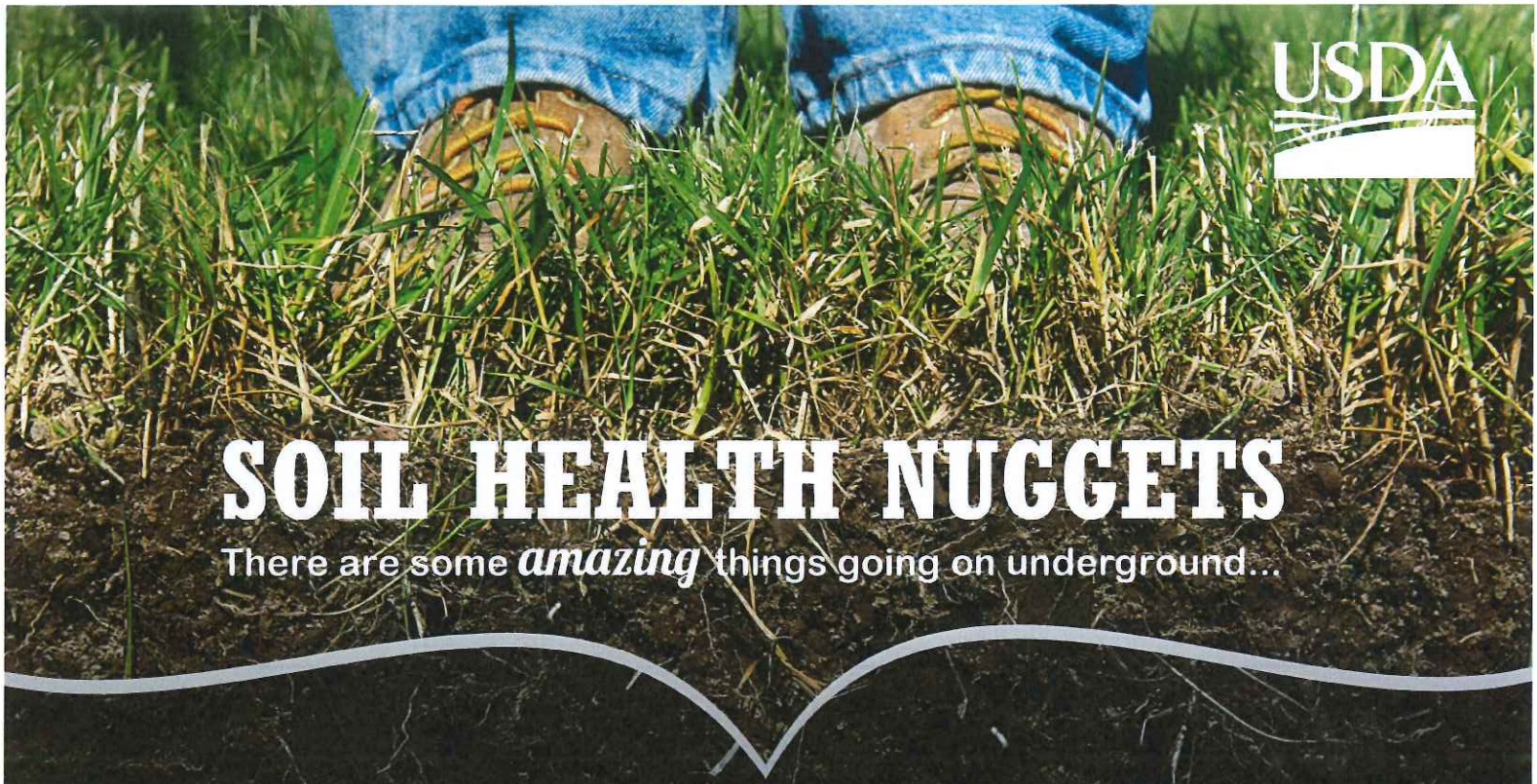


USDA

SOIL HEALTH NUGGETS

There are some *amazing* things going on underground...

Here are some things you may not know...

1. **There are more soil microorganisms in a teaspoon of healthy soil than there are people on the earth!**

Millions of species and billions of organisms—bacteria, algae, microscopic insects, earthworms, beetles, ants, mites, fungi and more—represent the greatest concentration of biomass anywhere on the planet! Microbes, which make up only one half of one percent of the total soil mass, are the yeasts, algae, protozoa, bacteria, nematodes, and fungi that process organic matter into rich, dark, stable humus in the soil.

2. **The best soil on most farms is found in the fence row.**

These undisturbed remnants of what soil properties were once like is no surprise to farmers who have dug into that soil. It's crumbly, dark, and loose, and it's a model of soil structure and organic matter for farmers who are trying to make their soil healthier.

3. **Tillage (or plowing) destroys the soil's structure!**

Tillage destroys "aggregation" or the soil's structure – the habitat soil microorganisms depend upon to ensure critical soil functions like nutrient cycling. Tillage also reduces organic matter content and increases erosion, which reduces the sustainability of our food production system.

4. **Tilling the soil up does NOT allow more water to soak into it.**

Don't believe it? Fill two containers with untilled and tilled soil and simulate rainfall on them. Watch the water stand on top of the tilled sample, but soak down through the untilled sample. Or, give them the slake test (placing clods of untilled and tilled soils on wire mesh at the top of water filled jars). You'll find if you submerge tilled soil just below the surface it will soon collapse in a heap at the bottom of the jar, but untilled soil will still be intact for the most part even 24 hours later. Tilling soils causes pores to collapse and seal over, causing more rain to runoff than soak in.

unlock the SECRETS of the SOIL

lf) Gone!

the campus of the University of Illinois indicate soil organic
rie grass borders was 5.5 to 6.5 percent in 1876. Less than half
e case with most prairie soils—oxidation of organic matter
ops has reduced organic matter levels to between 2 - 3 percent

rmer's favorite cocktail mix might not be what you think.

6.

e breathing new life into their soil by seeding a "cocktail mix"
iversity above-ground, which creates much-needed diversity
rough that diversity, farmers are mimicking the soil-building
y conditions of the diverse native prairies.

e healthy, you shouldn't see it very often.

nt that soil to be covered all the time, preferably with living
il covered all the time makes perfect sense when you realize
ull of life. The microorganisms living in the soil need food and
like other living creatures.

Roots of some plants can grow 3-feet deep in 60 days!

8.

aikon type radishes are a biological alternative to deep ripping
ction. After radishes winter kill the channels created by the
pen at the surface, improving infiltration, surface drainage
popular cover crop also is an excellent nitrogen scavenger.

as Jefferson know that we don't?

go, Thomas Jefferson, a farmer and conservationist, used
nd clover as cover crops and in rotation. He used these crops
ion to build soil that he knew was being depleted with his

Multiple "bennies" through multiple species.

10.

ergy created by crop rotations and multi-species cover crops
biological time by increasing organic matter, allowing crops
s while monocultures struggle. And as an added bonus,
tures work together to crowd out weeds, improve nutrient

United States Department of Agriculture
Natural Resources Conservation Service

Farming in the 21st Century
a practical approach to improve Soil Health

What is Soil Health? Why Should I Care?

A simple definition of soil health is *the capacity of a soil to function*. How well is your soil functioning to infiltrate water and cycle nutrients to support growing plants?

Soil works for you, if you work for the soil. Management practices that improve soil health increase productivity and profitability immediately and into the future. A fully functioning soil produces the maximum amount of products at the least cost. Maximizing soil health is essential to maximizing profitability. Soil will not work for you if you abuse it.

Soil is a living factory of macroscopic and microscopic workers who need food to eat and places to live to do their work. Amazingly, there are more individual organisms in a teaspoon of soil than there are people on earth; thus, the soil and its processes are controlled by these organisms. The living 'soil factory' is powered primarily by sunlight.

Farms and ranches are provided with soil, water, and sunlight. The challenge is to feed the soil, harvest sunlight and farm sustainably to make a living now and in the future. Tillage, fertilizer, livestock, pesticides, and other management tools can be used to improve soil health, or they can significantly damage soil health if not applied correctly.

Managing for soil health (improved soil function) is mostly a matter of maintaining suitable habitat for the myriad of creatures that comprise the soil food web. This can be accomplished by disturbing the soil as little as possible, growing as many different species of plants as practical, keeping living plants in the soil as often as possible, and keeping the soil covered all the time.

Manage More by Disturbing Soil Less

Tilling the soil is the equivalent of an earthquake, hurricane, tornado, and forest fire occurring simultaneously to the world of soil organisms. Physical soil disturbance, such as tillage with a plow, disk, or chisel plow, that results in bare or compacted soil is destructive and disruptive to soil microbes and creates a hostile, instead of hospitable, place for them to live and work. Simply stated, tillage is bad for the soil.

The soil may also be disturbed chemically or biologically through the misuse of inputs, such as fertilizers and pesticides. What happens when we supply inputs to the soil? Soil and all the organisms that live and grow in it have been cycling plant nutrients for a very long time without any human intervention. Consequently, soil and plants have very efficient and sophisticated ways of working together to ensure their mutual

Working in the Factory

The soil factory functions on the same principles as any other factory. For example, suppose you were to build and operate a factory to manufacture pickup trucks. How would you run the factory to produce the greatest number of high quality pickup trucks at the lowest cost each year? First, you might construct a building to provide a good working environment for your workers. Next, you might provide the means for your workers to live in a nice home, have enough food to eat, and enjoy other benefits to allow them to come to work and be at top productivity each day. Finally, you might find ways to maximize the use of energy and raw materials so nothing is wasted or hindered during the production of pickup trucks. Sounds good... a suitable factory filled with productive workers not wasting any energy.

