capacity of soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health'' (Doran and Parkin, 1994).

Compared to natural ecosystems, agricultural ecosystems undergo many disturbances and modifications and have many more nutrient inputs and outputs (Hendrix et al., 1992; Magdoff et al., 1997). The use of pesticides and nutrients to sustain high crop yields has resulted in pollution of surface and ground waters. Greatly accelerated soil erosion, associated with conventional tillage practices, degrades the receiving waters and the soil resource—because of topsoil loss—at the same time. While disturbance and soil modification during modern crop production are inevitable, there are ways to manage these disturbances to mimic natural systems, thereby reducing the adverse impact of agriculture on the environment.

Characteristics of healthy soils: Healthy soils are those that are able to sustain cropping under conditions of minimal plant stress. The most important characteristics of healthy soils are listed in Table 1.

Factors contributing to soil health: Soil health—involving biological, chemical, and physical aspects—is influenced by every aspect of soil and crop management. This makes it difficult to select any one practice or even set of practices as being of critical importance. However, soil organic matter has such a profound effect on many soil properties that organic matter management is the heart of creating soil health. Soil organic matter is made up of living soil organisms and roots, combined with fresh organic residues, and well-decomposed humic materials (Magdoff, 1996). A healthy soil contains (i) an active and diverse population of organisms, (ii) high levels of relatively fresh residues that provide food sources for the organisms (referred to in the scientific

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TABLE 1. Characteristics of healthy soils.

Characteristic	Description
Sufficient supply of nutrients	Although there needs to be sufficient nutrient supply for plant growth, at the end of the season there should not be too much nitrogen and phosphorous left in highly soluble forms or enriching the soil surface. Leaching and runoff of nutrients are most likely to occur after crops are harvested and before the following years' crops are well established.
Good soil tilth	Soil with good tilth is more spongy and less compact and allows roots to more fully develop than a soil with poor tilth. A soil that has a favorable and stable soil structure also promotes water infiltration and storage for later plant use.
Sufficient depth	Soils with sufficient depth to a layer that can restrict drainage and(or) root development promote full root system development.
Good internal drainage	Timely field operations can occur when soils dry quickly. Also, oxygen must be able to reach the root zone to promote optimal root health, and that is best with good drainage.
Low populations of parasites	Crop yields are higher when plants are not harmed by parasitic bacteria, fungi, or nematodes.
High populations of plant-health promoting organisms	Organisms, such as earthworms and many bacteria, fungi, and nematodes help cycle nutrients and make them available to plants. Soil organisms also produce plant-growth-promoting substances.
Low weed pressure	Having few weeds is important so there is little competition with the crop for nutrients, water, and light.
No chemicals that harm plants	Harmful chemicals can occur naturally, such as soluble aluminum in acidic soils or excess salts in arid regions. Potentially harmful chemicals may be introduced by human activity, such as fuel-oil spills, or the application of sewage sludge that has high concentrations of toxic elements.
Resistance to being degraded	Soils with good tilth and internal drainage and that have low populations of plant parasites can better resist the negative effects of compaction or periods of wet weather.
Resilience	Healthy soils are able to recover quickly after unfavorable changes, such as compaction.

literature as *particulate* or *light fraction* organic matter), and (iii) high levels of humified organic matter that retains water and provides cation exchange (negatively charged) sites that retain nutrients such as Ca^{++}, Mg^{++}, and K^{+}.

Another aspect of soil health is the soil's physical condition—degree of compaction, amount of water storage, and drainage. When aeration, water availability, and soil strength are beyond optimum ranges, plant growth suffers. For example, crops growing on compacted soils, with reduced aeration and relatively high soil strength, are more adversely affected by both wet and dry conditions than those growing in soils with good structure. During wet periods compacted soils have insufficient aeration, and, because the soil dries out more quickly, it becomes a physical barrier to root growth. A soil's physical condition is influenced partially by organic matter because polysaccharides and polyuronides produced during decomposition help promote aggregation of soil particles. Secretions of mycorrhizal fungi are also important in promoting soil aggregation (Wright and Starr, 1998; Wright and Upadhyaya, 1996).

The levels of available nutrients, the pH, the salt content, etc. are important determinants of soil health. Plant growth can be adversely affected by either low nutrient levels, high levels of a toxic element (such as Al), or high salt concentrations.

The biological, chemical, and physical aspects of soils all interact with, and affect, one another. For example, a very compact soil has few large pores and thus is less hospitable to organisms such as springtails, mites, and earthworms (Aritajat et al., 1977). In addition, lower levels of oxygen in compact soils may influence the forms of nutrients present and their availability (e.g., significant quantities of NO_3^- may be lost under anaerobic conditions).

Strategies for improving soil health: Managing for improved soil health requires a holistic approach that involves a long-term commitment to using combinations of practices that enhance the soil's biological, chemical, and physical characteristics (Magdoff and van Es, 2000). These practices tend to reduce plant stress and, at the same time, frequently inhibit a pest, and(or) stimulate a natural enemy of a plant pest. A plant under low stress is better able to resist or compete with pests and is thus healthier.

