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This soil health management manual provides information about soil functions and services that are essential for sustainable agriculture systems. The research-based information in this soil health management manual highlights the relationships between soil properties that are easy to understand and useful to all, including farmers, agronomists, agricultural consultants, soil scientists, technical service providers, and extension educators.

The soil health management manual has four sections, including:
1. Fundamentals of soil functions and relationships
2. The concept of soil health
3. Management practices that impact soil health
4. Soil health evaluation and procedures indicators

This soil health management manual is the product of the collaborative efforts of Iowa State University and the Department of Natural Resources Conservation Service (NRCS) in Iowa.
1. Fundamentals of Soil Functions and Relationships

Definition of Soil
The definition of soil depends on its multiple uses as a medium for different purposes such as farming, engineering, environment, etc.

- A farmer looks at soil as a medium to produce food;
- A geologist views soil as a natural medium;
- An engineer views the soil as unconsolidated materials above the soil bedrock;
- An agronomist or pedologist views soil as a naturally occurring surface layer formed by complex biochemical and physical weathering processes that contain living matter capable of supporting plant, animal, and human life (Brevik, 2005).

As the weathered and fragmented outer layer of the earth’s surface, the soil is a nonrenewable natural resource that requires careful management to sustain its vital functions (Eswaran et al., 2001).

Soil Profile and Horizons
The soil profile is the vertical arrangement of distinct horizontal layers called soil horizons from the soil surface to the bottom of a soil pit (Fig. 1). The number of horizons in a soil pit depends on the age of the soil; its geographic location, climate, original vegetation where the soil was formed (Hillel, 1998); and the activities of humans. Younger soils typically have fewer horizons than older soils and each horizon has its unique characteristics that easily identify and distinguish it from other horizons in the same soil profile. Characteristics that can be used to identify and distinguish soil horizons in the same soil profile are the thickness, color, texture, structure, consistency, and pH of that horizon.

Soil horizons are unique to individual soils and are used to identify, classify, and interpret soils. Generally, there are three main horizons in the soil profile, namely A-, B-, and C-horizons (Fig. 1). Some soils may have a layer called the O-horizon on top of the A-horizon. The O-horizon, when it occurs as the surface horizon, is the layer of organic matter. The C-horizon is usually called the parent material from which the soil is formed. Further beneath the C-horizon is the bedrock or the R-horizon of the soil profile.
1. Fundamentals of Soil Functions and Relationships

The A-horizon, called the topsoil, is the zone of major biological activity because of its direct contact with the O-horizon at the soil surface. It is the surface mineral horizon that exhibits characteristics like much of the original rock from which the soil developed. It has an accumulation of highly decomposed organic matter mixed with its mineral material and also provides the best environment for the growth of plant roots, soil microorganisms, and other biological life. Over time, the A-horizon loses clay, iron, and other minerals through leaching, a process called eluviation. Minerals such as sand that are resistant to weathering tend to remain in the A-horizon as other minerals leach out.

The B-horizon, also called the subsoil, is the part of the soil profile with the greatest accumulation of chemicals that have leached from the A-horizon (a process called illuviation). The B-horizon is also a mineral horizon with more clay but lower in organic matter content than the A-horizon. The A and B soil horizons together are called the soil solum where most plant roots grow (Richter and Yaalon, 2012; Cline, 1961). Some soils may also have E-horizons between the A- and B-horizons. If the E-horizon exists in the soil profile, it loses the clay minerals, iron, and aluminum that have leached from the A-horizon into the B-horizon. Therefore, E-horizons in the soil solum are typically lighter in color because of the loss of clay minerals and oxides of iron and aluminum. The set of soil horizons from the soil surface to the bottom of the soil pit is called the soil profile.

Composition of Soil

Soil has three major components including the solid, liquid, and gaseous phases (Fig. 2).

SOLID PHASE

The solid phase of soil is approximately 50 percent of the total soil volume, consisting of 45 percent mineral particles called the primary separates component of the soil and approximately five percent soil organic matter depending on the soil type, which is influenced by parent materials, vegetation, climate, and human activity. (Fig. 2).
SOIL MINERAL COMPONENT
This component of soil is the combination of different proportions of the mineral particles of sand, silt, and clay (Fig. 4), giving rise to the three broad categories of soil texture (Table 1), namely sandy, clayey, and loamy soils (Brady and Weil, 1999). In any given amount of soil, the proportions of sand, silt, and clay particles add up to 100 percent. The combination of different portions of silt, sand, and clay determine what is called “soil texture,” which influences soil porosity, soil hydraulic properties, and soil chemical properties. The following are major categories of the soil texture of mineral soils.

FIGURE 4. Mineral composition of the soil
Source: (Whiting et al., 2014)

SOIL TEXTURAL CLASSIFICATION
Sandy soils
Sandy soils have the largest particle sizes among the three primary soil minerals (Fig. 4). Individual sand particles range in diameter from 0.078 to 0.002 inches (Brady and Weil, 1999). Sandy soils are coarse in texture and feel gritty to the touch. They cannot hold water because water drains easily and rapidly through the large pore spaces between the sand particles. Sandy soils can be worked easily and warm up quickly in the spring. To test for sandy soils by feel, moisten the soil and try to roll it in the palm. Sandy soils do not form balls in the palm and easily crumble through the fingers (Fig. 5 and Fig. 6).

Silt soils
Silt soils have much smaller particle sizes with particle size diameter in the range of 0.002 to 0.00008 inches compared to sand (Fig. 4). Silt soils form soil surface crust under dry conditions. To test for silty soils by feel, moisten the soil and rub it with the fingers. Silty soil particles are smooth to the touch and feel slick and soapy when wet (Fig. 5 and Fig. 6).

