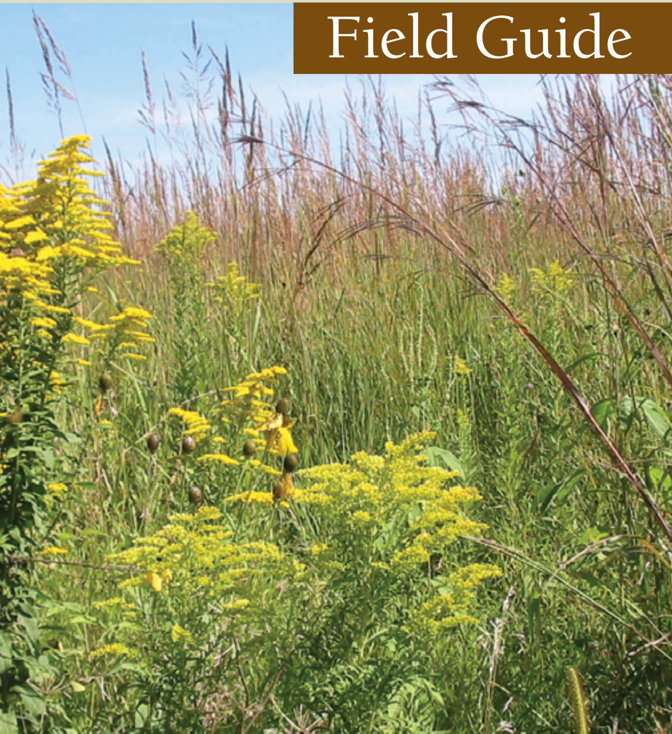
Iowa State University
Extension and Outreach

IOWA SOIL HEALTH

Field Guide



Introduction and Goal of the Field Guide

This soil health field guide provides information about soil health and its importance to sustainable agriculture systems. The research-based information in this soil health guide highlights the relationships between soil characteristics in an easy to understand format that is useful to farmers, agronomists, agricultural consultants, soil scientists, technical service providers, and extension educators.

This soil health field guide is the product of the collaborative efforts of Iowa State University and the Natural Resources Conservation Service (NRCS) in Iowa.

The guide has three sections, including:

1. The soil health concept
2. Management practices that influence soil health
3. In field soil health evaluation

SOIL HEALTH CONCEPT

Soil Profile (Source: NRCS)

1. Soil Health Concept

Definition of Soil Health

Soil health is defined as "the continued capacity of soil to function within natural or managed ecosystem boundaries, sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health."

The concept of soil health also means that healthy soils have the ability to sustain plant and animal life and productivity, as well as soil biodiversity, maintain or enhance water and air quality, and support human health and wildlife habitat.

Foundation of Soil Health

The foundation of soil health is **soil biodiversity**, which consists of all the biological components of the soil including plant roots, earthworms, bacteria, fungi, actinomycetes, algae, protozoa, nematodes, mites, springtails, and small insects. Soil biodiversity plays a significant role in building soil aggregates (groups of primary soil particles—sand, silt and clay) that are held together by organic compounds and mineral oxides as essential components of a healthy soil.

MECHANISM OF AGGREGATE FORMATION AND BENEFITS

Substances that bind soil particles together into soil aggregates are from inorganic and organic sources. However, the most essential substance known to bind primary soil particles into aggregates is **glomalin** (Fig. 1 and Fig. 2). Glomalin is the glue-like substance secreted

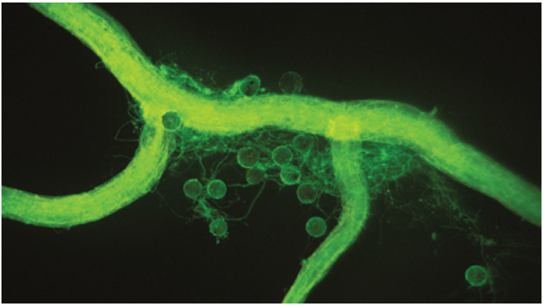


FIGURE 1. A microscopic view of an arbuscular mycorrhizal fungus growing on a corn root. The round bodies are spores, and the threadlike filaments are hyphae. The substance coating them is glomalin, revealed by a green dye tagged to an antibody against glomalin. Credit: Photo by Sara Wright. Source: www.ars.usda.gov/is/graphics/photos/sep02/k9968-1.htm

by the hyphae of a group of soil microorganisms called **arbuscular mycorrhizal fungi** (AMF). The hyphae of AMF are thread-like structures through which nutrients and water enter plant roots (Fig. 2). The hyphae of AMF grow beyond nutrient depleted zones found around roots and root hairs and form a frame for soil particles to collect into aggregates coated with glomalin.

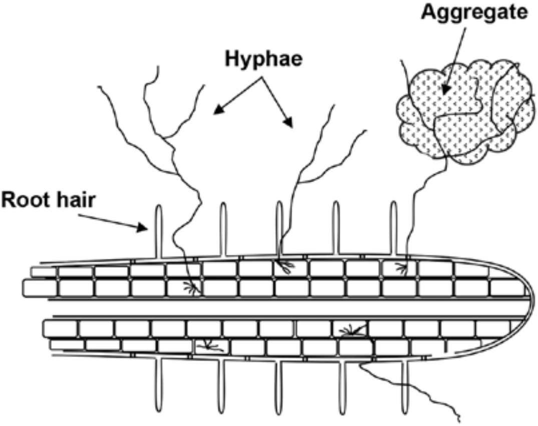


FIGURE 2. Hyphae of arbuscular mycorrhizal fungi on roots and root hairs (Source: Nichols, www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1144429.pdf)

When glomalin binds with iron or other heavy metals, it can keep carbon from decomposing. Even without heavy metals, glomalin stores carbon in the inner recesses of soil particles where only slow-acting microbes live. This carbon in organic matter is also saved like a slow-release fertilizer for later use by plants and hyphae.

Characteristics of a Healthy Soil

The characteristics of a healthy soil are related to the **stable or inherent** and **dynamic** properties of the soil.

INHERENT SOIL PROPERTIES

Inherent (Static) Soil Properties are associated with the process of soil formation and influenced by parent materials, vegetation, climate, time, and topography. These properties define soil's natural ability to function. These soil properties include soil texture, depth to bedrock, drainage class, and cation exchange capacity (CEC). Some of these inherent properties, such as CEC, can be influenced by other properties, such as type and content of clay and soil organic matter (SOM) content, as the increase in both increases CEC.

DYNAMIC SOIL PROPERTIES

Dynamic soil properties are soil properties that are affected by management and constantly changing either with or without human activities within a shorter period of time or in the long-term. These soil properties are soil organic matter (SOM), microbial community, bulk density, infiltration rate, soil water, and nutrient holding capacity.