What if our imaginary pickup truck factory were suddenly hit by a tornado and an earthquake, and then it caught fire!? How many high quality pickup trucks could be produced the next day, week, month, or year? Injured (or dead) workers in a damaged factory would probably not be able to produce as many pickups as healthy workers in a well-built factory operating at peak efficiency. This is the scene that is created when soil is physically disturbed by tillage. Soil structure and habitat for soil organisms is destroyed, water infiltration is reduced, runoff is increased, soil erodes, and productivity declines. *cont. on page 3*

sustainability. When we add chemical inputs to the soil, we need to understand and respect existing soil and plant relationships, or we might actually be setting the system up to be inefficient, or worse, to fail altogether.

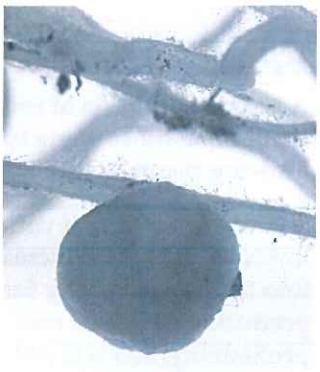
If crop nutrients are applied to the soil in excess, plants will not develop associations with soil organisms that help them acquire water and nutrients. After the "party is over" and the synthetic fertilizer is gone, the plants are left "high and dry" with few to no soil factory workers to help them access water and nutrients for the remainder of the growing season. The plants then give up valuable energy (sugars) in an attempt to make connections with microbes mid-way through the growing season when the plant should be putting that energy into flowering and seed development to produce a harvestable yield. By applying excess fertilizer, particularly nitrogen or phosphorus, we create plants that are very inefficient as they try to function without the support system of the soil with which they evolved.

By reducing nutrient inputs, we can take advantage of the nutrient cycles in the soil to supply crop nutrients and allow plants to make essential associations with soil organisms. This ensures that plants are able to achieve their full potential, and the soil is allowed to perform all of its desired functions to its full potential. If we acknowledge the complex life in the soil and work with it instead of disturbing it, we will harness a tremendous engine for biological production (growing crops).

The 'soil factory' workers can be most productive when they have a good working environment with an ample supply of energy. When they are most productive, the farmer is most profitable.

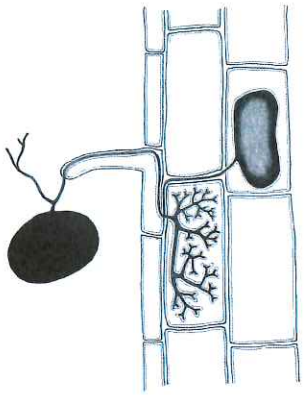
Symbiosis and Mutualism

One of the many beneficial relationships between plants and soil organisms is the acquisition of nitrogen from the atmosphere by a variety of organisms, including bacteria (rhizobia) that live symbiotically with leguminous plants, such as beans, clover and vetch. When these organisms die, or the plants they associate with shed leaves, shoots, stems, or roots, this material becomes part of the soil along with the nitrogen it contains.



Rhizobia bacteria fix atmospheric nitrogen into ammonium after becoming established in root nodules of leguminous plants.

Another example involves a group of fungi (arbuscular mycorrhizae) that extend the plant root system out into the soil, forming 'pipelines' to acquire nutrients and water that the plant roots themselves cannot access. As with the bacteria that fix nitrogen, the fungi are given sugar energy from the plant to keep the association working.



Arbuscular mycorrhizae fungi live inside plant roots and help plants capture nutrients from the soil.

Images courtesy of Dr. James Nardi, University of Illinois at Urbana-Champaign.

Photo left: In association with rhizobia bacteria, legumes, such as crimson clover (foreground), convert atmospheric nitrogen into ammonia.

Diversify with Crop Diversity

A living functioning soil depends on an efficient flow of light energy originating from the sun. Using chlorophyll to absorb sunlight energy, green plants transform atmospheric carbon dioxide and water into carbohydrates (starches, sugars, lignin, cellulose) in a process known as photosynthesis. The sun's light energy is stored in these carbon compounds, which provide the building blocks for plant roots, stems, leaves, and seeds.

There are two primary mechanisms for carbon to get into the soil and feed the organisms in the soil food web. The first mechanism involves the association between plants and particular types of microbes, in which sugars made by the plant are released from their roots and traded to microbes for nutrients that support plant growth. The second mechanism is by soil life eating dead plant material, such as leaves, stems, and roots, and subsequently releasing carbon into the soil in their waste products or as they die and decompose. In these ways, carbon that was once in the atmosphere is transferred into the soil as organic matter.

Soil microorganisms are responsible for decomposing organic matter and releasing plant available nutrients. A diversity of plant carbohydrates is required to support the assortment of soil microorganisms that live in the soil. To achieve this level of diversity, different plants must be grown. The key to improving soil health is that food and energy chains and webs consists of several types of plants or animals, not just one or two. A guiding principle is that diversity above ground (plants) equals diversity below ground (the soil food web). Growing a diverse rotation of crops is an excellent way to increase the diversity of the soil food web.

Biodiversity is ultimately the key to success of any agricultural system. Lack of biodiversity severely limits the potential of any cropping system and disease and pest problems are increased. A diverse and fully functioning soil food web provides for nutrient, energy, and water cycling that allows a soil to express its full potential. Increasing the diversity of a crop rotation and cover crops increases soil health and soil function, reduces input costs, and increases profitability.

Working in the Factory

...cont.

In a factory making pickup trucks, there is an assembly line for building and installing the engine and another one for the electrical system. The workers in these lines have different needs to complete their tasks. Likewise, the soil factory contains assembly lines of skilled workers that turn raw materials into carbon, oxygen, nitrogen, phosphorus, micronutrients, and water that plants need. These assembly lines require a vast population of diverse workers in order to function properly; and these diverse workers require diversity in their food supply... throughout the year and under optimum soil conditions.

Crop Diversity Tools

- Read *The Power Behind Crop Rotations: A Guide for Producers* by Dr. Dwayne Beck, South Dakota State University, Dakota Lakes Research Farm. Look for it and the Crop Rotation Intensity and Diversity tool at http://www.dakotalakes.com/crop_rotations.htm
- Download a spreadsheet to make diversity and intensity calculations for you from http://www.ag.ndsu.nodak.edu/dickinso/agronomy/jons%20worksheet.htm
- Use the USDA ARS crop sequence calculator to assist with crop rotations and residue management. Access the calculator at http://www.ars.usda.gov/Services/docs.htm?docid=10791

This cover crop mixture of buckwheat, cowpeas, soybeans, and millet provides the soil system with diversity in rooting depth, root structure, organic exudates, and biomass quality, creating different habitat niches to stimulate the variety of microorganisms that live in the soil.

Grow Living Roots Throughout the Year... to feed soil organisms

The soil food web is a complex association of organisms responsible for breaking down crop residues and cycling plant-available nutrients in the soil. Every organism has something that it eats…or something that eats it. There are many sources of food in the soil that feed the soil food web, but there is no better food than the sugars exuded by living roots.

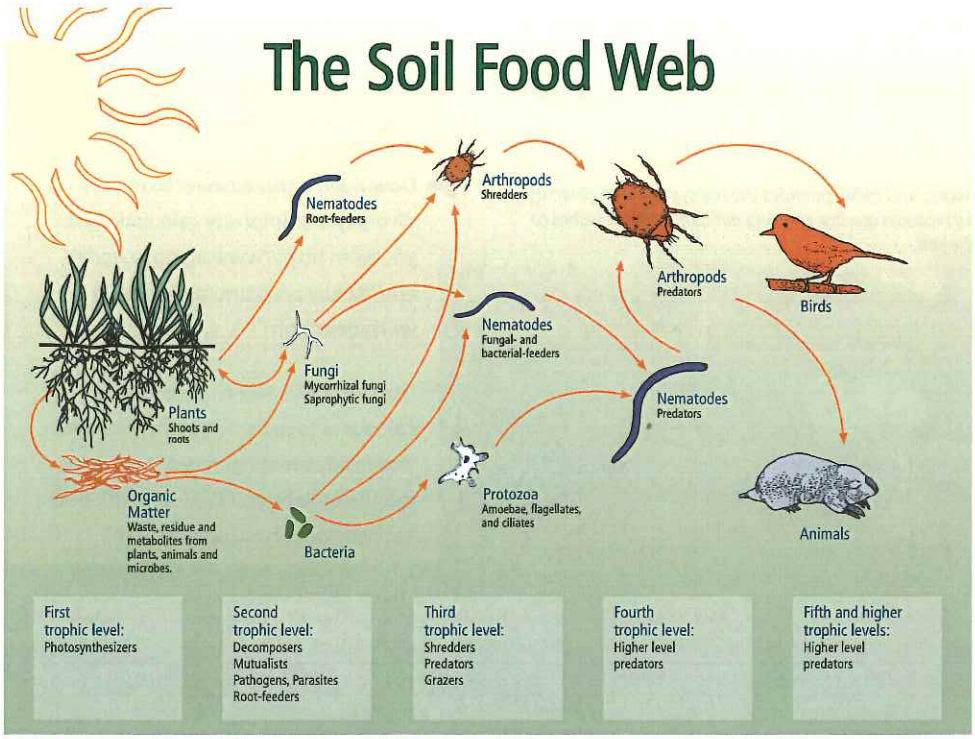
Living plants maintain a rhizosphere, an area of concentrated microbial activity close to the root. The rhizosphere is the most active part of the soil factory because it is where the most easy to eat food is available, and it is where peak nutrient and water cycling occurs. Microbial food is exuded by plant roots to attract and feed microbes that provide nutrients (and other compounds) at the root-soil interface where the plant can take them up. Since living roots provide the easiest source of food for soil microbes, growing long season crops or a cover crop following a short season crop, feeds the foundation species of the soil food web as much as possible during the growing season.

When carbon is not available from living roots, nutrient and water cycling occur at a much slower rate. The process is slower because the microbes involved have to do more work, often allocating parts of tasks to many other organisms and transporting the resources further.