The primary general strategies for improving soil health are as follows.

a) Add plentiful amounts of soil organic matter from crop residues (including cover crops) as well as off-field organic materials such as animal manures and composts. Use a variety of sources of organic materials because they have different effects on soil physical, chemical, and biological properties. For ex-

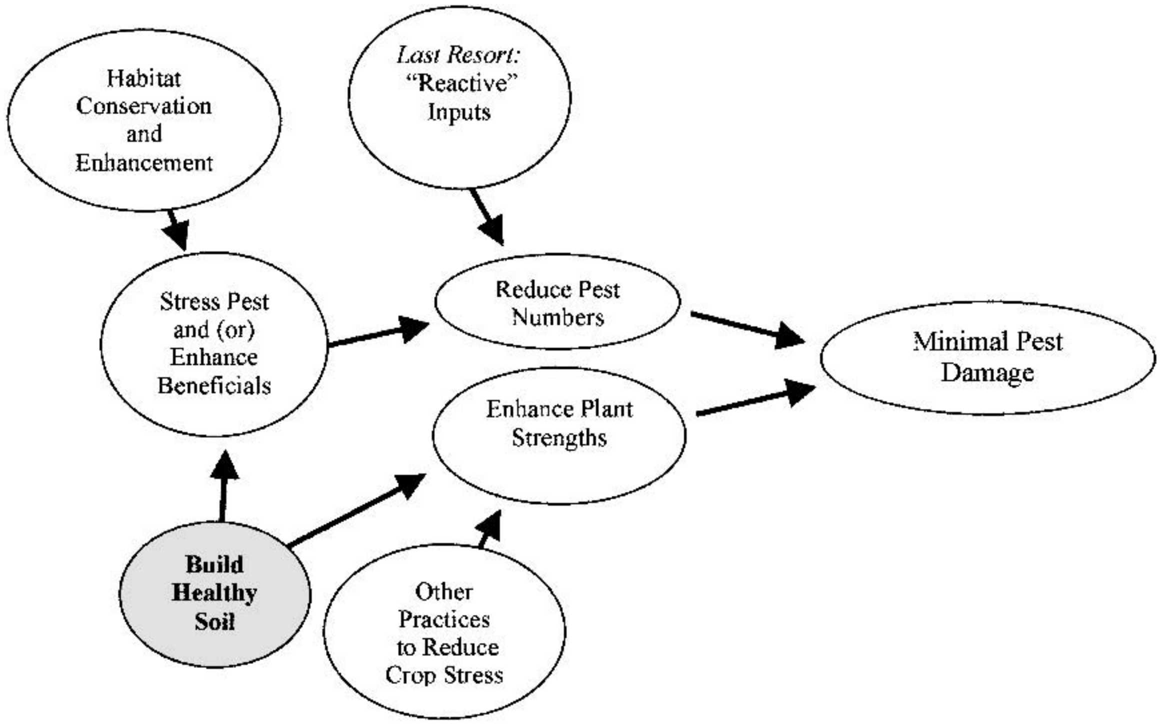

FIG. 1. Contribution of soil health to pest management.

ample, decomposed composts do not enhance soil aggregation but may suppress crop diseases (Hoitink et al., 1997; Magdoff and van Es, 2000).

b) Keep the soil covered with living vegetation and(or) crop residue. Use cover crops extensively. Living and dead residue on the soil surface protects the soil from moisture and temperature extremes and enhances rainfall infiltration, which provides more water for crops and at the same time reduces runoff and erosion.
c) Reduce tillage intensity. Reduced tillage leaves more residue on the soil surface and minimizes organic matter oxidation.
d) Use better crop rotations and include perennials (usually forages) in annual cropping systems whenever possible.
e) Use other practices that reduce erosion (e.g., strip cropping). Erosion decreases soil health by removing topsoil rich in organic matter.
f) Reduce the severity of compaction. This can be accomplished by staying off soils that are too wet, using controlled traffic lanes (including use of raised beds), better load distribution, etc.
g) Use best management techniques to supply nutrients to plants without causing water pollution.

Individual soil-improving practices have multiple effects on the agroecosystem. Farmers using cover crops commonly have a particular goal, such as supplying nitrogen to the following crop. However, growing a cover crop can (i) reduce the amount of runoff and erosion, (ii) enhance the amount of N available to the following crop (if a legume), (iii) reduce nitrate leaching to ground water, (iv) enhance the numbers of arbuscular mycorrhizal fungi spores, (v) provide habitat for beneficial insects, (vi) increase the amount of soil organic matter, (vii) suppress weeds, (viii) decrease root diseases, and (ix) reduce the numbers of plant-parasitic nematodes (Phatak, 1998).

Managing for improved soil quality does not focus on one strategy, such as reduced tillage or the use of cover crops. The key to increasing soil quality is to combine as many of the strategies as make sense on a given farm. Farmers have found that a combination of good crop rotations, routine use of cover crops, and reduced tillage provides many benefits. Incorporating other aspects of soil quality management—applying animal manures or composts to soils in such a system, using techniques to decrease soil compaction, and improving nutrient management—provides even more benefits.

Soil health and pest management: Three main strategies are used to reduce pest damage to crops. Practices that enhance plant defense mechanisms make plants more resistant and(or) unattractive to pests. Second, those practices or conditions that decrease pest numbers also reduce the severity of damage the pests can have on crops. Third, using multiple tactics for controlling pests, rather than one major tactic (frequently a pesticide), reduces the chance that the pest will be able to adapt to control measures.

Managing to promote soil health frequently leads to the reduction of many plant pests (Abawi and Widmer, 2000; Liebman and Davis, 2000; Phatak, 1998; and Phelan et al., 1995). Practices that promote soil health commonly contribute to the first two strategies. By reducing plant stress, inherent plant capabilities to resist pests are better expressed (Fig. 1). In addition, healthier soils have more diverse and active populations of soil organisms. Populations of many soilborne pests are maintained at low numbers because of competition for resources or outright antagonism from other organisms.

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