SOIL HEALTH INDICATORS

Unlike the inherent properties of the soil, the dynamic soil properties are all affected by land management practices including soil tillage, cropping systems, and other land use practices. Therefore, the focus of soil health indicators is on the **dynamic soil properties** and how those properties change in relation to the **inherent**

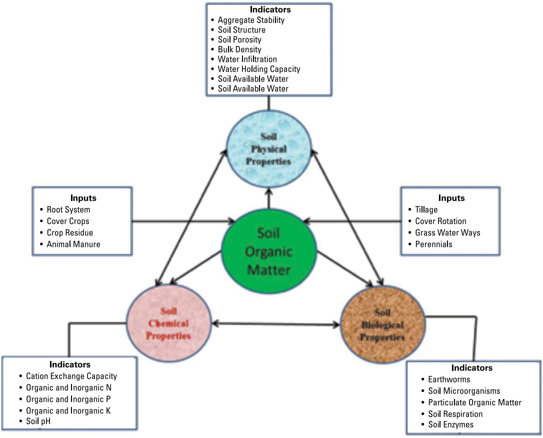


FIGURE 3. Soil health indicators and factors (Al-Kaisi, 2015)

properties to keep the soil healthy (Fig. 3 and Fig. 4). The inherent and dynamic properties of soils are used as indicators to evaluate soil health based on the three broad categories of **physical, chemical, and biological** properties of the soil.

SOIL PHYSICAL PROPERTIES

Generally, the physical properties of soil show how well the soil can provide physical stability and support for plants and soil organisms. The physical properties of soil also show the relationships between soil-water, air, and plant. The following are some soil physical properties that can be evaluated to determine the level of soil health and functionality: bulk density, aggregate stability, water infiltration rate, field capacity, and plant available water (Fig. 3).

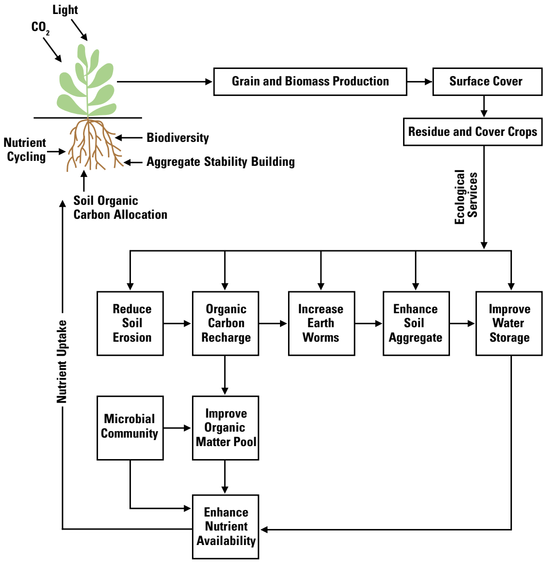


FIGURE 4. Crop residue and cover crops for improving soil health functions and nutrient cycling (Al-Kaisi, 2015)

Soil Bulk Density

Soil bulk density is a measure of porosity expressed as the amount of solid soil particle weight per volume of such mass and defined as gram per cubic centimeter (g/cm^3). Soil bulk density is an important soil health indicator because it reflects the level of porosity and compaction in the soil. Compacted soils have less porosity, lower air content, lower water infiltration rate, restrictive root growth, and poor plant growth compared to a non-compacted soil.

TABLE 1. General relationship of soil bulk density to root growth based on soil texture

Soil Texture	Ideal bulk densities for plant growth (g/cm^3)	Bulk densities that affect root growth (g/cm^3)	Bulk densities that restrict root growth (g/cm^3)
Sands, loamy sands	< 1.60	1.69	> 1.80
Sand loams, loams	< 1.40	1.63	>1.80
Sandy clay loams, clay loams	< 1.40	1.60	> 1.75
Silts, silt loams	<1.40	1.60	>1.75
Silt loams, silty clay loams	<1.40	1.55	>1.65
Sandy clays, silty clays, clay loams	<1.10	1.49	>1.58
Clays (>45% clay)	<1.10	1.39	>1.47

Source: USDA-NRCS Soil Quality Kit-Guides for Educators 2014. (http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053260.pdf)

Table 1 shows bulk density values for different soil textures that are ideal for, or restrictive of plant root growth. Management practices that result in higher soil bulk density involve conventional

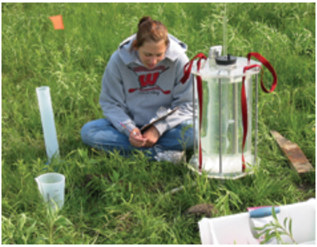
Effect of soil compaction on root and seedling growth at three different soil bulk densities: Low, 0.7 g/cm^3; Medium, 1.1 g/cm^3; High, 1.6 g/cm^3 (Al-Kaisi, 2006)

tillage and mono-cropping systems, overgrazing with livestock, burning and removal of crop residue, and random equipment traffic, especially on wet soils.

Soil Aggregate Stability

Soil aggregate stability means the ability of soil to strongly bind together and withstand the force or pressure applied by rain intensity and traffic. It is another way to describe the strength of the soil structure to resist the impact of any external force or pressure, especially rainfall. Healthy soils should have stable soil aggregates capable of resisting the destructive impact of rainfall and water and wind erosion. Soil aggregate stability is affected by **soil texture, type of clay, extractable cations**, the amount of organic matter, and **type and population of soil microorganisms** present in the soil. **Soil tillage destroys the stability of soil aggregates.**

Water Infiltration


Measuring water infiltration

Water infiltration is the movement of water through the soil surface into the soil profile. The rate of infiltration is relative to the rate of rain intensity or water supplied to the soil surface, which influences how much water will enter the root zone and how much will run off the soil surface. Soil texture, soil structure (bulk density and aggregate stability), and slope impact water infiltration rate of soils the most, especially pore size distribution and the continuity of pores.

Determining infiltration in the field

Conventional tillage practices can reduce water infiltration significantly because of the destruction of soil structure as shown in Fig. 5. Management practices—such as no-tillage or strip-tillage—improve water infiltration, increase water recharge, and reduce water runoff. Runoff

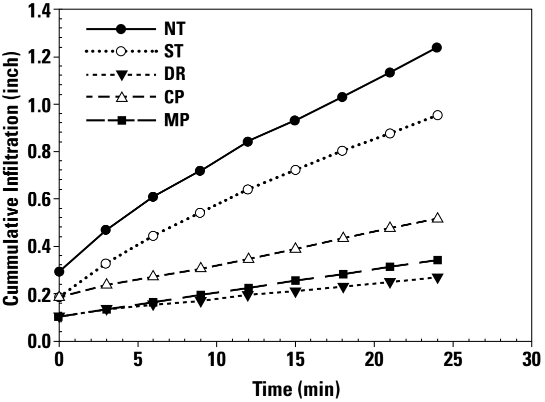


FIGURE 5. Cumulative water infiltration in different tillage systems. NT=no-till; ST=strip-tillage; CP=chisel plow; DR=deep rip; MP=moldboard plow (Al-Kaisi, 2015)

is the major contributor to nutrients and sediment loss, and water quality deterioration. Field measurements and observation of water infiltration can be achieved by using a simple ring method or water conditions after rain events as a reflection of management effects on soil health.

Field Capacity

Measuring soil surface moisture

Field capacity (FC) of a soil is the amount of water or moisture content held in soil after excess or free water has drained downward to lower depths. Soil at FC provides the optimal condition of water and air for plant growth. After a rain or irrigation event, any excess or free water (saturation condition) in the soil drains by gravity to lower soil depths. The amount of water that remains in the soil is easily available to plants.