Soil organisms feed on sugar from living plant roots first. Next, they feed on dead plant roots, followed by above-ground crop residues, such as straw, chaff, husks, stalks, flowers, and leaves. Lastly, they feed on the humic organic matter in the soil.

Dead plant roots and crop residues have to be shredded by soil microarthropods, such as mites, springtails, woodlice, earwigs, beetles, and ants. Crop residues have to be transported from the soil surface to living plant roots through long lines of multiple organisms. The humic organic matter has to be processed by a wide variety of organisms before the nutrients locked up in such material are available to the plant.

Healthy soil is dependent upon how well the soil food web is fed. Providing plenty of easily accessible food to soil microbes helps them cycle nutrients that plants need to grow. Sugars from living plant roots, recently dead plant roots, crop residues, and soil organic matter all feed the many and varied members of the soil food web. While the mission statement of the Natural Resources Conservation Service is *helping people help the land*, a farmer's mission statement might be *helping microbes help the plants* by providing soil microbes with the best soil habitat possible, including food.



From Soil Biology Primer [online]. Available: soils.usda.gov/sqi/concepts/soil_biology/biology.html [September 2010].

The soil food web is the community of organisms living all or part of their lives in the soil. The food web diagram shows a series of conversions of energy and nutrients as one organism eats another. The food web is fueled by plants and other organisms that use the sun's light energy to fix carbon dioxide from the atmosphere. Most other soil organisms get energy and carbon by consuming the organic compounds found in plants, other organisms, and waste by-products. As organisms decompose complex materials, or consume other organisms, nutrients are converted from one form to another, and are made available to plants and to other soil organisms.

Keep the Soil Covered as Much as Possible

Soil cover conserves moisture, intercepts raindrops to reduce their destructive impact, suppresses weed growth, and provides habitat for members of the soil food web that spend at least some of their time above ground. This is true regardless of land use (cropland, hayland, pasture, or range). If improving soil health is your goal, you should not see the soil very often.

Soil should always be covered by growing plants and/or their residues and, it should rarely be visible from above. Soil cover cannot be taken for granted. Even in a no-till system, there are times when soil cover may be lacking because of crop harvest methods, amounts of residue produced, and low carbon:nitrogen ratios of some crop residues that make them decompose quickly.

Soil cover protects soil aggregates from 'taking a beating' from the force of falling raindrops. Even a healthy soil with water-stable aggregates (held together by biological glues) that can withstand wetting by the rain may not be able to withstand a 'pounding' from raindrops. When water-stable soil aggregates are covered by crop residues or living plants, they are protected from disintegration by the hammering energy of raindrops. When soil aggregates remain intact at the soil surface, water infiltrates the soil and is available to plant roots.

A mulch of crop residues on the soil surface suppresses weeds early in the growing season giving the intended crop an advantage. This is particularly the case with a rolled cover crop that may cover the entire soil surface at once. They also keep the soil cool and moist which provides favorable habitat for many organisms that begin residue decomposition by shredding residues into smaller pieces. If these "shredders" have good residue habitat they can increase residue decomposition, and therefore nutrient cycling, by up to 25%.

Keeping the soil covered while allowing crop residues to decompose (so their nutrients can be cycled back into the soil) can be a bit of a balancing act. Producers must give careful consideration to their crop rotation (including any cover crops) and residue management if they are to keep the soil covered and fed at the same time.

Did You Know?

The High Plains subregion of the Great Plains is characterized as semiarid, shortgrass prairie. Extreme temperature changes and high winds characteristic of the area can have drastic and devastating effects on exposed soil. In the High Plains, more than 65% of the soil must remain covered to limit evaporation of water. In this rainfall limited area (average rainfall is 10 - 20 inches), maintaining soil cover is an important management strategy for profitable agricultural production. Bare soil heats up quickly in direct sunlight; and the hotter it gets, the faster water evaporates from it. This not only wastes water, but leaves salts behind at the soil surface. Residue cover also limits the drying effect of the wind and traps snow during the winter.

Turnip (above) and forage radish (below) cover crops provide a lot of above and below ground biomass; and their "bio-drilling" action penetrates compacted layers to improve soil health.

Soil should be covered with living plants or residue at all times, realizing that high quality residue from legumes decomposes relatively quickly. Pictured: hairy vetch.

Residue cover protects soil from the impact of raindrops, keeps it cool and moist for soil organisms, and suppresses weed growth. Pictured: rye rolled down with a cultipacker creates a blanket of residue.

Soil Health for Your Farm, Ranch... for You!

The key to building soil health is to first understand that soil is a biological system. Soil health is improved by disturbing the soil less, growing the greatest diversity of crops (in rotation and as diverse mixtures of cover crops), maintaining living roots in the soil as much as possible (with crops and cover crops), and keeping the soil covered with residue at all times.

Drills, planters, seed, fertilizer, pesticides, livestock, fences, water, farm implements, etc. are all tools that can be used to manage the soil habitat for the benefit of living members of the soil food web.

Organisms in the soil food web cycle crop nutrients and release organic glues that increase soil aggregate stability. Soil aggregates provide these organisms with protected habitat. Stable soil aggregates are critical for water infiltration and gas exchange, both of which are essential to crop production.

Many soils have a water infiltration problem that causes a water runoff problem. If soil health is improved, the structure of the soil results in greater water infiltration, less runoff, less or no erosion, and reduced incidence of flooding and sedimentation.

Managing for Soil Health must begin by changing the way you think about Soil.

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Developed by the
National Soil Health and Sustainability Team
with contributions from North Dakota NRCS

soil health matters:
MAKE YOUR SOIL HEALTHIER

Natural Resources Conservation Service

March 2013

If you want a more productive, self-sustaining soil that will improve rather than degrade with time, take a few lessons from Mother Nature. That's the advice from soil health experts who have worked with farmers to regenerate degraded soils.

Take lessons from Mother Nature, soil health experts say

"The diverse plants of the prairies cycled carbon back to the soil," says Dwayne Beck, manager of South Dakota State University's Dakota Lakes Research Farm near Pierre, South Dakota. "That slow, steady return of carbon to the soil boosted soil organic matter which continuously fed billions of microbes," Beck says. "Those microbes, in turn, broke down organic matter, making nutrients available to plants. This cycle produced the high levels of active organic matter in virgin prairie soils that accounted for the astounding yields sodbusters enjoyed in past generations."

But constant cultivation of farmland has taken its toll on organic matter and the topsoil itself. On average, most sloping agricultural land in the Midwest has only about half the organic matter and half of the topsoil that it had before it was first cultivated.

Tillage is the culprit

The latest research shows the less you till, the more carbon you keep in the soil to build organic matter—living and dead plant roots, microorganisms, insects and earthworms. "In tillage-based systems, mineralization is 'boom and bust.' Booms occur after tillage with busts following shortly after. In contrast, mineralization in no-till soils is more evenly spread over the season," Beck says.

Beck, who has researched no-till and used no-till farming methods on his own farm for more than 30 years, says no-till more closely mimics nature.

Using a no-till process retains organic matter in soil.

Create fields with soil like fence rows

All you have to do to be convinced of the soil-building power of nature is to look at the soil in a fence row, says Jim Hoorman, an assistant professor and Extension educator at Ohio State University.

"Any farmer can tell you his or her fence rows have the best soil on the farm," Hoorman says. "The organic matter there, where the soil was built naturally, may be 5 to 6 percent or higher, but on the soils being tilled, organic matter levels have been cut in half. And the critical part of what's missing is the active organic matter that comes from live roots." To create farm fields with soil like the fence rows, he says, tillage needs to be eliminated and continuous living cover needs to be growing as long as practical.

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No-till and cover crops emulate natural prairies

"Using no-till and cover crops, we can try to emulate the ecosystem functions of natural prairies," says David Lamm of the USDA Natural Resources Conservation Service (NRCS). "Prairies and prairie soils flourished with a diversity of plants, a minimum amount of disturbance, and living roots that grew throughout most of the year."

"Some of the most innovative cover crop users have continued to experiment with as many as eight to 15 different cover crops in mixtures on their farms, to see what each contributes to their system," says Lamm, the leader for the NRCS National Soil Health and Sustainability Team in Greensboro, North Carolina. "These farmers are breathing new life into their soils with no-till and cover crop mixes, and they're telling us they're getting all kinds of benefits."

No one species can deliver all the advantages multiple cover crops deliver in combination, he says. Some fix nitrogen, some are very good at scavenging leftover nitrogen in the soil, and some have deep roots that extend benefits deeper into the soil profile. Still others help control specific weeds or attract beneficial insects, etc.

Misconceptions about multiple species

Jay Fuhrer, NRCS district conservationist in Bismarck, North Dakota, agrees. Fuhrer has been studying, observing, practicing and recommending soil health measures for 20 years.

"Most farmers don't have enough crop types in their operation," Fuhrer says.

Having grown up on a small grain and livestock farm before he started his conservation career, Fuhrer knows the misconceptions well. "I used to think multiple crops would compete with each other, but I've learned they help each other grow if you follow the model of native rangeland diversity," he says. "You get some benefits from using two or three cover crops together, but the benefits are exponential with the synergy you create to feed the soil biology with a dozen species together."

"You get some benefits from using two or three cover crops together, but the benefits are exponential with the synergy you create to feed the soil biology with a dozen species together."

- Jay Fuhrer, NRCS District Conservationist

"First-time cover crop users tend to use only one or two species because they think that's simplest," Fuhrer says. "I think using one or two species is a step in the right direction, but using 10 or 12 species can actually accelerate biological time."

A multiple-species planting is actually easier and safer to manage than a single species cover crop, Fuhrer maintains. "The more diversity you have, the more plant balance you have above ground, and with that plant balance comes a more balanced soil biology below ground," he says.