TABLE 1. General terms used to describe soil texture in relation to the basic textural class names

<table>
<thead>
<tr>
<th>Common names</th>
<th>Texture</th>
<th>Basic soil textural class names</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy soils</td>
<td>Coarse</td>
<td>Sands</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loamy sands</td>
</tr>
<tr>
<td></td>
<td>Moderately coarse</td>
<td>Sandy loam</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fine sandy loam</td>
</tr>
<tr>
<td>Loamy soils</td>
<td>Medium</td>
<td>Very fine sandy loam</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loam</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Silty loam</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Silt</td>
</tr>
<tr>
<td></td>
<td>Moderately fine</td>
<td>Sandy clay loam</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Silty clay loam</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clay loam</td>
</tr>
<tr>
<td>Clayey soils</td>
<td>Fine</td>
<td>Sandy clay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Silty clay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clay</td>
</tr>
</tbody>
</table>


STEP 1: Start with a small handful of soil, about the size of a golf ball, and slowly add water a drop at a time, mixing as you go, until you have a ball of soil that has the consistency of putty. Gently squeeze the ball to determine if it will stay together in a ball or fall apart.

STEP 2: If the ball of soil stays intact, gently press the ball between your thumb and index finger, trying to work out to form a ribbon. If you can form a ribbon, measure how long the ribbon is before it falls apart.

STEP 3: After completing the ribbon test, add water to a pinch of soil in the palm of your hand until you have a muddy puddle. Rub the mud puddle against your palm and determine if it feels gritty, smooth, or equally gritty and smooth.

FIGURE 5. Three simple steps to determine soil texture by feel
(Source: Ritchey et al., 2015)
1. Fundamentals of Soil Functions and Relationships

Clay soils
Clay soils have the finest particles among the three soil mineral particles (Fig. 4) with particle sizes smaller than 0.00008 inches in diameter. Clay soils have good water storage qualities because of the very fine pore spaces between the particles. Clay soils are smooth when dry and stick like glue to shoes and garden or farm tools when wet. During dry weather clay soils become very hard and difficult to work. To test for clay soil by feel, moisten the soil and try to roll it into a ball in the palm. Clay soils will roll easily into balls or form a sausage-like shape in the hand when wet (Fig. 5 and Fig. 6).

The different portions of sand, silt, and clay particles form different classes of soil textures with distinct soil physical and chemical properties that influence the soil environment, which includes soil moisture availability, drainage, nutrient availability, microbial activities, and organic compounds. Examples of different soil texture classes are summarized in Table 2. One of the tools used to determine soil texture is the USDA soil textural triangle chart (Fig. 7). The following text is the procedure for using the USDA textural triangle chart.

TABLE 2. Guide for judging how much moisture is available for crops according to soil texture

<table>
<thead>
<tr>
<th>Available Soil Water</th>
<th>Medium (Coarse) Texture</th>
<th>Medium (Fine) Texture</th>
<th>Fine and Very Fine Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 percent soil moisture</td>
<td>Upon squeezing, no free water appears on soil but wet outline of ball is left on hand 1.8 in/ft</td>
<td>Upon squeezing, no free water appears on soil but wet outline of ball is left on hand 2.2 in/ft</td>
<td>Upon squeezing, no free water appears on soil but wet outline of ball is left on hand 2.0 in/ft</td>
</tr>
<tr>
<td>75 percent available soil moisture remaining</td>
<td>Forms a ball, is pliable 1.35 in/ft (0.5 in/ft)</td>
<td>Forms a ball, is pliable, sticks readily 1.65 in/ft (0.55 in/ft)</td>
<td>Easily ribbons out between fingers, slicks 1.50 in/ft (0.5 in/ft)</td>
</tr>
<tr>
<td>50 percent available moisture remaining</td>
<td>Forms a ball, somewhat plastic 0.9 in/ft</td>
<td>Forms a ball, somewhat plastic, will stick slightly with pressure 1.1 in/ft</td>
<td>Forms a ball, ribbons out between thumb and forefinger 1 in/ft</td>
</tr>
</tbody>
</table>


How to Use the USDA Soil Textural Triangle
In order to classify a given soil by its texture using the USDA soil textural triangle chart, find the point of intersection of the lines drawn from the sides of the triangle that represent the percentage of the primary separates (sand, silt, or clay) in the soil. The sum of the percentages of all the mineral particles add up to 100 percent and the point of intersection of the lines identifies the textural class of the soil.

In the USDA soil textural triangle chart, the right and left sides of the textural triangle represent the respective percentages of silt and clay in the soil. The base of the triangle represents the percentage of sand in the soil.

For example, assume a soil has 55 percent sand, 15 percent silt, and 30 percent clay. In order to determine the textural class of the soil, locate the percentage of sand at the base of the triangle and draw a line upwards parallel to the right side of the triangle (silt). Next, locate the percentage of silt on the right side of the triangle and draw a line downward toward the base of the triangle parallel to the left side of the triangle (clay). Subsequently, locate the percentage of clay on the left side of the triangle and draw a line parallel to the base of the triangle (sand) and determine the point of intersection of the three lines you drew on the textural triangle chart (Fig. 8). The point of intercession of the three lines will represent the texture of that particular soil, according to the USDA.
1. Fundamentals of Soil Functions and Relationships

Using the above percentages of sand, silt, and clay, a person can determine the point of intersection of the lines, which in this case is in the sandy clay loam section on the triangle (Fig. 8) and is the class of the soil texture (sandy clay loam).

How to Determine Soil Texture

The following is a simple way to determine the proportions of sand, silt, and clay in your soil sample (Whiting et al., 2014).

1. Spread the soil on a newspaper to dry. Remove all rocks, roots, and any trash and crush lumps and clods.
2. Finely pulverize the soil.
3. Fill a tall slender jar (like a quart jar) one-quarter full of soil (Fig. 9).
4. Add water until the jar is three-quarters full.
5. Add a teaspoon of powdered, non-foaming dishwasher detergent.
6. Place a tight fitting lid on the jar and shake hard for 10 to 15 minutes to break aggregates.
7. Set the jar where it will not be disturbed for the next 2 to 3 days.
8. Observe that soil particles will settle out according to size with the largest particles settling to the bottom. One minute after setting down the jar after shaking, mark on the jar the height of the large particles (sand) at the bottom.
9. After 2 hours, mark on the jar the depth of the medium-size particles (silt).
10. When the water clears, mark on the jar the depth of the small particles (clay) between the clear water and the silt. This typically takes 1 to 3 days, but with some soils it may take weeks.
11. Measure the thickness of the sand, silt, and clay layers marked on the jar.
12. Add all the measured values and consider that value as 100 percent.
13. Calculate the percentages of the sand, silt, and clay from the 100 percent.
14. Follow the example in Fig. 8 to determine the textural class of the soil.