Plant Available Water

Plant available water (PAW) is defined as the difference between soil water or moisture content at field capacity (optimal moisture condition) and the permanent wilting point (PWP), the driest soil condition in which soil water is not available to plants. The plant available water is highly influenced by soil texture. Loam textured soils have a higher amount of plant available water than clay textured soils.

SOIL BIOLOGICAL PROPERTIES

Soil biology plays an important role in building soil health by facilitating soil organic matter decomposition, nutrient cycling, and the release of macro-nutrients such as nitrogen (N) and phosphorus (P), and secondary and micronutrients that plants can absorb to grow. The process of converting organic N into inorganic N by soil microorganisms is called **nitrogen mineralization**, which is part of the nitrogen cycle as shown in Fig. 6. In the nitrogen cycle, soil bacteria play a vital role in converting organic N to NH_4^+ and NO_3^- that will be available for plant uptake.

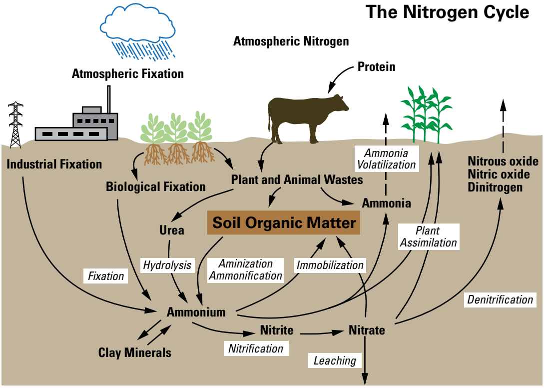


FIGURE 6. The nitrogen cycle. (Source: "Soil as a Plant Sees It," The University of Nebraska, 1991)

The decomposition of organic materials in the soil by microorganisms ultimately produces humus, the most stable portion of organic matter that helps build soil structure (e.g., soil aggregates) and a nutrient pool. A large diverse population of soil microorganisms also competes with disease-causing organisms in the soil to reduce their numbers. Soil organisms, like earthworms, play an important role in building soil tilth. Earthworms provide a rich source (castings) of nutrients by the breakdown of plant materials in their digestive system. Earthworms also create channels that aid in the redistribution of nutrients in the soil profile.

Soil Organic Matter

Soil organic matter (SOM) is the single most important soil health factor because it affects the soil physical, chemical, and biological properties. Soil organic matter, which constitutes 1 to 6 percent of the total soil mass depending on soil forming conditions may include:

- 7 to 21 percent of readily decomposable organic matter;
- 3 to 9 percent of soil microbial biomass, which includes 30 percent bacteria and actinomycetes, 10 percent fauna, 10 percent yeast, algae, protozoa, nematodes, 50 percent fungi; and
- 70 to 90 percent of stable soil organic carbon (humus).

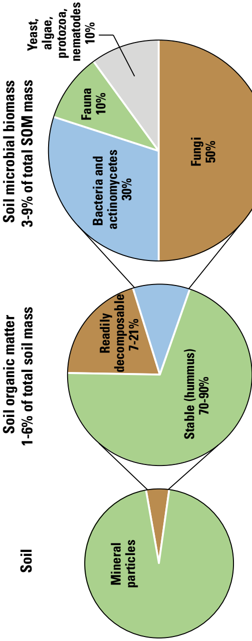


FIGURE 7. Soil organic matter composition

Decomposition of soil organic matter can be rapid or slow depending on its chemical structure. Starches and proteins decompose faster than cellulose, fats, waxes, resins, and lignin. Soil organic matter that has completely decomposed is called **humus**. About 70 to 90 percent of the non-living part of soil organic matter is humus. Soil organic matter is the source of the soil nutrients, such as nitrogen (N), phosphorus (P), and sulfur (S), which are released into the soil during decomposition.

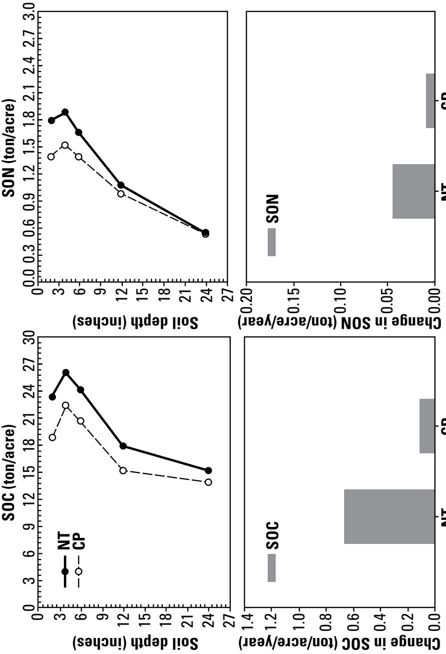


FIGURE 8. Tillage effects on soil organic carbon inputs from crop residue. NT = no tillage and CP = chisel plow (Al-Kaisi, 2005)

Conventional tillage is a major factor in destroying soil organic matter by accelerating its oxidation as shown in Fig. 8. Tillage operation increases soil aeration, which can increase microbial activity to decompose organic matter in the soil.

The unique benefits of soil organic matter for soil health include:

- Increasing soil fertility by retaining positively charged elements called cations.
- Conserving soil nutrients in their organic forms to slowly be released in the soil as condition becomes optimum (moisture and temperature).
- Producing hormones that help plants to grow.
- Providing food for soil microorganisms.
- Binding soil particles together into aggregates that improve soil structure, and water and air movement.
- Improving soil water holding capacity for plant use and cation exchange capacity.

Other biological indicators to evaluate soil biological activities may include microbial biomass carbon (MBC), rate of CO_2 evolution or respiration, phospholipids fatty acids (PLFA), earthworm population, soil organic carbon (SOC) concentration, and enzyme concentrations in soil. These are properties that can be evaluated in the laboratory using procedures that are specific to each one. The overarching property and most important in evaluating soil biological health is the determination of soil organic matter as the precursor for a healthy soil environment. These indicators are sensitive to management practices such as tillage and cropping systems.

SOIL CHEMICAL PROPERTIES

Soil chemical properties are essential for well-functioning soils to support the growth and functions of plant and soil organisms. In the soil a number of inorganic and organic chemical reactions and processes takes place that are essential for soil productivity and plant growth. These include cation and anion exchanges and base saturation, which is the portion of cation exchange capacity (CEC) occupied by bases. These chemical reactions and processes in the soil are controlled by clay minerals, oxides and hydroxides of iron and aluminum, and humus. The following are soil chemical properties that affect the soil environment: soil pH, CEC, and the soil nutrient pool.

Soil pH

Soil pH is the measure of the level of soil acidity or alkalinity based on amount (concentration) of free hydrogen ions (H^+) in the soil (Fig. 9). When the concentration of hydrogen ions in the soil is high, the pH of the soil is acidic. Alkaline soils have low concentration of hydrogen ions. Soil pH is measured on a scale of 0 to 14. Soil pH value of 7 is neutral. Soil pH is acidic when the value is lower than 7 and alkaline or basic when the value is higher than 7.

Soil pH is important because it directly affects **soil fertility**. Many annual crops grow best when the soil pH is close to neutral in the range of 6 to 7.5. However, when the soil becomes acidic from farming practices, including excess fertilizer application, it affects nutrients availability. Lime application is the recommended management practice to correct the acidic soil condition.