Jump-start microbes with cover crops

Most farmers with experience in improving soil health have converted from conventional tillage to no-till farming. Then over time they added cover crops into their farm operations.

But there's no need to master no-till before you use cover crops with no-till, says Hoorman. In fact, he says farmers may be able to shorten or eliminate the short-term yield drop that often comes with no-till if they use cover crops from the beginning. "Those microbes in the soil need food year round, like any living organism," he says. "You can speed up microbial activity significantly with cover crops. The literature says there are 1,000 to 2,000 times more microbes associated with living roots than in soil without live roots."

Taken together with intensive rotations, no-till becomes a comprehensive program. "There's no need to fall back on occasional tillage," Beck says. "You don't

Forage legumes like alfalfa are a good option for crop rotations that do not deplete nitrogen from soil.

want to till occasionally, because one year of tillage destroys that environment for microorganisms you've been building for years."

"Cover crops are considered old-fashioned by some people in modern agriculture, but cover crop pioneers have figured out how to make them work on their farms, with some impressive results," says Joel Gruver, Western Illinois University's go-to guy in cover crops. "It's going to take home-grown innovation by farmers who haven't used cover crops to really ramp up their use. I say that because everyone's situation is different—cover crops aren't an 'off the shelf' practice that can be done the same way on every farm."

Gruver, an assistant professor of soil science and sustainable agriculture at WIU, points out that before World War II, when cheap nitrogen fertilizer wasn't readily available, most farmers included forage legumes like alfalfa and red clover in crop rotations ahead of nitrogen-demanding crops like corn. Forage grasses and small grains were also commonly used to curb soil erosion.

Low on the learning curve

"We're still relatively low on the learning curve of figuring out how to get millions of acres of cover crops planted and managed effectively," Gruver says. To make cover crop use mainstream, he believes many more farmers will have to adapt the practice to their farms, not just adopt the practice.

"Fortunately, many of the farmers trying cover crops now are experienced no-tillers or strip-tillers who have a track record of doing the type of trouble shooting necessary to make cover crops work consistently," Gruver says.

The principles of building healthy soils are the same everywhere, soil health experts agree. Key actions are to stop tilling the soil and to switch from a monoculture crop to a diversity of crops and rotations that provide a living cover on the soil throughout the year. Sounds a lot like Mother Nature!

Want to unlock the secrets in YOUR soil? Go to: www.nrcs.usda.gov

unlock the SECRETS IN THE SOIL

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soil Organic Matter

Soil Quality Kit – Guides for Educators

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Soil organic matter (SOM) is the organic component of soil, consisting of three primary parts including small (fresh) plant residues and small living soil organisms, decomposing (active) organic matter, and stable organic matter (humus). Soil organic matter serves as a reservoir of nutrients for crops, provides soil aggregation, increases nutrient exchange, retains moisture, reduces compaction, reduces surface crusting, and increases water infiltration into soil. Components vary in proportion and have many intermediate stages (Figure 1). Plant residues on the soil surface such as leaves, manure, or crop residue are not considered SOM and are usually removed from soil samples by sieving through a 2 mm wire mesh before analysis.

Soil organic matter content can be estimated in the field and tested in a lab to provide estimates for Nitrogen, Phosphorus and Sulfur mineralized available for crop production and adjust fertilizer recommendations. Soil organic matter impacts the rate of surface applied herbicides along with soil pH necessary to effectively control weeds. Soil organic matter impacts the potential for herbicide carryover for future crops, and amount of lime necessary to raise pH.

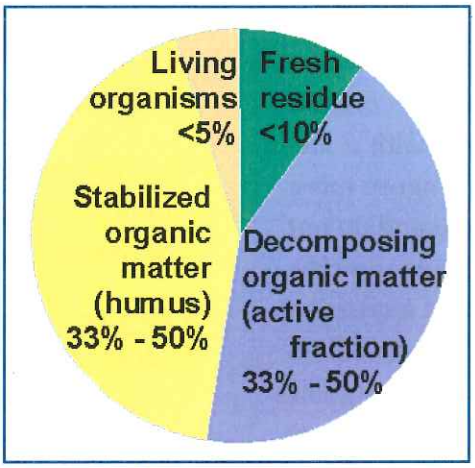

Figure 1. Major soil organic matter components (Source: The Soil Food Web, USDA-NRCS).

Inherent Factors Affecting Soil Organic Matter

Inherent factors affecting soil organic matter such as climate and soil texture cannot be changed. Climatic conditions, such as rainfall, temperature, moisture, and soil aeration (oxygen levels) affect the rate of organic matter decomposition. Organic matter decomposes faster in climates that are warm and humid and slower in cool, dry climates. Organic matter also decomposes faster when soil is well aerated (higher oxygen levels) and much slower on saturated wet soils (refer to soil respiration guide Figure 2 for more information).

Soils formed under grass (prairie) vegetation usually have organic matter levels at least twice as high as those formed under forests because organic material is added to topsoil from both top growth and roots that die back every year. Soils formed under forests usually have comparably low organic-matter levels because of two main factors listed below:

1. Trees produce a much smaller root mass per acre than grass plants, and
2. Trees do not die back annually and decompose every year. Instead, much of the organic material in a forest is tied up in the tree's wood rather than being returned to the soil annually.

A general map of soil organic matter distribution across the United States is shown in Figure 2 (darkest represents the highest level).

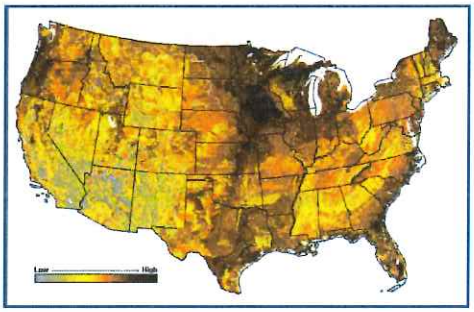

Figure 2. Soil organic matter content; STATSGO Database (USDA-NRCS)

Soil Organic Matter Management

Soil organic matter generally increases where biomass production is higher and where organic material additions occur. Plant residue with a low C/N ratio (high nitrogen content) decompose more quickly than those with a high C/N ratio and do not increase soil organic matter levels as quickly. Excessive tillage destroys soil aggregates increasing the rate of soil organic matter decomposition. Stable soil aggregates increase active organic matter and protect stable organic matter from rapid microbial decomposition. Measures that increase soil moisture, soil temperature, and optimal aeration accelerate SOM decomposition.

Management measures utilized on the field you are evaluating can either degrade or increase SOM. Some key management measures that can increase SOM are shown below.

- Use of cropping systems that incorporate continuous no-till, cover crops, solid manure or other organic materials, diverse rotations with high residue crops and perennial legumes or grass used in rotation.
- Reducing or eliminating tillage that causes a flush of microbial action that speeds up organic matter decomposition and increases erosion.
- Reduce erosion using appropriate measures. Most SOM is in the topsoil. When soil erodes, organic matter goes with it. Saving soil and SOM go hand in hand.
- Soil-test and fertilize properly. Proper fertilization encourages growth of plants, which increases root and top growth. Increased root growth can help build or maintain SOM, even if you are removing much of the top growth.
- Use of perennial forages provides for annual die back and re-growth of perennial grasses and their extensive root systems and aftermath contributing organic matter to soil. Fibrous root systems of perennial grasses are particularly effective as a binding agent in soil aggregation.

Soil Organic Matter Relationship to Soil Function

Under average conditions in temperate regions approximately 1.5 percent of SOM mineralizes yearly for most crops (2% spring planted row crops, 1% small grains, and 0.5% perennial grass; Ray Ward, 2012) while maintaining current organic matter levels on soils with 2 to 5% SOM (Doran 2012). Depending on site conditions, management, and climate mineralization rates and loss of SOM can increase dramatically if temperature, aeration, and moisture conditions are favorable. Key soil functions SOM provide for include:

- Nutrient Supply. Upon decomposition, nutrients are released in a plant-available form. While maintaining current levels. Each percent of SOM in the top 6 inches (15.2 cm) of a medium textured soil (silt and loam soils with a bulk density of 1.2) releases about 10-20 pounds of nitrogen, 1 to 2 pounds of phosphorus, and 0.4 to 0.8 pounds of sulfur per acre per year.
- Water-Holding Capacity. Organic matter behaves somewhat like a sponge. It has the ability to absorb and hold up to 90 percent of its weight in water. Another great advantage of organic matter is that it releases nearly all of the water it holds for use by plants. In contrast, clay holds great quantities of water, but much of it is unavailable to plants.
- Soil Aggregation. Organic matter improves soil aggregation, which improves soil structure. With better soil structure, water infiltration through the soil improves, which improves soil's ability to take up and hold water.
- Erosion Prevention. Because of increased water infiltration and stable soil aggregates erosion is reduced with increased organic matter.

Estimating Organic Material Needed to Increase Soil Organic Matter

The term **steady state** is where the rate of organic matter addition from crop residues, roots and manure or other organic materials equals the rate of decomposition. If the **rate of organic matter addition** is less than the **rate of decomposition**, SOM **will decline** and, conversely if the rate of organic matter addition **is greater** than the **rate of decomposition**, SOM will **increase**.

An acre of soil 6 inches (15.2 cm) deep weighs approximately 2,000,000 pounds, which means that 1 percent SOM weighs about 20,000 pounds per acre. Under average conditions it takes at least 10 pounds of organic material to decompose into 1 pound of organic matter, so it takes at least 200,000 pounds (100 tons) of organic material applied or returned to the soil to add 1 percent stable organic matter under favorable conditions ("What Does Organic Matter Do In Soil", Funderburg 2001, Samuel Roberts Noble Foundation).

What management measures are being used do you predict will affect soil organic matter?

_____

_____

_____

What impact do you expect these practices will have on soil organic matter and why?