Soil Structure

Soil structure is the arrangement of individual soil particles (sand, silt, and clay) into secondary particles or groups (Fig. 9) called aggregates that are held together by organic matter and mineral oxides (Tisdall and Oades, 1984) in the horizon of the soil profile. The number of horizons in a soil profile (Fig. 1) depends on the location and the factors of soil formation. However, soil aggregates only occur in the A-, E-, and B-horizons with the aggregates separated by planes of weakness. Therefore soil structure is one of the defining characteristics of soil horizons.

FIGURE 8. Example for determining point of intersection of three red lines showing the percentages of sand (55%), silt (15%) and clay (30%) particles in a sandy clay loam soil on the USDA soil textural triangle chart. (Source: Emerson, 2015)

FIGURE 9. Soil texture by measurement: Measure the depth of the sand, silt, and clay. Source: Estimating soil texture: Sand, silt, or clayey (Whiting et al., 2014)
Classification of soil structure
Soil structure has been classified in a number of ways depending on the bonding of individual soil particles within or between aggregates or the shapes of the soil aggregates. Based on bonding within or between the aggregates, soil structure may be classified as structureless, weak, moderate, or strong. Based on shape of soil aggregates, soil structure may be classified as granular, prismatic, massive, small grain, blocky, or platy (Fig. 10).

Soil porosity
Soil porosity represents 50 percent of the total soil volume and is the void space in the soil that can be filled by air and water. Soil porosity therefore influences soil bulk density, whereby less porous soils have higher bulk densities compared with more porous soils. The porosity of soils generally varies with soil particle sizes and soil aggregation. A volume of clay or organic soil with smaller particle sizes is more porous than the same volume of a sandy soil. The higher number of smaller particles in the clay or organic soil produces a higher total volume of soil pores. On the other hand, the fewer and larger particles of the sandy soil occupy the same volume with fewer pores as depicted by the period of time it takes water to flow through clay and sandy soils (Fig. 11). The ability of soils to hold and allow water to move through the soil depends on the sizes and number of pores, which also depends on the texture and structure of the soil.

LIQUID PHASE
The liquid phase of soil or the soil solution is soil water with dissolved plant nutrients. Figure 12 shows how soil solution moves into the root of plants based on the energy of soil water, which determines how free soil water can move in the soil (McElrone, 2013). The amount of water in the soil and its energy are important factors that affect plant growth (Hillel, 1998). The ability of water to freely move through the soil profile depends on the energy of soil water also called the soil water potential. Soil particles are collectively called the soil matrix. When the force of attraction between the soil matrix, also called the soil matric potential, and soil water is low, soil water potential is high and soil water easily moves in the soil to drier areas. When soil matrix potential is high, it means the soil is dry with restricted soil water movement in the soil.
SOIL WATER TERMS AND RELATIONSHIPS

As explained in the previous paragraph, water movement in soil is controlled by the soil water potential and the matric potential. However, another factor, the osmotic potential, also affects soil water movement. Soil water is in the form of a solution because of dissolved salts and nutrients. The attraction between soil water and its dissolved salts or soil nutrients is the osmotic potential, which has a negative value and always reduces the energy with which soil water moves in the soil. When the concentration of salts and nutrients in the soil increases from fertilizer application, the osmotic potential of the soil solution increases and further restricts soil water movement. Also, when the soil gets drier, osmotic potential increases because of the reduction in the amount of water in the soil compared to the concentration of salts and nutrients; and coupled with the force of attraction between water and the soil.
1. Fundamentals of Soil Functions and Relationships

matrix, soil water potential becomes more negative with very little energy to move in the soil (Fig. 13). When the soil is saturated with water, water moves in the soil by the force of gravity. Therefore the three factors that influence soil water movement are the gravitational potential, matric potential, and osmotic potential.

GRAVITATIONAL POTENTIAL
Gravitational potential is the energy of soil water when its movement is influenced by the force of gravity. This occurs when the soil is completely saturated with water, especially after a heavy rainfall or irrigation event. Under saturated soil conditions the soil pores are completely filled with water and no air; the only force that influences soil water movement under saturated conditions is the force of gravity, which pulls soil water downward to lower soil depths and into tile drains (Fig. 13).

MATRIC POTENTIAL
Matric potential is the force of attraction between the surfaces of soil particles and soil water. When the soil is dry, matric potential is higher, and lower when the soil is wet. When the soil is not saturated, water moves only from wet to dry areas in the soil, supplying water and nutrients to plant roots from different directions in the soil profile.

OSMOTIC POTENTIAL
Osmotic potential results from dissolved salts and nutrients (e.g., fertilizers) in soil water. When fertilizer is applied to the soil it dissolves in the soil water to form a solution and also increases the concentration of salts and nutrients in the solution, which makes soil water less available to plants. This creates a concentration gradient in the soil solution such that soil water in areas of lesser concentration of salts and nutrients flows to the area with a higher concentration of the salts and nutrients. The force that drives soil water from areas of lower concentration of the solution to areas of higher concentration is the osmotic potential. When the high concentration of nutrients in close proximity to the root system is high, it allows the dissolved nutrients to flow into the root system, thus creating a lower concentration of the soil solution around the root zone. This in turn allows more soil solution to flow toward the root zone to replenish the nutrients absorbed into the roots.

SOIL WATER AVAILABILITY
In the soil, different moisture conditions such as drought and wet events affect soil water availability, which is also influenced by soil texture. The three soil water conditions that describe the different forms of available soil water are soil saturation, field capacity, and permanent wilting point.

SOIL SATURATION
Soil saturation is the condition of the soil when all its pores both large (macro-pores) and small (micro-pores) are completely filled with water. At this condition, the soil has no air, and soil water has greatest energy to move. The energy of soil water at soil saturation is zero (0 bars) and flows only under the pull of gravity, especially as it occurs in fields with tile drains during heavy rain events. When soil water drains freely under the force of gravity, it drains only from the macro-pores and that soil water is called gravitational water or Saturated Water Condition (SWC). Gravitational water is not absorbed by plants because it drains beyond the root zone (Fig. 13). This kind of condition can lead to nutrient loss beyond the root zone (leaching), especially soil nitrate.
FIELD CAPACITY (FC)
Field capacity is the condition of the soil after gravitational water has stopped draining from the soil and the macro-pores are filled with air. Therefore soil water at field capacity is only held in the micro-pores of the soil. The energy of soil water at field capacity is 0.3 bar, which makes soil water readily and easily available to the plant to absorb. Because soil water at field capacity is held in the micro-pores, which form tiny capillary tubes, it is called capillary water and only moves upwards through the capillary tubes by a process called capillary action. Capillary water at field capacity is easily absorbed by plant roots because it is not strongly held to the surfaces of the soil particles (Fig. 13 and Fig. 14).