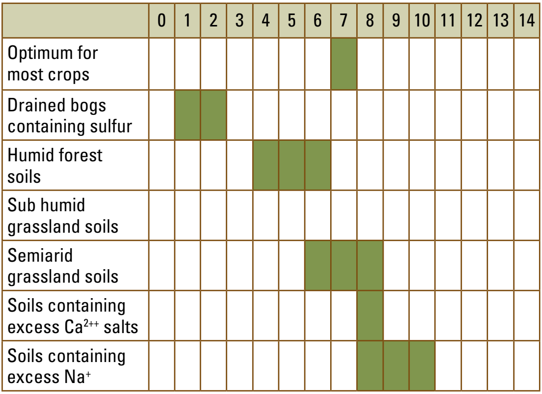


FIGURE 9. Typical pH ranges for various types of soils (Source: Troeh and Thompson, 1993 in Smith and Doran, 1996)

Cation Exchange Capacity

Cation exchange capacity (CEC) is the ability of the soil to hold nutrients (cations) and release them during chemical reactions for plant uptake. In the soil, a number of cations including calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), and others contribute to soil fertility. These cations are held by the negatively charged surfaces of the clay minerals and organic matter (humus) in the soil.

The CEC values depend on soil texture, clay type and amount, soil pH, and organic matter content. Soils with higher clay and organic matter content will have higher CEC. Therefore, managing soil for high crop yields and residue input, including soil pH and nutrient supply, will help to maintain or increase soil CEC.

Soil Nutrient Pool

The **soil nutrient pool** is simply the reservoir of nutrients in the soil, which is generally reported in mass or weight of the nutrient per unit area of soil as pounds per acre (lb/acre). The primary nutrient pools of the soil include:

- Soil organic matter and compounds that provide nutrients through the mineralization process.
- The soil solution (water with dissolved nutrients).
- Exchangeable positively charged elements (cations) and negatively charged elements (anions).
- Bonding of cations and anions with the mineral surfaces of the soil.
- Primary and secondary minerals as a result of chemical reaction process in soil.

Soil health is directly linked to soil fertility, which depends on the amount and availability of nutrients in the soil nutrient pools. Soil organic matter is one of the major sources of nutrients released into the soil system for plant uptake. The availability of plant nutrients from these different pools varies greatly. Plant materials such as cover crop, crop residues, fine root turnover, and manure inputs can help boost some nutrient pools.

Understanding the Carbon to Nitrogen (C:N) Ratio

Soil microorganisms use the carbon (C) and nitrogen (N) in crop residue for energy and building new tissue, respectively. The ratio of the amounts of carbon and nitrogen (C:N ratio) in the crop residue left in the field plays a significant role in how fast the residue breaks down and adds organic carbon and nitrogen into the soil.

Therefore, a basic understanding of the concept of C:N ratio is essential for practical farming.

When organic matter breaks down in the field it may result in the net release of nitrogen (N) into the soil; this process is called mineralization or N release. When the residue decomposition results in an N deficit without any release of N into the soil, the process is called immobilization or tied-up. With immobilization, soil microorganisms utilize all the N in the residue to form new tissue, in which case the N is not immediately available to plants for use. Therefore, whether residue decomposition results in mineralization (release) or immobilization (tied-up or no-release), will depend on the C:N ratio of the plant material added to the soil. Plant materials with high C:N ratio, such as corn (75:1), will have a slow decomposition process, whereas plants with low C:N ratio (35:1), such as soybean residue, will have a much faster decomposition. The optimal C:N ratio for soil microbes to decompose plant materials is less than 20:1.

Determining soil air composition

How to Determine Residue Decomposition

Example of Residue Breakdown:
A farmer leaves 4400 lb of crop residue on his field after harvest, which contains 55% carbon with a C:N ratio of 20:1. Will residue decomposition result in mineralization or immobilization?

Solution: Step 1
Determine the amount of carbon (C) by weight present in the crop residue left in the field as follows:
4400 pounds × 55% = 2420 pounds

Step 2
Determine the amount of nitrogen (N) present in the residue based on the [C over N] ratio of 20:1 as follows:

$$\frac{C}{N} = \frac{20}{1} = \frac{2420\ lb}{N},\ \frac{2420\ lb}{20} = 121\ \textit{pounds}\text{ of organic N.}$$

Step 3
Calculate the amount of carbon (C) and nitrogen (N) needed by soil microorganisms to form new tissues: During residue decomposition, soil microorganisms will decompose 0.75 or 75% of total carbon (C). 0.25 or 25% will be used by the microbes to build new tissue. This amount is: 0.25 × 2420 *pounds* = 605 *pounds* of carbon used by the microorganisms.

To build new tissue, soil microorganisms need on average $\frac{C}{N}$ ratio 8:1

Therefore, the amount of N required by soil microorganisms to form new tissue will be

$$\frac{605}{8} = 75.63\ \textit{pounds}\text{ of N.}$$

Step 4
Finally, compare the original amount of N in the residue, in step 2, (121 *pounds* of N) and the amount of N from the residue used by the soil microorganisms (76 *pounds* of N).

There is a **net positive balance** of 45 *pounds* N, (121-76 = 45 *pounds*) released into the soil that may be available to plants and this means **N mineralization**.

The Importance of Soil Health

A healthy soil environment is the foundation for food and fiber production, environmental services, and wildlife habitat. Human activities, including some farming practices, disrupt vital soil processes such as the building and storage of soil organic carbon, building stable soil aggregates, and nutrient cycling.

Soil has long been perceived as the “home” for the greatest microbial diversity among all ecosystems. Therefore, the ability of soils to remain healthy to prevent degradation is dependent on maintaining the soil biodiversity that is essential for supporting processes, such as residue decomposition and nutrient cycling, regulation of microclimate, local hydrological processes, suppression of undesirable organisms, and the detoxification of undesirable chemicals in the soil.

Implementation of conservation systems can lead to the improvement of many soil health indicators that are interdependent to provide a balanced soil environment for plant and soil organisms as shown in Fig. 10.

SOIL FUNCTIONS AND SERVICES

Soil, air, and water are three essential natural resources and the relationships among them define the unique functions of the soil. The major functions and services of soil are:

- Nutrient cycling
- Water and chemical regulation
- Biodiversity and habitat
- Physical stability and support
- Climate modifier

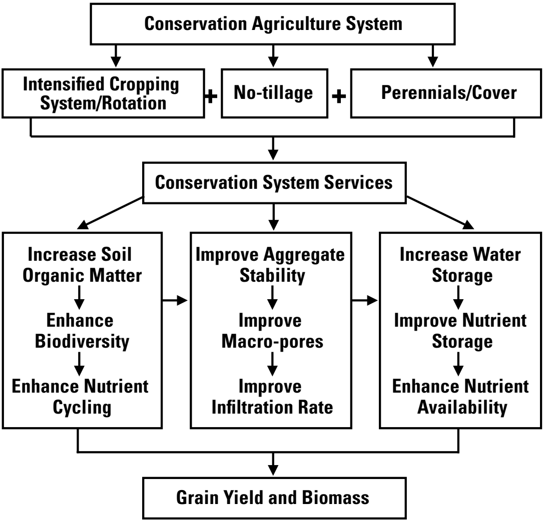


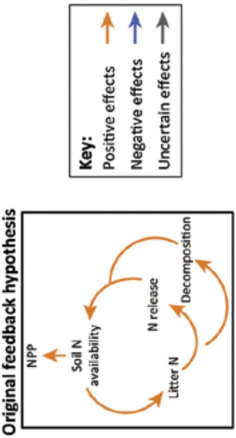
FIGURE 10. System approach for building soil health and productivity (Al-Kaisi, 2015)

NUTRIENT CYCLING

Soils are the reservoir of plant nutrients, and function by cycling and controlling the release of the nutrients that plants need to produce healthy crops. During nutrient cycling, the following three important plant nutrients, calcium (Ca), nitrogen (N), and phosphorus (P), transform into forms that plants can easily absorb, as shown in Figure 11 for nitrogen cycling.