_____

_____

_____

Measuring Soil Organic Matter

Materials Needed to Measure Soil Organic Matter

____ Soil color chart for estimating organic matter

____ Plastic bucket and probe for gathering and mixing soil samples

____ Squirt bottle with water (to moisten soil if dry)

____ Pen, field notebook, sharpie, and zip lock bags (for labeling soil samples taken back to the classroom)

Considerations – Soil organic matter typically is measured in a lab. The University of Illinois soil color chart provides an estimate of the amount of SOM in mineral soils formed under grass, as many soils are in the Midwest and other natural grassland regions around the world. It can be used for other soils, but is not as accurate. Please read color chart instructions for details and other considerations. Other accepted methods to estimate organic matter such as color charts for other types of soils, lab testing, or tools can be used.

In-field Estimate for Soil Organic Matter (refer to color chart for more guidance)

1. Soil Sampling: Soil organic matter is highly variable. At least 10 small samples are gathered randomly from an area that represents the soil type and management history from the surface 0-8 inch depth and placed in the small plastic bucket and mixed. You may also estimate organic matter at each sample site and average organic matter readings for the area you are assessing. Repeat for each sampling area.
2. Use moist soil. If the sample is dry moisten it.
3. Match the soil with the color that it most closely matches (Figure 3) organic matter color chart (or other method of estimating organic matter content). Record associated organic matter content in Table 3 and complete calculations in interpretations section of this document (suggest averaging several samples).

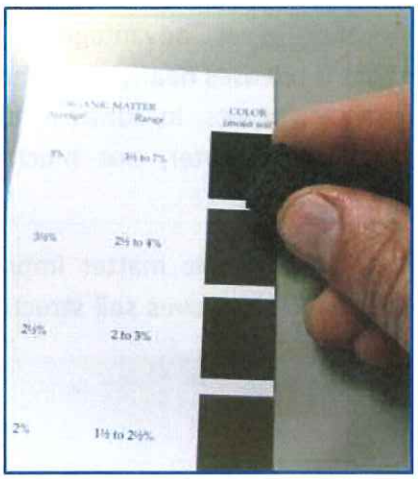

Figure 3. Soil color chart with soil at 3.5% soil organic matter (Kucera 2012).

soil pH

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Soil pH is a measure of soil acidity or alkalinity. It is an important indicator of soil health. It affects crop yields, crop suitability, plant nutrient availability, and soil micro-organism activity which influence key soil processes. Soil pH can be managed by measures such as applying the proper amount of nitrogen fertilizer, liming, and cropping practices that improve soil organic matter and overall soil health.

Inherent Factors Affecting Soil pH

Inherent factors affecting soil pH such as climate, mineral content and soil texture cannot be changed. Natural soil pH reflects the combined effects of soil-forming factors (parent material, time, relief or topography, climate, and organisms). The pH of newly formed soils is determined by minerals in the soil's parent material.

Temperature and rainfall control leaching intensity and soil mineral weathering. In warm, humid environments, soil pH decreases over time in a process called soil acidification, due to leaching from high amounts of rainfall. In dry climates, however, soil weathering and leaching are less intense and pH can be neutral or alkaline.

Soils with high clay and organic matter content are more able to resist a drop or rise in pH (have a greater buffering capacity) than sandy soils. Although clay content cannot be modified, organic matter content can be changed by management. Sandy soils commonly have low organic matter content, resulting in a low buffering capacity, high rates of water percolation and infiltration making them more vulnerable to acidification.

Soil pH Management

Soil pH is affected by land use and management. Vegetation type impacts soil pH. For example, areas of forestland tend to be more acidic than areas of grassland. Conversion of land from forestland or grassland to cropland can result in drastic pH changes after a few years. These changes are caused by a loss of organic matter, removal of soil minerals when crops are harvested, erosion of the surface layer, and effects of nitrogen and sulfur fertilizers.

Addition of nitrogen and sulfur fertilizers can lower soil pH over time.

Measures that limit or correct acidification

- Liming to raise the pH of an acid soil
- Applying nitrogen and sulfur according to crop needs
- Apply N fertilizer in appropriate amounts, in a timely manner (relative to crop uptake) and use of good irrigation management to minimize nitrate-N leaching
- Diversified crop rotations to interrupt acidifying effects from N fertilizer application
- Applying irrigation water, manure, and other organic materials that have a high content of calcium or magnesium bicarbonates

- Use of continuous no-till, cover crops, applications of solid manure, and diverse rotations with high-residue crops in order to increase organic matter content and improve soil buffering capacity to limit changes in pH.

Table 1. Crop yields relative to pH.

Crop	Soil pH				
	4.7	5	5.7	6.8	7.5
	Relative Yield (100 is the best, 0 is the worst)				
Corn	34	73	83	100	85
Wheat	68	78	89	100	99
Soybeans	65	79	80	100	93
Oats	77	93	99	98	100
Barley	0	23	80	95	100
Alfalfa	2	9	42	100	100
Timothy (grass)	31	47	66	100	95

Methods for Assessing Soil Quality, page 173 (SSSA, 1996)

Problems Related to pH and Relationship of pH to Soil Function

Soil pH is an excellent indicator of a soil's suitability for plant growth. For most crops, a range of 6 to 7.5 is best as shown in Table 1.

Soil pH levels that are too high or too low (Figure 1.) lead to deficiency of many nutrients, decline in microbial activity, decrease in crop yield, and deterioration of soil health. For example, soil pH values below 5.5 and between 7.5 and 8.5 limit availability of phosphate to plants (Figures 2 and 3). Four major management strategies to increase availability of phosphate to plants are:

1. Liming acid soils to increase soil pH to between 6.5 and 7.0
2. Applying phosphorus fertilizer frequently in small amounts rather than one time in a large amount
3. Reducing contact between soil and phosphorus source (manure and/or fertilizer) by banding or injecting
4. Locating P-fertilizers near crop row where roots are most active

Nitrogen cycling is inhibited by low pH. The effectiveness and degradation of herbicides and insecticides and solubility of heavy metals depend on pH. Some diseases thrive when soil is alkaline or acidic. Effectiveness and potential carryover of certain soil-applied herbicides is also impacted by soil pH.

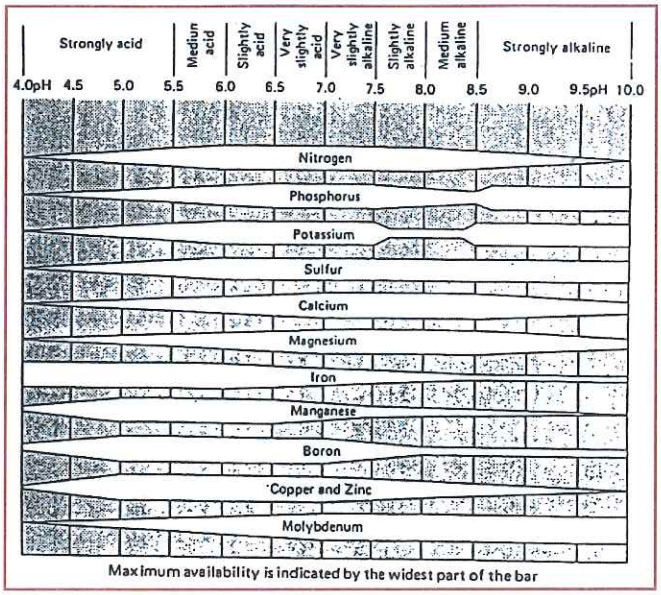

Figure 1. Relationship between plant nutrient availability and soil reaction (*National Soil Survey Manual*, NRCS).

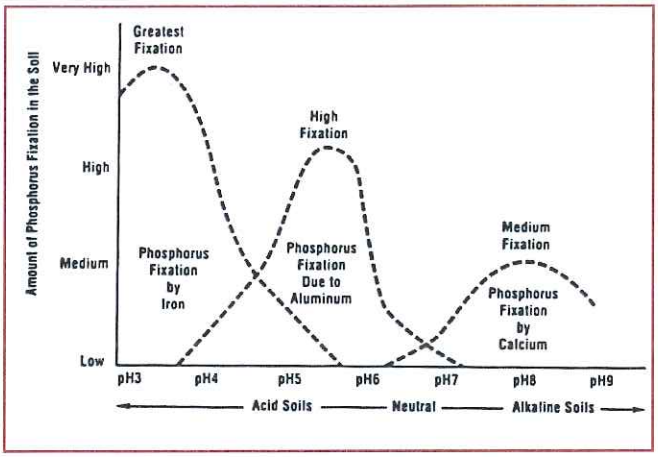

Figure 2. Phosphorus availability relative to pH ranges (California Fertilizer Association, 1995).

Figure 3. Image of corn with a phosphorus deficiency (R.L. Croissant, Bugwood.org).

What current practices do you think affect soil pH?

_____

_____

_____

What impact do you expect these practices to have on soil pH and why?

_____

_____

_____

Measuring Soil pH

Materials Needed to Measure pH

____ Probe and plastic bucket for gathering and mixing soil samples

____ Roll of pH test strips

____ 1/8-cup (29.5-mL) measuring scoop

____ Calibrated 120-mL shaking vial with lid

____ Squirt bottle

____ Distilled water or rainwater

____ Pen, field notebook, sharpie, and zip-lock bags

Considerations – Electical conductivity should always be measured before pH when using the same sample. Soil phosphate, nitrate, and nitrite levels can be measured using the following steps.

In-Field Quick Hand Test

1. Soil Sampling: Soil pH level is highly variable, depending on field location and time of year. It is affected by fertilizer placement in rows or between rows, soil texture, organic matter content, and applications of manure or fertilizer. Using a soil probe gather at least 10 small samples randomly from an area that represents soil type and management history to a depth of 8 inches and place in a small plastic bucket. Do not include large stones and residue in sample. Repeat this step for each sampling area.