PERMANENT WILTING POINT (PWP)
Permanent wilting point is soil water condition under extreme dry conditions, when soil water is below the field capacity and the soil micro-pores are filled with air. At the permanent wilting point, there is only a thin film of soil water on the surfaces of the soil particles, which cannot be absorbed by plant roots because it is held at a pressure equal to -15 bars. When soil water is at such a condition, plants experience permanent damage to their tissues unless there is immediate rain or irrigation. Soil water at the permanent wilting point is called hygroscopic water (Fig. 13 and Fig. 14).

PLANT AVAILABLE WATER (PAW)
Plant available water is the amount of soil water held between field capacity and the permanent wilting point (Fig. 13 and Fig. 14). It is called plant available water because it is soil water with nutrients for growth that plants can absorb. Different soil textures have different amounts of plant available water (Fig. 14). Loamy soils hold more plant available water than pure sand and clay soils.

MEASUREMENT OF SOIL WATER CONTENT
There are a number of ways to measure soil water content. Among these are those primarily used in research, including the use of electrical resistance blocks, watermark blocks, the gamma-ray absorption method, and the use of time-domain reflectometry (TDR) methods. These methods provide information that is essential for water management, especially with irrigated agriculture. Most of these methods are affected by soil conditions such as soil texture, salt concentration, and the requirement for equipment calibration.

On the other hand, soil water measurement methods such as the gravimetric and hand-feel methods are not expensive, not sophisticated, and very practical for use by farmers to accurately determine soil water content. Of the two, the hand-feel method can be used on the spot in the field with accuracy.

HAND-FEEL METHOD
The hand-feel method for determining soil water content in the field is qualitative and faster. However, it depends on experience, is subjective, and prone to error. The hand-feel method requires only a handful of soil for every one foot of soil depth across the active root zone in the soil profile. The only equipment required for this method is a soil probe, an auger, or a shovel to extract the soil samples.
Soils have different texture; therefore, soil texture plays a significant role in the hand-feel method for soil water determination with regard to soil consistency, the formation of shapes, and traces of soil moisture on the hand.

Typically, soil sampling for this method is done in 1-foot (30 cm) increments to the root depth of the crop. The following are the steps to follow for the hand-feel method.

1. Collect soil samples using a soil probe, an auger, or a shovel.
2. Squeeze a handful of the soil sample firmly in your hand several times to form an irregularly shaped “ball.”
3. Squeeze the soil sample out of your hand between your thumb and your forefinger to form a ribbon.
4. Observe soil texture, ability to form a ribbon, firmness, surface roughness of ball, water glistering, loose soil particles, soil/water stains on fingers, and soil color (Fig. 5 and Fig. 6).
5. Consult Table 2 to determine how much soil water is available for crops according to soil texture.

THE GRAVIMETRIC METHOD
This method for determining soil water content is quantitative, reliable, and simple, but can be labor intensive and requires time. The method requires using a soil probe, an auger, or a shovel to extract the soil from a known soil depth. The wet weight of the soil sample is determined by weighing the sample as it is at the time of sampling. To obtain the dry weight of the soil sample, place the sample in an oven at 105°C in an aluminum can and allow drying to a constant weight, for 24 hours. An ordinary household microwave oven can also be used for drying the soil sample (place soil in a nonmetal, microwave safe container). Allow the oven-dry soil sample to cool before weighing. The amount of water in the soil sample, also called the mass wetness or the gravimetric wetness, is determined as the ratio of weight of water in the wet soil to the weight of the oven-dried soil.

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of can, ( W_c )</td>
<td>24.42 g</td>
</tr>
<tr>
<td>Weight of can + wet soil, ( W_{c+w} )</td>
<td>194.54 g</td>
</tr>
<tr>
<td>Weight of Wet soil, ( S_{wm} )</td>
<td>170.12 g</td>
</tr>
<tr>
<td>Weight of can + dry soil, ( W_{c+sdm} )</td>
<td>177.52 g</td>
</tr>
<tr>
<td>Weight of dry soil, ( S_{dm} )</td>
<td>153.10 g</td>
</tr>
<tr>
<td>Weight of water, ( W_m )</td>
<td>17.02 g</td>
</tr>
<tr>
<td>Gravimetric Water, ( G )</td>
<td>0.11116</td>
</tr>
<tr>
<td>Percent Gravimetric Water (%)</td>
<td>11.12%</td>
</tr>
</tbody>
</table>

GASEOUS PHASE
The gaseous phase of the soil is the air-filled and water vapor pore space of the soil medium, which is a continuation of the air in the atmosphere. Soil air is in constant circulation with the air of the atmosphere, which results in the addition of fresh air from the atmosphere to the soil, a process called soil aeration.
**COMPOSITION OF SOIL AIR**
Soil air is a mixture of gases, which include nitrogen, oxygen, carbon dioxide, and water vapor. The source of oxygen, nitrogen, and carbon dioxide in soil air is the atmosphere. However, part of the carbon dioxide in soil air comes from root respiration and the decomposition of organic matter in the soil. The nitrogen content of soil air (79.2 percent) is 0.7 percent lower than the nitrogen content (79.9 percent) of air in the atmosphere. The oxygen content of soil air (20.6 percent) is 1.8 percent lower than the oxygen in the atmosphere (20.97 percent) and the carbon dioxide in soil air (0.3 percent) is 10 times higher than the carbon dioxide (0.03 percent) in the atmosphere (Russel and Appleyard, 1915).

**FACTORS THAT AFFECT THE COMPOSITION OF SOIL AIR**
Factors that affect the composition of soil air include the nature and condition of the soil, type of vegetation/crop and microbial activities in the soil, and seasonal variation.