Soil microorganisms play a significant role in nutrient cycling. Humified soil organic matter forms a slow/passive pool, whereas the fast/active nutrient pool—

such as recent plant residues in early stages of decomposition and soil organisms—has a turnover time of months to years that has the greatest impact on plant growth. In agricultural soils, the interaction between soil microorganisms and



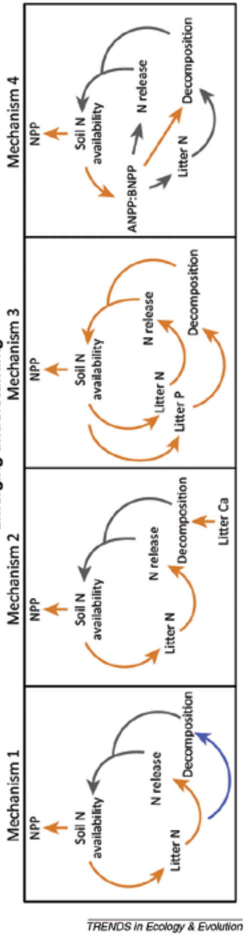


FIGURE 11. Mechanisms of species effect on nutrient cycling. (Source: Hobbie, 2015). NPP= Net Primary Productivity, ANPP= Aboveground Net Primary Productivity, BNPP= Belowground Net Primary Productivity)

nutrient cycling depends on the type of cropping system and crop residue management. When plant residue is left on the soil surface, fungi develop and the population of organisms that feed on fungi increases in the surface layers of the soil. The decomposition of crop residue in the field by soil micro-organisms is influenced by the C:N ratio of the crop residue, soil moisture, and soil temperature among other factors.

WATER AND CHEMICAL REGULATION

Soil is a porous medium like any spongy material with the ability to absorb and hold water and dissolved plant nutrients. Therefore, the soil controls and regulates the movement and amount of water and the major plant nutrients through the soil profile. Soil also buffers excess plant nutrients and modifies and filters toxic compounds like arsenic, pesticides, and other chemicals to make them unavailable to plants and animals. Examples of soil ecosystems that regulate and filter chemicals are wetlands (Fig. 12). Wetlands function as filters by improving water quality, reducing floods and storm damage, and providing important habitat for aquatic life and wildlife.

FIGURE 12. Restoring Iowa Wetlands (Source: USDA-NRCS. www.nrcs.usda.gov/wps/portal/nrcs/detail/ia/newsroom/factsheets/?cid)

BIODIVERSITY AND HABITAT

Soil provides a diverse physical, chemical, and biological environment that supports the growth of a variety of plants, animals, and microorganisms including bacteria and fungi. Soil diversity, also known as soil biodiversity, is the variation in soil life. The soil is also home for a number of organisms such as worms and insects like centipedes. One gram of soil contains a significant number of bacterial cells of different species and other microorganisms.

Soil microorganisms are responsible for breaking down resistant organic matter (e.g., lignin) or toxic chemicals such as pesticides. The presence of soil biodiversity makes the soil a living ecosystem, and the understanding of the soil as a living ecosystem is the basis for good soil management practices to maintain and enhance soil health.

Neal Smith National Wildlife Refuge, Prairie City, Iowa

PHYSICAL STABILITY AND SUPPORT

Healthy soils have the ability to maintain their porous medium to allow the passage of air and water and also withstand the erosive forces of water and air because of the presence of stable aggregates. The soil provides the growing medium and holding support for plant roots and man-made structures like buildings and roads. Healthy soil provides a strong soil structure that can minimize soil compaction under relatively dry soil conditions, especially under natural or conservation agriculture systems as compared to conventional tillage systems.

CLIMATE MODIFIER

Soil plays a key role in amending and modifying the risks and effects of climate variability. It acts as earth's major carbon sink by sequestering atmospheric carbon dioxide and contributes to the mitigation of greenhouse gas emission by reducing their levels in the atmosphere. The storage of soil carbon contributes to the health of soil and to improvement of soil physical, biological, and chemical properties.

MANAGEMENT PRACTICES and SOIL HEALTH

2. Management Practices and Soil Health

Soil is the farmer's most valuable natural resource because it provides the growth medium for crop production. Soil is a vital ecosystem that contains actively growing organisms including plant roots and macro- and microorganisms. Production of food and fiber can be improved and sustained in a healthy soil. Therefore, managing the topsoil is essential to crop production.

Factors and Management Practices Affecting Soil Health

A number of factors and management practices affect soil health.

FACTORS AFFECTING SOIL HEALTH

- Soil properties, which include soil type, texture, drainage, pH, bulk density, aggregate stability, and soil organic matter.
- The types of crops grown including crop residue, cover crops, cropping systems, and crop rotation.
- The biology of the soil, which includes soil bacteria, fungi, protozoa, nematodes, earthworms, and mammals. The bacteria and fungi contribute to organic matter decomposition and nutrient cycling.
- The environment, which includes factors such as precipitation, temperature, humidity, wind, season length, and carbon dioxide levels.

MANAGEMENT PRACTICES THAT AFFECT SOIL HEALTH

Agricultural management practices that affect soil health include tillage practices, plant diversity, fertilizer application, cover crops, residue management, manure application and use, and field equipment traffic control.

TILLAGE PRACTICES

Tillage practices are major agricultural management practices used for a variety of reasons including seedbed preparation, incorporation of fertilizers and crop residue, and weed control. The effect of tillage on soil health can be very destructive to soil physical and biological properties, such as the loss of organic matter, structure, and reduction of water infiltration. Intensive tillage, especially under moist soil conditions, can cause excessive soil compaction below the tillage depth creating plow pans, especially under wet soil conditions. The conventional tillage practice also destroys biopores and breaks the continuity in soil pores to create depressions and surface ponding and leads to potential

Soil crusting in tilled field

Soybean planted in no-tillage with corn residue

soil erosion that can contribute to nutrients and sediment loss.

Water infiltration in Strip-tillage (ST) and Conventional-tillage (CT)

PLANT DIVERSITY

Planting diverse crop species contributes to soil aggregation. The planting of crops increases soil macro-aggregate stability. Soil aggregate stability varies among different cropping systems and plant species. Different plant species with differing root density and organic exudates, and degree of mycorrhiza colonization impact soil aggregation and ultimately soil health and biological diversity.