2. Neutralize hands by rubbing wet soil across palms (discard the soil).

3. Place a scoop of mixed soil in your palm, and saturate soil with "clean" water (distilled water or rainwater).

4. Squeeze soil gently until a water slurry runs out of the cup of the hand and onto the side.

5. Touch the end of a 1-inch-long piece of pH test strip directly to slurry so that the tip is barely wet and solution can be drawn up the strip at least 1/4" to 1/2" beyond the area masked by soil (Figure 4).

6. Compare the color approximately 1/3 of the way up the colored portion of the strip to color chart on dispenser (Figure 5). Record soil pH and interpretations (Table 2).

Figure 4. Quick hand test.

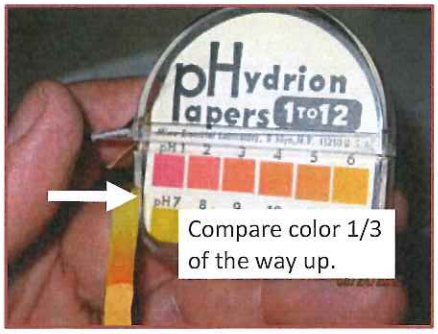

Figure 5. Soil pH color chart.

1:1 Soil-Water Soil pH Test in Classroom

1. Soil Sampling: Same as step 1 described for the in-field quick hand test.
2. Tamp down one sampling scoop (29.5 mL) of mixed soil by striking scoop carefully on a hard, level surface. Place sample in plastic mixing vial. Add one scoop (29.5 mL) of water to the same vial. The vial will contain a 1:1 ratio of soil to water, on a volume basis.
3. Tightly cap vial and shake 25 times. Let the sample settle for 1 minute. Remove cap and decant 1/16 inch of soil-water solution carefully into lid. Let sample sit in the lid for 2 to 3 minutes.
4. Take the end of a 1-inch-long piece of pH paper and immerse it 1/16 inch into solution (Figure 6) until the liquid is drawn up at least 1/4 to 1/2 inch beyond area covered by soil (Figure 4).
5. Compare color approximately 1/3 of the way up colored portion of the strip to color chart on dispenser (Figure 5). Record soil pH and interpretations (Table 2).

Figure 6. 1:1 soil water test.

Interpretations

Record soil pH and complete Table 2 by comparing measured soil pH to that given in Figure 1, Figure 2, and Table 1 and by answering discussion questions.

In general, pH values between 6 and 7.5 are optimum for crop and forage production and nutrient uptake. Soil pH impacts nutrient availability and overall soil health. Soil acidification can also be an indication of excessive nitrogen fertilizer application.

Table 2. Soil pH and interpretations.

Site	Soil pH	Soil pH Category (from Figure 1, such as very acid)	Nutrients Impacted by Soil pH (from Figures 1 and 2)	Crops Impacted by Soil pH Level (from Table 1)	Notes
Ex 1	5.8	Medium Acid	P, K, Ca, Mo	All but oats	Spring test on corn stubble

Compare test results recorded in Table 2 to values in Figure 1, Figure 2, and Table 1. Are soil pH levels ideal for crops or forages grown? Why or why not?

_____

_____

_____

Based on results of soil pH test, do you recommend liming or other measures to adjust pH? Why or why not?

_____

_____

_____

Glossary

Acidity – Soil pH is less than 7.

Alkalinity – Soil pH is greater than 7.

Anion – A negatively charged ion.

Buffering Capacity – A soil's ability to resist change in pH. Soils with high contents of clay and organic matter have a greater buffering capacity.

Cation – A positively charged ion.

Nitrification – Oxidation of ammonium-nitrogen compounds in organic material or fertilizer into nitrites and nitrates by soil bacteria, making nitrogen available to plants.

Phosphorus Fixation – Phosphorus is tied up by calcium, iron, or aluminum compounds, making it unavailable for plant uptake. Fixation is impacted by soil pH.

Soil pH – A measure of soil acidity or alkalinity.

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soil Infiltration

Soil Quality Kit – Guides for Educators

USDA NRCS
United States Department of Agriculture
Natural Resources Conservation Service

Soil infiltration refers to the soil's ability to allow water movement into and through the soil profile. It allows the soil to temporarily store water, making it available for uptake by plants and soil organisms. Infiltration rates are a measure of how fast water enters the soil and are typically expressed in inches per hour. For initial in-field assessments, however, it is more practical to express infiltration time in the number of minutes it takes soil to absorb each inch of water applied to the soil surface. Water entering too slowly may lead to ponding on level fields, erosion from surface runoff on sloping fields, or inadequate moisture for crop production. An adequate amount of water must infiltrate the soil profile for optimum crop production. Porous soils allow water to infiltrate and recharge ground-water aquifers and sustain base flow in streams. An infiltration rate that is too high can lead to nitrate-nitrogen or pesticide leaching, if they are not managed correctly. Management measures, such as residue management, cover crops can improve infiltration.

Inherent Factors Affecting Soil Infiltration

Inherent factors affecting soil infiltration, such as soil texture, cannot be changed. Soil texture (percentage of sand, silt, and clay) is the major inherent factor affecting infiltration. Water moves more quickly through large pores of sandy soil than it does through small pores of clayey soil, especially if clay is compacted and has little or no structure or aggregation.

Depending on the amount and type of clay minerals, some clayey soils develop shrinkage cracks as they dry. The cracks are direct conduits for water entering the soil, causing clayey soils to have high infiltration rates under dry conditions. Where cracks do not occur, clayey soils have slow infiltration rates.

Infiltration Management

Management practices (such as providing ground cover and managing equipment traffic to avoid compaction) impact infiltration by affecting surface crusting, compaction, and soil organic matter. Without a protective vegetative or residue cover, bare soil is subject to direct impact and erosive forces of raindrops that dislodge soil particles. Dislodged soil particles fill in and block surface pores, contributing to the development of surface crusts which restrict water movement into the soil. Compaction can result from equipment traffic, especially on wet soils, and tillage pans. Compacted or impervious soil layers have less pore space and restrict water movement through the soil profile.

As soil moisture levels increase, infiltration rates decrease. Soil moisture is impacted by water uptake by plants, residue and vegetative cover, irrigation practices, and drainage measures. Dry soils tend to have pores and cracks that allow water to enter faster than wet soils. As soils become wet, infiltration rate slows to a steady rate based on how fast water can move through the most restrictive layer, such as a compacted layer, or a layer of dense clay.

Soil organic matter binds soil particles together in stable aggregates, increasing porosity and infiltration. Soils with a high content of organic matter also provide good habitat for soil biota, such as earthworms. Soil biota increase pore space and create continuous pores linking surface soil layers to subsurface soil layers.

Long-term solutions for maintaining or improving soil infiltration include practices that increase organic matter content and aggregation and minimize runoff, soil disturbance, and compaction. Increases in organic matter content result in increased aggregation and improved soil structure, which lead to improved infiltration rates.

Measures that can improve infiltration rates:

- Avoiding soil disturbance and equipment operation when soils are wet
- Using designated field roads or rows for equipment traffic
- Reducing the number of trips across the field
- Subsoiling to break up existing compacted layers
- Using continuous no-till
- Adding solid manure or other organic materials
- Using rotations with high-residue crops, such as corn and small grain, and perennial crops, such as grass or alfalfa
- Planting cover crops and green manure crops
- Farming on the contour
- Establishing terraces or other runoff- and erosion-control structures

Problems Related to Infiltration and Relationship of Infiltration to Soil Function

When rainfall occurs at a rate that exceeds the soil's infiltration capacity, runoff moves downslope or ponds on the surface of level land. When runoff occurs on bare or poorly vegetated soil, erosion occurs. Runoff carries away nutrients, chemicals, and soil, resulting in decreased soil productivity, offsite sedimentation of water bodies, and diminished water quality. Tables 1 and 2 show, for periods of 1 year to 100 years, rainfall frequencies, duration of rainfall events, and inches of rainfall.

Table 1. Rainfall intensity and duration patterns for Mead, NE.*

Frequency	Duration of Rainfall Event (inches of rain)		
	30 minutes	1 hour	2 hours
1 year	1.2	1.1	1.8
2 years	1.3	1.7	1.9
5 years	1.7	2.1	2.4
10 years	2.0	2.5	2.8
100 years	2.8	3.7	4.2

* D.M. Herschfield, *Rainfall Frequency Atlas of the U.S.*, U.S. Weather Bureau, 1961.

Table 2. Rainfall intensity and duration patterns for North Platte, NE.*

Frequency	Duration of Rainfall Event (inches of rain)		
	30 minutes	1 hour	2 hours
1 year	0.9	1.1	1.2
2 years	1.1	1.4	1.5
5 years	1.5	1.9	2.1
10 years	1.8	2.2	2.5
100 years	2.6	3.4	3.7

* D.M. Herschfield, *Rainfall Frequency Atlas of the U.S.*, U.S. Weather Bureau, 1961.

Restricted infiltration and ponding result in poor soil aeration. This leads to poor root function, poor plant growth, reduced availability of nutrients to plants, and reduced cycling of nutrients by soil organisms.

Infiltration rate is most affected by conditions near the soil surface and can change drastically according to management. Infiltration is rapid through large continuous pores at the soil surface and slows as pores become smaller. Steady-state infiltration rates typically occur when soil is nearly saturated and are listed for varying textural classes in Table 3. These are average values and should not be generalized for all soil types.

Table 3. Steady infiltration rates for general soil texture groups in a very deeply wetted soil (Hillel, 1982). (Only use these values to compare infiltration rates to the second inch of water.)

Soil Type	Steady infiltration rate (inches per hour)
Sands	> 0.8
Sandy and silty soils	0.4 - 0.8
Loams	0.2 - 0.4
Clayey soils	0.04 - 0.2
Sodic clayey soils	< 0.04

What measures are being used that impact infiltration rates? _____

_____

_____

Do they increase or decrease infiltration rates? (Why or why not?)