**Soil Condition, Crop and Microbial Activities in the Soil**
The amount of oxygen in soil air depends on the degree of soil wetness and varies with soil depth. Wetter soils have lesser amounts of oxygen in the soil air because of the presence of much water in the soil and a smaller amount of air in the soil pores. At lower soil depths, the amount of oxygen in soil air decreases. This is because air in the topsoil layers readily circulates with the air in the atmosphere (Hillel, 1998). Generally, the carbon dioxide content of soil air is higher than that of the atmosphere. However, at lower soil depths carbon dioxide in soil air is highest because of root respiration and poor aeration of subsoils.

Plant roots get oxygen for respiration from soil air, and in the process, deplete the amount of oxygen in the soil. Therefore, soils with actively growing plants contain lesser amounts of oxygen than soils without actively growing plants.

**Seasonal Variation**
Seasonal variations affect the composition of soil air. During the growing season when plants are actively growing in the field, soil air has less oxygen and a high concentration of carbon dioxide because of root respiration and soil microbial activities. During winter, cold air and soil temperatures slow down soil microbial activity and air circulation between the soil and the atmosphere. This reduces the amount of oxygen and carbon dioxide in soil air compared to the growing season. During spring and summer as soils warm up and become drier, there is increased soil microbial activity and air circulation between the soil and the atmosphere, especially during summer and that leads to soil aeration with more oxygen in the soil. Also, higher air and soil temperatures during summer increases soil microbial activity, thereby increasing the carbon dioxide content of soil air.
2. The 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, to 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 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, from the standpoint of soil health, the most essential substance known to bind primary soil particles into aggregates is glomalin (Fig. 15). Glomalin is the glue-like substance secreted 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. 16). 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. 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.

Figure 15. 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

Figure 16. Hyphae of arbuscular mycorrhizal fungi on roots and root hairs. (Source: Nichols, www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1144429.pdf)

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 because the increase in SOM 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 short period of time or in the long-term. The 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 properties to keep the soil healthy (Figs. 17 and 18). 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. 17).

**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

- Effect of soil compaction on root and seedling growth at three different soil bulk densities: Low, 0.7 g/cm³; Medium, 1.1 g/cm³; High, 1.6 g/cm³ (Al-Kaisi, 2006)
2. The Soil Health Concept

Grain and Biomass Production → Surface Cover

Residue and Cover Crops → Ecological Services

- Surface Cover
- Residue and Cover Crops

- Soil Health Functions
  - Improve Water Storage
  - Enhance Soil Aggregate
  - Increase Earth Worms
  - Enhance Organic Matter Pool
  - Improve Organic Matter Pool
  - Reduce Soil Erosion

- Nutrient Availability
- Microbial Community
- Biodiversity
- Aggregate Stability Building
- Nutrient Cycling
- Soil Organic Carbon Allocation

- Soil Organic Carbon Allocation

FIGURE 18. Crop residue and cover crops for improving soil health functions and nutrient cycling (Al-Kaisi, 2015)

centimeter (g/cm³). 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 3 shows bulk density values for different soil textures that are ideal for, or restrictive of plant root growth. Management practices

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>Ideal bulk densities for plant growth (g/cm³)</th>
<th>Bulk densities that affect root growth (g/cm³)</th>
<th>Bulk densities that restrict root growth (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sands, loamy sands</td>
<td>&lt;1.60</td>
<td>1.69</td>
<td>&gt;1.80</td>
</tr>
<tr>
<td>Sand loams, loams</td>
<td>&lt;1.40</td>
<td>1.63</td>
<td>&gt;1.80</td>
</tr>
<tr>
<td>Sandy clay loams, clay loams</td>
<td>&lt;1.40</td>
<td>1.60</td>
<td>&gt;1.75</td>
</tr>
<tr>
<td>Silt loams</td>
<td>&lt;1.40</td>
<td>1.60</td>
<td>&gt;1.75</td>
</tr>
<tr>
<td>Silt loams, silty clay loams</td>
<td>&lt;1.40</td>
<td>1.55</td>
<td>&gt;1.65</td>
</tr>
<tr>
<td>Sandy clays, silty clays, clay loams</td>
<td>&lt;1.10</td>
<td>1.49</td>
<td>&gt;1.58</td>
</tr>
<tr>
<td>Clays (&gt;45% clay)</td>
<td>&lt;1.10</td>
<td>1.39</td>
<td>&gt;1.47</td>
</tr>
</tbody>
</table>

that result in higher bulk density involve conventional 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 including iron and calcium, the amount of organic matter, and the type and population of soil microorganisms present in the soil. Soil tillage destroys the stability of soil aggregates.

**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.

Conventional tillage practices can reduce water infiltration significantly, because of the destruction of soil structure as shown in Fig. 19. Management practices—such as no-tillage or strip-tillage—improve water infiltration, increase water recharge, and reduce water runoff. Runoff 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.

**FIGURE 19. 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)**
2. The Soil Health Concept

Field Capacity
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 where 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 compared to clay textured soils.

SOIL BIOLOGICAL PROPERTIES
Soil biology plays an important role in building soil health, facilitating soil organic matter decomposition and nutrient cycling, and the release of nutrients such as nitrogen (N), phosphorus (P), and potassium (K) and other macro 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. 20. In the nitrogen cycle, soil bacteria play a vital role in breaking organic N to \( \text{NH}_4^+ \) and \( \text{NO}_3^- \) that will be available for plant uptake.

The decomposition of organic matter in the soil by microorganism ultimately produces humus, the most stable organic matter that helps build soil structure (i.e., soil aggregates) and a nutrients 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 rich source (castings) of nutrients such as nitrogen, phosphorus, and potassium by the breakdown of plant materials in their digestive system. Also, they create channels that aid in the redistribution of nutrients in the soil profile.

Figure 20. The nitrogen cycle. ("Soil as a Plant Sees It," University of Nebraska–Lincoln, 1991)
2. The Soil Health Concept

Soil Organic Matter

Soil organic matter (SOM) is the single most important soil health factor because it affects the soil’s 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, and 50 percent fungi); and
- 70 to 90 percent of stable soil organic carbon (humus).

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 only released into the soil during decomposition.