Remnant prairie with mixture of grasses and forbs

FERTILIZER APPLICATION

Adequate nutrient availability is essential for high crop productivity and quality. When the soil supply of available nutrients is low, use of fertilizers and manures can provide needed plant nutrients. However, nutrient applications should be based on soil and plant testing as appropriate, and to avoid more than needed inputs that might adversely affect soil and plant growth.

COVER CROPS

Cover crops protect the soil surface from the impact of rain intensity during the off season by reducing soil erosion and carbon loss, and improving soil macro-aggregates stability. Additionally, cover crops such as grasses, legumes, barley, and wheat add carbon to the soil through root exudation and the decomposition of their dead leaves and roots. Leguminous cover crops fix nitrogen.

Mixed cover crop

RESIDUE MANAGEMENT

Crop residue left on the soil surface a) protects the soil by reducing aggregate breakdown by raindrops, thereby increasing aggregate stability and b) enhances water infiltration and reduces soil erosion. The C:N ratio of crop residue and their decomposition rate to release organic carbon will influence soil structure and other soil biological properties. The soil water content, soil temperature, and nitrogen availability influence the rate of residue decomposition.

Residue removal

MANURE APPLICATION USE

Organic fertilizers such as manure and compost are good sources for increasing soil C and N contents resulting in the increase of microbial biomass C and N. The application of organic byproducts and manure to the soil increases soil water-stable macro- and micro-aggregates. The improvement of soil organic matter with addition of organic sources dry or liquid has many benefits in improving nutrients capacity and physical properties of the soil.

TRAFFIC CONTROL

The repeated use of heavy farm equipment for farm operations (such as tillage, planting, and fertilizer and pesticide application) damages the soil structure resulting in soil compaction over time, which affects soil health. Working the field when at wet condition—such as field capacity or saturated condition—can compact the soil and destroys the soil structure. Therefore, avoiding wet conditions and controlling traffic in the field are essential to reducing soil compaction, improving soil health, and preventing yield reduction. Soil compaction resulting from farm equipment is inevitable, but it can be controlled by using the same path during planting, fertilizer and pesticide applications, and harvest.

In summary, soil tillage is detrimental to soil health as it increases soil organic matter loss and destroys physical properties and soil organisms. The addition of organic matter—including plant residue, manure, or cover crops—to the soil can build soil organic matter over time and protect the soil from erosion by wind and water. Generally, a no-tillage system has many benefits in addition to reducing soil erosion, including increasing soil moisture storage, which is essential for yield, especially during dry conditions.

Soil Health and Productivity

Soil is a dynamic ecosystem that supports a diversity of life and provides ecological services and over 90 percent of the food we eat. Management decisions farmers make have profound impact on the overall quality, health, and productivity of the soil. Farmers can keep the soil healthy and productive by doing the following:

- Maintaining topsoil depth by minimizing soil erosion, and reducing sediment, nutrients, and organic matter loss.
- Improving the soil as a medium for root growth and development through reducing, localizing, or eliminating tillage.
- Using fertilizers, herbicides, and pesticides appropriately to minimize adverse effects on the environment.
- Maintaining live plant growth throughout the growing season by using crop rotations and cover crops.
- Enhancing and maintaining soil biodiversity with conservation practices and agriculture systems that include cover crops, surface residue, strip-tillage, and no-tillage.
- Minimizing and controlling soil compaction.
- Building and maintaining soil organic matter with conservation systems.
- Enhancing water infiltration and retention in the root zone for extraction by plants.
- Minimizing water evaporative losses with soil surface residue using conservation systems (e.g., strip tillage or no-tillage).

Because soil is a dynamic system with multiple functions essential to life, it is appropriate to think about soils in terms of health, vitality, and productivity. From the standpoint of soil productivity, there is strong dependence of grain and biomass production on soil health.

Corn growing in no-tillage (NT)

Soil Health Indicators

Depending on land use and location, soil health indicators may differ. However, for agricultural purposes, soil health indicators have been broadly grouped as physical, chemical, and biological (Fig. 3). Of the three broad categories of soil health properties, the physical and chemical properties have been well studied by soil scientists and the basic tests and procedures are well established. On the other hand, many of the tests for the biological properties of the soil are fairly new and more challenging given the complexity of the soil biological system. Although soils have inherent quality (e.g., soil texture) in relation to their physical, chemical, and biological properties within the limits set by climate ecosystem, soil health changes over time as a result of natural events or human activities. Land managers are the ultimate determinant of its quality or health.

The three major criteria for assessing soil health—the physical, chemical, and biological properties listed in Table 3—are all sensitive to the management practices listed in Table 2 and to climatic changes that affect soil health.

TABLE 2. Agricultural management practices that affect soil health

Activities that degrade soil health	Activities that promote soil health in agriculture land
Aggressive soil tillage	No-tillage or conservation tillage
Annual or seasonal soil fallow	Use of cover crops and relay cropping
Mono-cropping	Diverse crop rotations
Planting of annual crops	Planting of perennial crops
Excessive use of inorganic fertilizers	Organic fertilizer (manures)
Excessive removal of crop residue	Retention of crop residue
Use of broad spectrum fumigants/pesticides	Integrated pest management
Use of broad spectrum herbicides	Weed control by mulching and non-chemical and less soil disturbance methods

Source: Soil biology for resilient, healthy soils (Lehman et al., 2015)

TABLE 3. Selected soil health physical, chemical, and biological indicators that can be assessed in laboratory and field

Soil properties	Soil health indicator	Relationship to soil condition and function	Methods of evaluation and reference
Physical	Bulk density, typically expressed in g/cm^3	Structural support for plants, water, and solute movement, soil aeration	Cylindrical core method, USDA-NRCS, 2008 Arshad et al. 1996.
	Penetration resistance	Soil compaction	Penetration resistance method, Licht and Al-Kaisi, 2005
	Infiltration rate	Soil's ability to allow water movement into and through soil profile	Penetration resistance method
	Water holding capacity	Amount of water held in soil. Provides water for plant and soil organism functions	Single or double ring infiltrometer method, USDA-NRCS, 2008
	Aggregate stability	Provide soil structure and growth environment	Gravimetric Method, Time Domain Reflectometry (TDR)

TABLE 3. Continued

Soil properties	Soil health indicator	Relationship to soil condition and function	Methods of evaluation and reference
Chemical	Cation exchange capacity (CEC)	Soil fertility and plant nutrition	Laboratory analysis, Summer and Miller, 1996
	Organic matter (Organic Carbon, Nitrogen and Phosphorous)	Soil fertility, plant nutrition and aggregate stability	Numerous laboratory methods are available SSSA Book Series: 5
	Electrical conductivity (EC)	Indicates how much nutrient is available to plants and salinity levels. Defines microbial activity in the soil	Electrical conductivity pocket meter, USDA-NRCS, 2008
	pH	Plant nutrition, growth, and crop yields, biological and chemical activity in the soil	Portable pH pocket meter, USDA-NRCS, 2011. Standard lab measurements (KCL or water extractions).
	Heavy metals and plant toxins, examples are Copper, Zinc, Nickel, Cadmium and Lead	Plant nutrition in smaller amounts can be harmful to plants. High levels can be harmful for plants or animals.	Reed and Martens, 1996; Amacher, 1996 Soil digestion Cornell test #2021 EPA Method 3051-6010