_____

_____

_____

Soil Science Education by NASA

How Does Your Garden Grow?

Some Information on Soil Fertility

Have you ever planted a seed or seeds in soil and watched in amazement as tiny chutes begin to emerge from the soil and then eventually grow into a healthy, stable plant? Did you know that besides needing water (which is very important!) the type of soil that plants grow in and what actually goes on in soil determines how well plants grow? Five factors determine what types of soil form on Earth and critters that live in the soil are part of the amazing soil forming process:

Parent Material- the primary material from which the soil is formed. Soil parent material could be bedrock, organic material, an old soil surface, or a deposit from water, wind, glaciers, volcanoes, or material moving down a slope. Bedrock is broken down as water, wind, or other weathering processes wear away mineral particles from rocks.

Organisms- Soil is also formed as organic matter (such as leaves and dead plants) decomposes and as critters living in the soil change the chemistry of soil. Each of these parts work together to make soil that plants can grow well in. Fertile soils are those that have enough Nitrogen (N), Phosphorus (P), and Potassium (K), along with other nutrients that plants take up.

Topography- The location of a soil on a landscape can affect how the climatic processes impact it. Soils at the bottom of a hill will get more water than soils on the slopes, and soils on the slopes that directly face the sun will be drier than soils on slopes that do not. Also, mineral accumulations, plant nutrients, type of vegetation, vegetation growth, erosion, and water drainage are dependent on topographic relief.

Climate-heat, rain, ice, snow, wind, sunshine and other environmental forces break down the parent material and affect how fast or slow soil formation processes go.

Time- All of the above factors assert themselves over time, often hundreds or thousands of years.

Soil and plants play a very important part in the survival of humans and animals. Soil protects plant roots from exposure to the Sun's heat at Earth's surface, soil filters pollution that comes from rain and water runoff from farms. Soil is used to build with and on, and soil is what plants need to grow and be supported while growing. Plants are not only used for food but are also used to make fabrics and dyes, medicines and beauty products, fragrances, rubber and building materials, just to name a few.

The most important function of plants involves photosynthesis. Photosynthesis is a process in which all plants and algae as well as certain types of photosynthetic bacteria produce their own food, and in doing so take in carbon dioxide (CO_2) and then release oxygen (O_2) into Earth's atmosphere, which many living species on Earth need to survive.

You will learn here about three important minerals:

- **Nitrogen**
- **Phosphorus**
- **Potassium**

Plants must have these nutrients in order to grow healthy and strong.

WHY PLANTS LIKE NITROGEN (N):

Nitrogen (N) helps plants use carbohydrates to gain energy, like certain foods we eat help us to gain energy. Nitrogen controls how plants take their form and how they function inside, and nitrogen helps plants make protein that help them grow strong and healthy. Humans and animals benefit from eating vegetables and plants that are rich in nitrogen because proteins are passed on to humans and animals when they eat vegetables and plants.

THE NITROGEN CYCLE AND HOW NITROGEN MOVES THROUGH THE SOIL:

The nitrogen cycle involves certain processes that change nitrogen into different forms. Organic nitrogen in materials, like dead leaves and plants, are changed into inorganic nitrogen by microorganisms (critters) in the soil. Plants take up

these available forms of inorganic nitrogen (NO_3 and NH_4^+) so they can grow. Unfortunately, these forms of nitrogen are not always used by plants because they either get onto clay particles in soil, they leach into the groundwater because they cannot be absorbed by the soil, or they change into nitrogen gases that escape into **Earth's atmosphere. Luckily there are specific kinds of**

microorganisms living in the soil that can convert gaseous forms of nitrogen into inorganic nitrogen that plants can use.

When plants die the dead plant matter falls to the ground and certain microbes, yet again, do their job of decomposing dead plant matter (which contains organic N) and changing it into inorganic N that living plants can use! This cycle is continuous. Processes in the nitrogen cycle are: Adsorption/Fixation, Denitrification, Erosion, Immobilization, Leaching, Mineralization, Nitrification, and Volatilization.

HOW PLANTS TAKE UP NITROGEN

Plants take up nitrogen in forms of nitrate (NO_3^-) and ammonium (NH_4^+). Most plants thrive on equal amounts of these ions but nitrates are more quickly available to plants because they move through the soil solution, whereas ammonium ions become fixed or held on to clay particles, called colloids, because of their positive charge.

WHAT HAPPENS WHEN PLANTS DON'T GET ENOUGH NITROGEN:

Plants deficient in nitrogen have thin, spindly stems and their growth is stunted. Their older leaves turn yellowish-green from nitrogen starvation (chlorosis), while newer leaves are supplied with the available, but limited nitrogen.

WHAT HAPPENS WHEN PLANTS GET TOO MUCH NITROGEN:

Plants that get too much nitrogen have alot of foliage (leaf) growth but are not strong. Plants that are not strong can get diseases more easily, can be bothered more by bugs, and can eventually fall over and die. An excess amount of nitrogen in plants can affect the amount of sugar and vitamins in fruits and vegetables, making them taste different. More importantly excess nitrogen can build up in plant tissues causing toxicity (poisoning) in livestock and in small children who eat nitrogen rich, leafy vegetables.

WHY PLANTS LIKE PHOSPHORUS (P):

Phosphorus (P) plays an important part in how plants and animals form and in how they function and grow. Phosphorus is known to help plants during photosynthesis, P helps plants respire (breathe), P provides energy transfer and storage, and P also helps plants efficiently use water. Seedlings and roots grow more quickly and vegetable and fruit production is increased when plants get enough phosphorus. Soil phosphorus comes mainly from the weathering of rocks that contain the inorganic mineral Apatite

Because minerals containing P are mostly insoluble and because P is fixed, or held, on to soil particles that erode away during rain storms, plants cannot get enough P. Over the past 100 years, farmers and gardeners have heavily added phosphorus fertilizers to their fields to help plants get more of this nutrient.The main reason phosphorus pollution occurs in the environment is because too much P fertilizer is added to soil, then during rain storms it travels on soil particles, across the land, and into surface waters.

Unfortunately, excess P in the environment has caused and continues to cause pollution in streams, rivers, lakes, and groundwater which is used for drinking water. Aquatic life and wildlife living in and around these waterways also are affected.

HOW PHOSPHORUS MOVES THROUGH THE SOIL AND HOW PLANTS TAKE UP PHOSPHORUS:

Inorganic and organic forms of P are found in soils, with most organic P being located at the soil surface. The same processes for nitrogen also occur for P: organic forms of phosphorus are changed into inorganic forms of P by microbial activity in the soil (mineralization) or when inorganic forms of P are changed into organic forms of P that plants cannot use (immobilization).

Soil pH affects phosphorus availability to plants. In alkaline soils, in arid climates, calcium phosphate ($CaPO_4$) is dominant. If soil pH gets too high a chemical reaction takes place that fixes the phosphorus and makes it insoluble and unusable by plants. In acid soils aluminum phosphate ($AlPO_4$), iron phosphate ($FePO_4$) and sometimes manganese phosphate (MnPO4) are dominant. If soil pH gets too low a chemical reaction takes place that fixes phosphorus to Al, Fe, or Mn and phosphorus becomes insoluble and unusable by plants.

Other factors that prevent plants from taking up phosphorus include lack of oxygen, low soil moisture, low organic matter, extreme temperatures within soil, soil type, and plant type. Plants living in highly weathered soils use organic forms of phosphorus; plants living in soils that contain organic matter and are less weathered use inorganic forms of phosphorus.

When soil contains enough organic matter (dead leaves and plants) at Earth's surface P cannot become fixed as easily to clay surfaces. Adding organic matter to soil gives plants more time to take up P before P become fixed.

Of all phosphorus in existence on Earth, only 0.01% becomes available for plant use!

WHAT HAPPENS WHEN PLANTS DON'T GET ENOUGH PHOSPHORUS:

Plants that don't get enough P have spindly, thin-stems that are weak. Their growth is stunted or shortened, and their older leaves turn a dark bluish-green. The ability of phosphorus deficient plants to produce seeds, flowers, and fruits is deminished. Farmers and gardeners add P fertilizer to soil to so their plants wont become unhealthy.

WHAT HAPPENS WHEN PLANTS GET TOO MUCH PHOSPHORUS:

Phosphorus is hard for plants to obtain, let alone get too much of because:

1.) inorganic P is scarce in the environment

2.) P can quickly become fixed on to soil

3.) P gets eroded in rain water runoff to streams, rivers, and lakes.

WHY PLANTS LIKE POTASSIUM (K):

Potassium (K) is very important in the plant photosynthesis process and in helping plants metabolize their food to get energy, like humans and animals do when they eat. Potassium controls water and chemicals inside plants that help plants function well. Potassium also controls the absorption of water into plant pores, like the pores on your skin.

HOW POTASSIUM MOVES THROUGH SOIL AND HOW PLANTS TAKE UP POTASSIUM:

K is found in high levels in most soils, except in those soils containing sand, but the availability of K to plants is low because a large percentage of K is held in mostly unavailable forms to plants. K can be held inside a clay particle as part of the clay's structure, or it can be held outside on the edges or surface of a clay structure because it has a positive charge.

Of all soil K, 90-98% is held in primary mineral structures that are very resistant to most weathering processes, and therefore not easily available to plants. This form of K is known as inorganic structural K. Roots of some plants do have the ability to take up K from solution around these primary minerals, making these minerals dissolve more easily.

Secondary minerals, such as vermiculite and smectite clays, adsorb or fix K on to their edges and in between their crystal layers, making K only slowly available to plants. This form of K is called nonexchangeable K.

More readily available K for plants is found on the surface of clay particles (colloids) where they can exchange places with other similar sized and positive charged ions in the soil solution. These forms of K are called exchangeable K and solution K. K in soil solution is the easiest form of K for plants to take up. The soil solution is, however, subject to loss by leaching.