Conventional tillage is a major factor in destroying soil organic matter by accelerating the oxidation of organic matter as shown in Fig. 22. 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, water, and air movement.
- Improving soil water holding capacity for plant use and cation exchange capacity.

Figure 22. Tillage effects on soil organic carbon inputs from crop residue. NT = no tillage and CP = chisel plow (Al-Kaisi, 2005)
Other Biological Indicators to evaluate soil biological activities may include microbial biomass carbon (MBC), rate of CO₂ 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 take place that are essential for soil productivity and plant growth including cations and anions 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 factors or 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. 23). 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 nutrient availability. Lime application is the recommended management practice to correct the acidic soil condition.

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 (Ca²⁺), magnesium (Mg²⁺), potassium (K⁺), aluminum (Al³⁺), 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, soil pH, and organic matter content. Soils with high clay content and organic matter will have high CEC. Typically, acidic soils can have low CEC. Therefore, increasing soil pH by applying soil amendments, such as lime, or by increasing soil organic matter through the proper management of crop residue can 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 mineralization process.
- The soil solution (water with dissolved nutrients).

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<tr>
<th>Optimum for most crops</th>
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<td>Drained bogs containing sulfur</td>
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<td>Sub humid grassland soils</td>
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<td>Semiarid grassland soils</td>
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<td>Soils containing excess Ca²⁺ salts</td>
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<td>Soils containing excess Na⁺</td>
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</table>

Figure 23. Typical pH ranges for various types of soils (Source: Troeh and Thompson, 1993 in Smith and Doran, 1996)
2. The Soil Health Concept

- 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 processes in soil.

Soil health is directly linked to soil fertility, which depends on the amounts and availability of nutrients in the soil nutrient pools. Soil organic matter is the primary source of nutrients that are predominantly released from the exchangeable cation pools. 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 of these nutrient pools such as soil organic matter.

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 can 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 20:1.

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 lb \times 55\% = 2420 lb

Step 2
Determine the amount of nitrogen (N) present in the residue based on the \( \frac{C}{N} \) ratio of 20:1 as follows:
\[
\frac{C}{N} = \frac{20}{1} \Rightarrow \frac{2420 \text{ lb}}{N} = \frac{2420 \text{ lb}}{20} = 121 \text{ lb of organic N.}
\]

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 \times 2420 lb = 605 lb 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
\[
\frac{605}{8} = 75.63 \text{ lb of N.}
\]

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

There is a net positive balance of 45 lb N, (121-76 = 45 lb) released into the soil that may be available to plants and this means N mineralization.
2. The Soil Health Concept

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. 24.

SOIL FUNCTIONS AND SERVICES

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

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

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, carbon (C), nitrogen (N), and phosphorus (P), transform into forms that plants can easily absorb as shown in Figure 25.

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 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 microorganisms is influenced by the C:N ratio of the crop residue, soil moisture, and soil temperature among other factors.

**WATER AND CHEMICALS 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. 26). Wetlands function as filters by improving water quality, reducing floods and storm damage, and providing important habitat for fish and wildlife.


**Neal Smith National Wildlife Refuge, Prairie City, Iowa**

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.

**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 emissions by reducing their levels in the atmosphere. The storage of soil carbon contributes to the health of soil and to improvement of the physical, biological, and chemical properties of soil.
3. 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 THAT AFFECT 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 bacterial, 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 (Carter, 1994). 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 erosion that can contribute to nutrient and sediment loss (Oades, 1993).
3. Management Practices and Soil Health

**PLANT DIVERSITY**
Planting diverse crop species contributes to soil aggregation. The planting of crops increases soil macro-aggregate stability (Monroe and Kladivko, 1987). Soil aggregate stability varies among different cropping systems and plant species. Different plant species with differing root density and organic exudates as well as degree of mycorrhizal colonization impact soil aggregation and ultimately soil health and biological diversity (Chan and Heena, 1996; Gijsman and Thomas, 1995).

**FERTILIZER APPLICATION**
Adequate nutrient availability is essential for high crop productivity and quality. The use of fertilizers can provide most readily available nutrients such as N, P, and K. However, the application of fertilizer needs to be managed carefully to minimize potential effects on the soil biological system, yet provide needed nutrients that influence plant growth with increased root biomass production, root exudates, and soil microbial growth (Amézketa 1999).

**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 by improving soil macro-aggregates stability (Roberson et al., 1991). 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 and the legume fix nitrogen in the soil.
3. Management Practices and Soil Health

RESIDUE MANAGEMENT
Crop residue left on the soil surface a) protects the soil by minimizing aggregate breakdown from raindrops, thereby increasing aggregate stability (Chan, 1995) and b) enhances water infiltration to reduce soil erosion. The C:N ratio of crop residue and its decomposition rate to release organic carbon influence the soil structure and other soil biological properties. The soil water content, soil temperature, and nitrogen availability influence the rate of residue decomposition.

MANURE USE/APPLICATION
Organic fertilizers such as manure and compost are good sources for increasing soil carbon (C) and nitrogen (N) contents resulting in the increase of microbial biomass C and N (Amézketa et al., 1996). The application of organic byproducts and manure to the soil increases soil water-stable macro-aggregates and micro-aggregation (Metzger et al., 1987). The improvement of soil organic matter with addition of organic sources (dry or liquid) has many benefits in improving nutrient 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 wet—such as field capacity or saturated condition—can compact the soil and destroy 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 during 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 reduced soil erosion, including increased 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 controlling or minimizing soil erosion, sediment, nutrients, and organic matter loss.
- Improving the soil as a medium for root growth and development through reducing, localizing, or eliminating tillage.

Corn growing in no-tillage (NT)
3. Management Practices and Soil Health

• 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 grains and biomass production on soil health.

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. 17). Of the three broad categories of soil health properties, the physical and chemical properties have been well studied by soil scientists and their basic tests and procedures 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 soil has inherent qualities (e.g., soil texture) in relation to their physical, chemical, and biological properties within the limits set by a climate ecosystem, soil health changes over time as the 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 5—are all sensitive to the management practices in Table 4 and climatic changes that affect soil health.