TABLE 3. Continued

Soil properties	Soil health indicator	Relationship to soil condition and function	Methods of evaluation and reference
Biological	Earthworms	Modify soil structure with pores and new aggregates with binding agents responsible for water stable aggregates	Counting the number of earthworms per unit area of soil, USDA-NRCS, 2009
	Microbial biomass carbon	Amount of carbon fixed in microbial community	Guzman and Al-Kaisi, 2010
	Soil microorganisms (bacteria, fungi, nematodes, viruses)	Nutrient cycling, decomposition, and respiration	Culture media, Rai, 1976
	Soil enzymes activities	Influence organic matter decomposition, and nutrient cycling	Biochemical assays, USDA-NRCS, 2010
	Particulate organic matter	Food and energy for soil micro-organisms and small animals, CEC, plant nutrients, buffers pH, suppresses soil borne diseases	Several different laboratory methods, Cambardella and Elliot, 1992; Fronning et al., 2008; USDA-NRCS, 2011

SOIL HEALTH EVALUATION

3. Soil Health Evaluation

Soil Health Evaluation Methods

Soil health evaluation involves both field and laboratory procedures.

Laboratory methods involve soil sample preparation and analyses of soil samples that may include chemical analyses—such as total carbon, total nitrogen, phosphorus, potassium, CEC, and soil pH—and for the biological characteristic—such as soil microbial biomass carbon and other biological indicators. Also, laboratory procedures can be used for determining soil aggregate stability and other physical properties. Table 3 summarizes the majority of soil health indicators, their relevance, and methods (field and laboratory) for their evaluation, and references of these methods.

Measuring soil surface moisture

Field methods involve scouting and observation of the field for physical signs of plant stress and soil biological, physical, and hydrological evaluation. These field observations and soil health assessment indicators can be summarized for future reference. Generally, the field assessment for soil health focuses on selected soil properties that are easy to evaluate, such as soil structure, compaction, plant appearance, earthworm counts, water infiltration, and other field indicators affected by management practices as summarized in the soil health assessment card (Table 4).

Measuring compaction

Soil Health Assessment

Soil health can be assessed by using the Iowa Soil Health Assessment Card. Its purpose, interpretation, and directions for use begin on page 44. The card itself is shown in Table 4 in the foldout on page 47.

PURPOSE OF THE IOWA SOIL HEALTH ASSESSMENT CARD

The Iowa Soil Health Assessment Card (ISHAC) is a tool designed to help farmers, operators, and other agricultural professionals (including Extension Educators) evaluate the health of the soil using soil biological and physical indicators in the field. The ISHAC is designed to reflect how well the soil is functioning when compared to its natural or inherent potential and to monitor improvement in soil health based on a person's field experience and working knowledge of a field specific soil resource. Regular use of the ISHAC allows users to monitor long-term trends and changes in soil health due to the effects of soil and crop management activities. The ISHAC provides a qualitative assessment of soil function and evaluation ratings, but does not represent an absolute measure or value and is most effective when filled out consistently by the same person over time. The purpose of using the ISHAC to evaluate soil health is to help users improve their understanding of how management decisions influence soil health and function at a specific farm.

INTERPRETATION OF THE IOWA SOIL HEALTH ASSESSMENT RESULTS

The rating descriptions for each indicator presented on the score card represent the worst and best soil conditions at the time of evaluation. As the ISHAC is used over time, the impact of different management systems can be documented. It is important that individual score cards for each location are kept as a record to monitor how specific soils are responding to overall soil and crop management decisions. Individuals may also consider using the NRCS Soil Quality Kit to assess the health of specific fields or soils more quantitatively. Contact a USDA-NRCS district conservationist for information on Soil Quality Kit purchase and help.

Terraces breaking slope

DIRECTIONS FOR USING THE IOWA SOIL HEALTH ASSESSMENT CARD

1. Divide the farm and fields into separate sections for evaluation in the same way operators would divide them for soil fertility sampling: systematic or grid locations, topography, history of tillage, crop rotation, and manure application.
2. Enter the Location, Date, Soil Type, Soil Condition, Crop Type, and Variety Hybrid information for the assessed field at the top of the ISHAC.
3. Use a shovel to get a representative soil sample from more than one spot within each portion of the field.
4. Rate each indicator on a scale from 1 to 10, with 10 being the best. Refer to the Rating Description as a guide to determine the score for each indicator. Record site-specific observations in the Notes section.
5. Review and evaluate the scoring. Follow changes in the soil health indicators over time, examine current field management practices, explore options, and consider alternatives of management changes in problem areas.
6. Consult recommended management practices for improving soil health that are listed in the last part of Table 4.

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TABLE 4. The Iowa Soil Health Assessment Card

Suggested timing for assessment of soil health indicators					
	GROWING SEASON				
	Early Spring	Spring	Summer	Fall	After Rainfall
Structure (aggregate stability, friability)	✓	✓	✓	✓	
Crusting		✓			✓
Compaction	✓	✓	✓	✓	✓
Earthworm	✓	✓			✓
Smell	✓	✓			✓
Residue Decomposition	✓	✓			
Infiltration					✓
Water Holding Capacity	✓	✓	✓	✓	✓
Emergence		✓			
Plant Health		✓	✓	✓	
Root Growth		✓	✓	✓	

TABLE 4. (Continued) Iowa Soil Health Assessment Card

Date ____________________

Location ____________________ **Crop Type** ____________________ **Variety/Hybrid** ____________________

Soil Type ____________________ **Slope** ____________________ **Corn Suitability Rating** ____________________

Soil Condition ☐ Dry ☐ Moist ☐ Wet

Field Characteristics - Field characteristics do not change frequently and can be checked less frequently

Description – check on per category				**Notes**
Topography	☐ Rolling to hilly	☐ Gently rolling	☐ Flat	____________________
Color	☐ Light	☐ Moderate	☐ Dark	____________________
Soil Texture	☐ Clay	☐ Loam	☐ Sand	____________________
Drainage	☐ Poorly drained	☐ Moderately drained	☐ Well drained	____________________

TABLE 4. (Continued) Soil Health Field Indicators

Indicators change with different management practices and therefore need to be determined more frequently.

1. Give a score for each indicator with 10 being best and 1 being poor.
2. For methods to evaluate the soil health indicators below, please consult Table 3.
3. After you complete scoring different indicators, average each major indicator (structure, soil life, soil air and water, and plant life).
4. Use these overall scores for each indicator to determine any correction in management practices recommendations below.

Indicator		Poor	Fair	Good	Observations	Rating Description		
		1-3	4-7	8-10		1-3	4-7	8-10
Soil Tilth	Structure/ aggregation					Hard, lots of clods, difficulty to till	Crumbles with pressure, few clods	Crumbles easily, mellow, easy to till
	Crusting					Surface seals easily after tillage and rain	Some sealing with little effect on emergence	Open, porous soil structure throughout growing season
	Compaction/ bulk density					Severely restricted penetration, horizontal root growth	Somewhat restricted penetration, both horizontal and vertical roots	Unrestricted penetration, vertical root growth
Overall Score								
Soil Life	Earthworm					No visible signs of casts or earthworms	Few casts, some earthworms	Many casts, lots of earthworms
	Smell					No or stagnant smell	Some smell to little smell	Pungent, fresh, sweet "earthy" smell
	Residue Decomposition					Residue removed or slow decomposition	Some residue remains, minimal decomposition	Residue left intact and at various stages of decomposition
Overall Score								

TABLE 4. (Continued) Soil Health Field Indicators

Indicator		Poor	Fair	Good	Observations	Rating Description		
		1-3	4-7	8-10		1-3	4-7	8-10
Soil Air and Water	Infiltration					Water ponds on the soil surface	Some ponding visible	No ponding
	Water Holding Capacity					Soil has limited capacity, frequent crop stress	Soil has moderate capacity, some crop stress intermittently	Soil holds water well, deep in the top soil, little crop stress
Overall Score								
Plant Life	Emergence					Slow uneven emergence	Inconsistent emergence	Rapid even emergence
	Plant Health					Yellow, stunted growth, variable stand height and population	Variation in color, height, population	Dark green vibrant growth, even stand
	Root Growth					Restricted roots, few fine roots	Somewhat restricted roots, some fine roots	Healthy uninhibited roots, lots of fine roots
Overall Score								

Overall Observation ____________________

____

____

TABLE 4. (Continued) Overall Soil Score and Management Practice Recommendations

Soil Health Indicator	Score	Management Practice Recommendation
Overall Soil Tilth	**1-3**	Use conservation practices such as no-tillage, strip-tillage, crop rotation with cover crops, apply manure, compost, reduce traffic and don’t work wet soils.
	4-7	Use cover crops and animal and plant-based soil amendments such as compost/farm yard manure.
	8-10	Maintain current soil management practices.
Overall Soil Life	**1-3**	Avoid/minimize soil tillage, leave crop residue after harvest, cover crop, crop rotation, and apply manure and compost.
	4-7	Apply manure and compost, leave crop residue on soil surface, include cover crop.
	8-10	Avoid soil tillage; maintain current soil management practices.
Soil Air and Water	**1-3**	Avoid bare soil surfaces, leave crop residue on the soil surface, consider tile drainage if condition is persistent annually, add cover crop, and eliminate tillage.
	4-7	Control traffic to avoid soil compaction, consider switching to no-tillage, strip-tillage, and use cover crop.
	8-10	Maintain current soil management practice.
Plant Life	**1-3**	Replant if plant population is extremely low and condition allows. Apply lime, N,P,K and other crop nutrients as needed for optimal production, and pesticides for weed and disease control.
	4-7	Apply lime, N, P, K and other crop nutrients as needed for optimal crop production.
	8-10	Maintain current management practices with special attention to proper fertilizer and manure application rates.

Glossary

Actinomycetes. Gram-positive anaerobic bacteria that form branching filaments.

Aggregate stability. Ability of soil particles bound together by cohesive forces to withstand any applied pressure or force, especially from rain.

Algae. Oxygen evolving photosynthetic organisms that contain plant-like chlorophyll (for example, seaweed).

Arbuscular. Intricately branched fungal hyphae (arbuscules) in the cortex of plant roots.

Arbuscular mycorrhizal fungi. A type of mycorrhiza in which the fungi penetrate the cortical cells of the roots of a vascular plant.

Bacteria. Tiny living single cell organisms (microorganisms) that are neither plants nor animals but belong to a group all by themselves either shaped like a ball, a rod, or a spiral.

Cations. Positively charged ions in the soil.

Cation exchange capacity (CEC). The number of exchangeable cations per dry weight that a soil is capable of holding, at a given pH value, and available for exchange with the soil water solution.

C/N ratio. Ratio of the mass of carbon (C) to the mass of nitrogen (N) in a plant material.

Cover crops. Crops grown on a piece of agriculturally productive land primarily to manage and control soil erosion, soil fertility, and water quality.

Crop residue. Plant materials including stalks, stems, leaves, and seed pods left in the field after harvest.

Decomposition. Natural processes by which large and complex organic materials are broken down into smaller and simpler ones with the release of carbon dioxide and water as by-products.

Ecosystem services. Benefits gained by humans from ecosystems.

Fertilizer. Any chemical or organic substance applied to the soil to increase the nutrients in the soil, soil diversity, and soil health.

Field capacity. Soil water condition when excess soil water has stopped draining from a saturated soil after a rain or irrigation event.

Fungi. Small and generally microscopic plants that have no chlorophyll and vascular tissues, and that live on dead organic matter.

Glomalin. Glue-like substance secreted by the hyphae of arbuscular mycorrhizal fungi and that aids in building soil aggregates.

Habitat. Ecological environment occupied by a group of species.

Humus. Completely decomposed soil organic matter.

Hyphae. Filament-like ramified fungal structures in the soil and in some cases in the root of plants as in the mycorrhiza.

Immobilization. Conversion of inorganic compounds to organic compounds by soil microorganisms or plants.

Ion. An atom that has either lost or gained an electron or electrons.

Lignin. A complex organic substance with cellulose in plants.

Matric potential. The force of attraction between soil water and the surfaces of soil particles.

Microbial biomass carbon. Carbon of soil bacteria and fungi.

Mineralization. Decomposition of organic matter to release carbon, nitrogen, and other elements into mineral forms.

Mycorrhiza. A symbiotic combination of the mycelium of fungi and plant roots.

Nematode. Round worms of the phylum Nematoda that occur as free-living parasites in the soil.

No-tillage. Soil conservation practice in which seeds are directly drilled into the soil with crop residue at the soil surface without overturning or mixing the soil.

Nutrient cycling. Transformation and movement of soil nutrients in the soil.

Plant available water. Soil water held between field capacity and the permanent wilting point that plants can extract and use.

Protozoa. Single-cell free-living microscopic organisms in the soil.

Soil aggregate. A group of primary soil particles that strongly adhere to each other rather than to others surrounding them.

Soil biodiversity. A group of plants, animals, and microorganisms in the soil.

Soil bulk density. Ratio of the dry mass of soil to the bulk volume of the soil (g/cm^3).

Soil fertility. Capacity of the soil to support plant growth by providing plants with essential plant nutrients.

Soil health. Continued capacity of the soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity.

Soil nutrient pool. The reservoir of nutrients in the soil.

Soil organic matter. Living plant roots and microorganisms, dead plant and animal tissues at various stages of decomposition, and soil animals.

Soil organic carbon. A component of soil organic matter or other organic sources.

Soil pH. Concentration of free hydrogen ions (H+) in the soil.

Soil productivity. The functioning of soil resulting from the balance in the growth factors of the physical, chemical, and biological properties of the soil.

Strip-tillage. A tillage system in which the tilled zone is 20 centimeters wide and 10 centimeters deep in close proximity to previous plant rows.

Tillage. Mechanical breaking, overturning, and mixing of the soil.

Traffic. Movement of vehicles, equipment, humans, and animals on the soil.

Water infiltration. Movement of water into the soil through soil surface and macrospores.

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SOURCE CREDITS

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Table 1	p. 10	USDA-NRCS Soil Quality Kit-Guides for Educators, 2014
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IOWA SOIL HEALTH Field Guide

Managing Soil Health—To sustain plant, animal, and human life and maintain or enhance ecosystems services

IOWA STATE UNIVERSITY
Extension and Outreach

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