TABLE 4. Agricultural management practices that affect soil health

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

Source: Soil biology for resilient, healthy soils (Lehman et al., 2015)
# 3. Management Practices and Soil Health

<table>
<thead>
<tr>
<th>Soil properties</th>
<th>Soil health indicator</th>
<th>Relationship to soil condition and function</th>
<th>Methods of evaluation and reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td>Bulk density, typically expressed in g/cm³</td>
<td>Structural support for plants, water, and solute movement, soil aeration</td>
<td>Cylindrical core method, USDA-NRCS, 2008; Arshad et al. 1996.</td>
</tr>
<tr>
<td></td>
<td>Penetration resistance</td>
<td>Soil compaction</td>
<td>Penetration resistance method, Licht and Al-Kaisi, 2005</td>
</tr>
<tr>
<td></td>
<td>Infiltration rate</td>
<td>Soil’s ability to allow water movement into and through soil profile</td>
<td>Penetration resistance method</td>
</tr>
<tr>
<td></td>
<td>Water holding capacity</td>
<td>Amount of water held in soil. Provides water for plant and soil organism functions</td>
<td>Single or double ring infiltrometer method, USDA-NRCS, 2008</td>
</tr>
<tr>
<td></td>
<td>Aggregate stability</td>
<td>Provide soil structure and growth environment</td>
<td>Gravimetric Method, Time Domain Reflectometry (TDR)</td>
</tr>
<tr>
<td>Chemical</td>
<td>Cation exchange capacity (CEC)</td>
<td>Soil fertility and plant nutrition</td>
<td>Laboratory analysis, Summer and Miller, 1996</td>
</tr>
<tr>
<td></td>
<td>Organic matter (Total organic carbon, nitrogen and potassium)</td>
<td>Soil fertility, plant nutrition and aggregate stability</td>
<td>Numerous laboratory methods are available SSSA Book Series: 5</td>
</tr>
<tr>
<td></td>
<td>Electrical conductivity (EC)</td>
<td>Indicates how much nutrient is available to plants and salinity levels. Defines microbial activity in the soil</td>
<td>Electrical conductivity pocket meter, USDA-NRCS, 2008</td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td>Plant nutrition, growth, and crop yields, biological and chemical activity in the soil</td>
<td>Portable pH pocket meter, USDA-NRCS, 2011</td>
</tr>
<tr>
<td></td>
<td>Heavy metals and plant toxins Copper, zinc, nickel, cadmium and lead</td>
<td>Plant nutrition in smaller amounts can be harmful to plants</td>
<td>Reed and Martens, 1996; Amacher, 1996; Soil digestion Cornell test #2021 EPA Method 3051-6010</td>
</tr>
<tr>
<td>Biological</td>
<td>Earthworms</td>
<td>Modify soil structure with pores and new aggregates with binding agents responsible for water stable aggregates</td>
<td>Counting the number of earthworms per unit area of soil, USDA-NRCS, 2009</td>
</tr>
<tr>
<td></td>
<td>Microbial biomass carbon</td>
<td>Amount of carbon fixed in microbial community</td>
<td>Guzman and Al-Kaisi, 2010</td>
</tr>
<tr>
<td></td>
<td>Soil microorganisms (bacteria, fungi, nematodes, viruses)</td>
<td>Nutrient cycling, decomposition, and respiration</td>
<td>Culture media, Rai, 1976</td>
</tr>
<tr>
<td></td>
<td>Soil enzymes activities</td>
<td>Influence organic matter decomposition, and nutrient cycling</td>
<td>Biochemical assays, USDA-NRCS, 2010</td>
</tr>
<tr>
<td></td>
<td>Particulate organic matter</td>
<td>Food and energy for soil microorganisms and small animals, CEC, plant nutrients, buffers pH, suppresses soil borne diseases</td>
<td>Several different laboratory methods, Cambardella and Elliot, 1992; Fronning et al., 2008; USDA-NRCS, 2011</td>
</tr>
</tbody>
</table>
4. 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 characteristics, 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 5 summarizes the majority of soil health indicators, their relevance, and methods (field and laboratory) for their evaluation, and references of these methods.

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 that are affected by management practices as summarized on the soil health assessment card (Table 6).
4. Soil Health Evaluation

Soil Health Assessment
Soil health can be assessed by using the Iowa Health Assessment Card. See its purpose, interpretation, and directions for use below. The card itself is shown in Table 6 beginning on page 31.

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 scorecards 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 assistance.

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: soil type, 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 Table 6 (p. 31-32).
### 4. Soil Health Evaluation

**TABLE 6. The Iowa Soil Health Assessment Card**

<table>
<thead>
<tr>
<th>Suggested timing for assessment of soil health indicators</th>
<th>GROWING SEASON</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Early Spring</td>
</tr>
<tr>
<td>Structure (aggregate stability, friability)</td>
<td>✓</td>
</tr>
<tr>
<td>Crusting</td>
<td>✓</td>
</tr>
<tr>
<td>Compaction</td>
<td>✓</td>
</tr>
<tr>
<td>Earthworm</td>
<td>✓</td>
</tr>
<tr>
<td>Smell</td>
<td>✓</td>
</tr>
<tr>
<td>Residue Decomposition</td>
<td>✓</td>
</tr>
<tr>
<td>Infiltration</td>
<td>✓</td>
</tr>
<tr>
<td>Water Holding Capacity</td>
<td>✓</td>
</tr>
<tr>
<td>Emergence</td>
<td></td>
</tr>
<tr>
<td>Plant Health</td>
<td>✓</td>
</tr>
<tr>
<td>Root Growth</td>
<td>✓</td>
</tr>
</tbody>
</table>

| Terraces breaking slope |

**TABLE 6. (Continued) Iowa Soil Health Assessment Card**

<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
<th>Crop Type</th>
<th>Variety/Hybrid</th>
<th>Soil Type</th>
<th>Slope</th>
<th>Corn Suitability Rating</th>
</tr>
</thead>
</table>

**Soil Condition**
- □ Dry
- □ Moist
- □ Wet

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

**Description – check on per category**

<table>
<thead>
<tr>
<th>Topography</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ Rolling to hilly</td>
<td>□ Gently rolling</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Color</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ Light</td>
<td>□ Moderate</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ Clay</td>
<td>□ Loam</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Drainage</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ Poorly drained</td>
<td>□ Moderately drained</td>
</tr>
</tbody>
</table>

This Table is adopted from PM2027, Al-Kaisi, 2006
### 4. Soil Health Evaluation

#### TABLE 6. (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 5.
3. After you complete scoring different indicators, average each major indicator (structure, 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.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Poor (1-3)</th>
<th>Fair (4-7)</th>
<th>Good (8-10)</th>
<th>Observations</th>
<th>Rating Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tilth</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structure/ aggregation</td>
<td>Hard, lots of clods, difficulty to till</td>
<td>Crumbles with pressure, few clods</td>
<td>Crumbles easily, mellow, easy to till</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crusting</td>
<td>Surface seals easily after tillage and rain</td>
<td>Some sealing with little effect on emergence</td>
<td>Open, porous soil structure throughout growing season</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compaction/ bulk density</td>
<td>Severely restricted penetration, horizontal root growth</td>
<td>Somewhat restricted penetration, both horizontal and vertical roots</td>
<td>Unrestricted penetration, vertical root growth</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Overall</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earthworm</td>
<td>No visible signs of casts or earthworms</td>
<td>Few casts, some earthworms</td>
<td>Many casts, lots of earthworms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smell</td>
<td>No or stagnant smell</td>
<td>Some smell to little smell</td>
<td>Pungent, fresh, sweet “earthy” smell</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residue/ Decomposition</td>
<td>Residue removed or slow decomposition</td>
<td>Some residue remains, minimal decomposition</td>
<td>Residue left intact and at various stages of decomposition</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Air and Water</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infiltration</td>
<td>Water ponds on the soil surface</td>
<td>Some ponding visible</td>
<td>No ponding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Holding Capacity</td>
<td>Soil has limited capacity, frequent crop stress</td>
<td>Soil has moderate capacity, some crop stress intermittently</td>
<td>Soil holds water well, deep in the top soil, little crop stress</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Overall</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emergence</td>
<td>Slow uneven emergence</td>
<td>Inconsistent emergence</td>
<td>Rapid even emergence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant Health</td>
<td>Yellow, stunted growth, variable stand height and population</td>
<td>Variation in color, height, population</td>
<td>Dark green vibrant growth, even stand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Root Growth</td>
<td>Restricted roots, few fine roots</td>
<td>Somewhat restricted roots, some fine roots</td>
<td>Healthy uninhibited roots, lots of fine roots</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Overall</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Overall Observation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### TABLE 6. (Continued) Overall Soil Score and Management Practice Recommendations

<table>
<thead>
<tr>
<th>Soil Health Indicator</th>
<th>Score</th>
<th>Management Practice Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Soil Tilth</td>
<td>1-3</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>4-7</td>
<td>Use cover crops and animal and plant-based soil amendments such as compost/farmyard manure.</td>
</tr>
<tr>
<td></td>
<td>8-10</td>
<td>Maintain current soil management practices.</td>
</tr>
<tr>
<td>Overall Soil Life</td>
<td>1-3</td>
<td>Avoid/minimize soil tillage, leave crop residue after harvest, cover crop, crop rotation, and apply manure and compost.</td>
</tr>
<tr>
<td></td>
<td>4-7</td>
<td>Apply manure and compost, leave crop residue on soil surface, include cover crop.</td>
</tr>
<tr>
<td></td>
<td>8-10</td>
<td>Maintain current soil management practices.</td>
</tr>
<tr>
<td>Soil Air and Water</td>
<td>1-3</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>4-7</td>
<td>Control traffic to avoid soil compaction, consider switching to no-tillage, strip-tillage, and use cover crop.</td>
</tr>
<tr>
<td></td>
<td>8-10</td>
<td>Maintain current soil management practice.</td>
</tr>
<tr>
<td>Plant Life</td>
<td>1-3</td>
<td>Replant if plant population is extremely low and condition allows. Side dress with NPK fertilizers, apply herbicides and pesticides for weed and disease control, check soil pH and use lime if needed.</td>
</tr>
<tr>
<td></td>
<td>4-7</td>
<td>Side dress plants with NPK fertilizers.</td>
</tr>
<tr>
<td></td>
<td>8-10</td>
<td>Maintain current management practices.</td>
</tr>
</tbody>
</table>
References


Al-Kaisi, M., A. Doule, and D. Kwaw-Mensah. 2014. Soil microaggregate and macroaggregate decay over time and soil carbon changes as influenced by different tillage systems. JSoilWaterCons 69(6): 574-580.


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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.

**Capillary action.** Upward movement of water at field capacity in the soil micropores.

**Capillary water.** Water at field capacity held in the soil micropores.

**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.** A given area where all living things and the non-living environment interact with each other.

**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.

**Force of gravity.** Force that acts on an object from the earth’s acceleration called the acceleration of gravity.

**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.
Glossary

**Gravitational potential.** Soil water energy by the pull of the force of gravity when the soil is saturated with water.

**Habitat.** Ecological environment occupied by a group of species.

**Humus.** Completely decomposed soil organic matter.

**Hygroscopic water.** Soil water at the permanent wilting point.

**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.

**Leaching.** Downward movement of dissolved soil nutrients with soil water beyond the root zone.

**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.

**Osmotic potential.** The force of attraction between soil water and dissolved salts and nutrients.

**Permanent wilting point (PWP).** Soil water condition when all the micropores are filled with air.

**Plant available water (PAW).** 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/cm³).

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

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

**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.

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

**Strip-tillage.** A tillage system in which the tilled zone is 20 cm wide and 10 cm 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.
SOURCE CREDITS

Tables, Photos and Figures: © Copyright as noted below

Table 1  p.4  Brady and Weil, 1999
Table 2  p.6  Al-Kaisi, 2000
Table 3  p.16  USDA-NRCS Soil Quality Kit-Guide for Educators 2014
Table 4  p.27  Lehman et al., 2015
Table 6  p.31  Adopted from PM2027, Al-Kaisi, 2006
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Protect soil heath with conservation practices.

- Healthy soil with earthworm
- Conservation buffers and terraces
- Contour farming and conservation tillage
- Grass waterway
- Cover crops
- Residue on the surface
Managing Soil Health—To sustain plant, animal, and human life and maintain or enhance ecosystems services