As plants take up solution K, exchangeable K takes the place of solution K, while another K ion (from nonexchangeable and structural K sources) moves into the position the exchangeable K was once using. In otherwords, these different forms of K move around (like people do in the game "musical chairs") to replace K used up by plants or to replace K that is lost in the environment.

Plants are known to take up five to ten times more K, as compared to N and P, however; plants cannot take up potassium (and other nutrients) when soil moisture and temperatures are low, when root growth is small, and when enough oxygen is not available. Like phosphorus, potassium is only available to plants in small amounts and is hard for plants to get. Like certain forms of nitrogen and phosphorus, potassium also becomes fixed onto clay particles in soil, making it even harder for plants to obtain..

WHAT HAPPENS WHEN PLANTS DON'T GET ENOUGH POTASSIUM:

Plants lacking in K do not have enough energy to properly grow, their roots are not well formed, and they have weak stems and stalks. The edges of older plant leaves appear "burned", as K deficient plants cannot regulate and use water efficiently. K deficient plants are more easily affected by pests, bugs, and diseases. Also, they cannot survive through winters or droughts (periods of time when water is not available to plants). So, you see, plants that do not get enough of these very important nutrients, (don't forget them- they are N, P, and K!) cannot grow well and eventually can die. But we also must use our knowledge about soils to ensure that nutrients are added to soil in the right amounts and that soil is managed in ways to prevent nutrients from leaving the soil and polluting our groundwater (drinking water), streams, lakes, and rivers.

Information derived from: "The Nature and Properties of Soil" by Nyle C. Brady and Ray R. Weil, Prentice Hall, Inc., 1996, Upper Saddle River, NJ 07458; ISBN: 0-02-313371-6, 11th Edition.

soil Bulk Density / Moisture / Aeration

Soil Quality Kit – Guides for Educators

USDA NRCS United States Department of Agriculture Natural Resources Conservation Service

Bulk density is an indicator of soil compaction and soil health. It affects infiltration, rooting depth/restrictions, available water capacity, soil porosity, plant nutrient availability, and soil microorganism activity, which influence key soil processes and productivity. It is the weight of dry soil per unit of volume typically expressed in grams/cm^3. Total volume of surface soil is about 50% solids, mostly soil particles (45%), and organic matter (generally < 5%); and about 50% pore space which are filled with air or water (Figure 1). When determining bulk density, the amount of soil moisture must be determined. Available water capacity is the amount of soil moisture available to plants, varies by texture (Figure 2), and is reduced when compaction occurs. Bulk density can be managed, using measures that limit compaction and build soil organic matter.

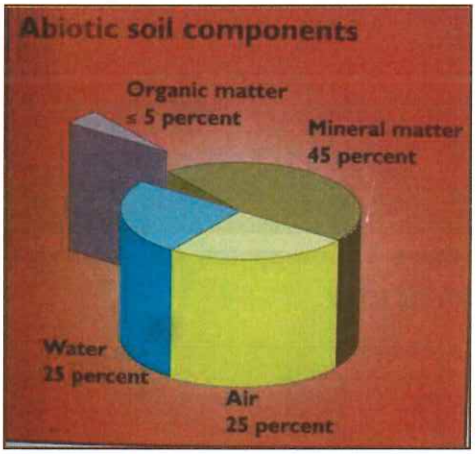

Figure 1. Four major components of soil volume (Michigan Field Crop Ecology, 1998, E-2646, p. 13).

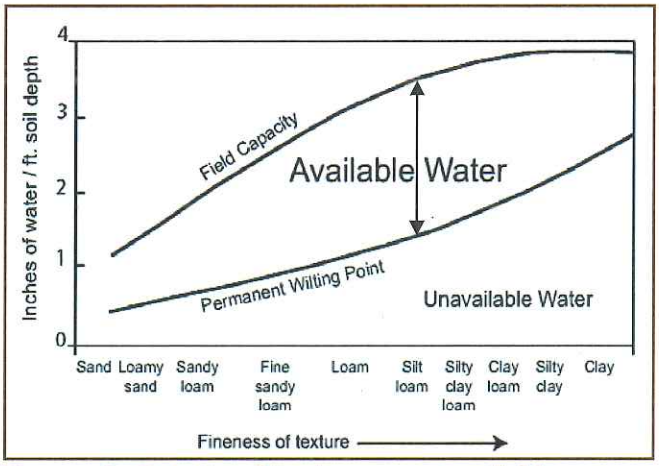

Figure 2. Relationship between available water and texture (Ohio Agronomy Guide, 14th Ed. Bull. 472-05).

Inherent Factors Affecting Bulk Density and Available Water Capacity

Inherent factors that affect bulk density such as soil texture cannot be changed. Bulk density is dependent on soil organic matter, soil texture, the density of soil mineral (sand, silt, and clay) and their packing arrangement. As a rule of thumb, most rocks have a density of 2.65 g/cm^3 so ideally, a silt loam soil has 50% pore space and a bulk density of 1.33 g/cm^3. Generally, loose, well-aggregated, porous soils and those rich in organic matter have lower bulk density. Sandy soils have relatively high bulk density since total pore space in sands is less than silt or clay soils.

Bulk density typically increases with soil depth since subsurface layers are more compacted and have less organic matter, less aggregation, and less root penetration compared to surface layers, therefore contain less pore space.

Available water capacity (Figure 2) is affected by soil texture, presence and abundance of rock fragments, soil depth and restrictive layers.

Bulk Density Management

Bulk density can be changed by management practices that affect soil cover, organic matter, soil structure, compaction, and porosity. Excessive tillage destroys soil organic matter and weakens the natural stability of soil aggregates making them susceptible to erosion caused by water and wind. When eroded soil particles fill pore space, porosity is reduced and bulk density increases. Tillage and equipment travel results in compacted soil layers with increased bulk density, most notably a "plow pan" (Figures 3 and 4). Tillage prior to planting temporarily decreases bulk density on the surface but increases at the depth of tillage. Subsequent trips across the field by farm equipment, rainfall events, animals, and other disturbance activities will also compact soil. Long-term solutions to soil compaction center on decreasing soil disturbance and increasing soil organic matter.

A soil's available water capacity is also affected by organic matter and compaction. Organic matter increases a soil's ability to hold water, both directly and indirectly. Compaction increases bulk density and reduces total pore volume, consequently reducing available water holding capacity.

The following measures increase organic matter, and reduce compaction, which improve bulk density and porosity:

- Practices that increase organic matter such as continuous no-till, cover crops, solid manure or compost application, diverse rotations with high residue crops and perennial legumes or grass used in rotation;
- Minimize soil disturbance and avoid operating equipment when soils are wet;
- Use designated roads or rows for equipment;
- Reduce the number of trips across a field;
- Subsoil to disrupt existing compacted layers; and
- Use multi-crop systems involving plants with different rooting depths to help break up compacted soil layers.

Figure 3. Compacted soil in wheel traffic row.

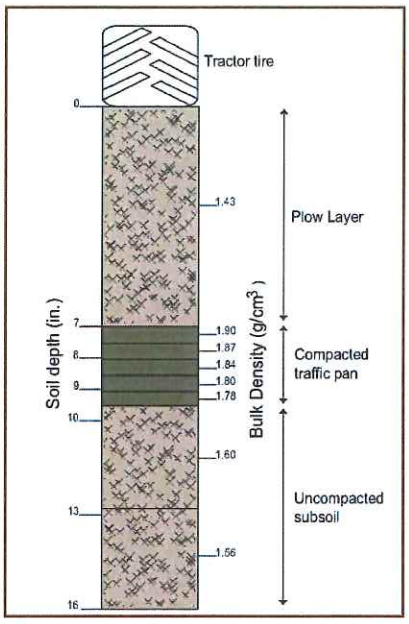

Figure 4. Compacted plow layer inhibiting root penetration and water movement through soil profile (adapted from: *The Nature and Properties of Soils*, 10th Edition).

Water-Filled Pore Space and Porosity

When determining bulk density, water-filled pore space and porosity can also be calculated. When water-filled pore space exceeds 60%, several important soil processes are impacted. Soil respiration and nitrogen cycling (ammonification and nitrification) increase with increasing soil moisture (Figure 5). Lack of aeration also interferes with a soil organism's ability to respire and cycle nitrogen. In dry soils, these processes decline because of lack of soil moisture.

As soil water-filled pore space exceeds 80%, soil respiration declines to a minimum level and denitrification occurs resulting in loss of nitrogen as gas, emission of potent greenhouse gases, yield reduction, and/or increased N fertilizer expense.

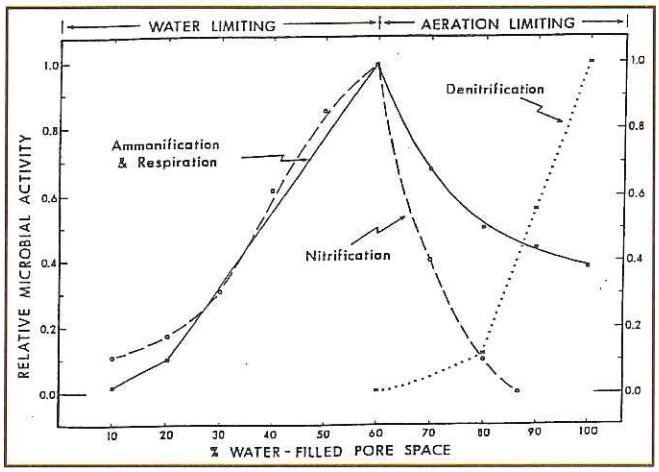

Figure 5. Relationship of water-filled pore space to soil microbial activity (Linn and Doran, 1984).

Soil Bulk Density Problems and Relationship to Soil Function

High bulk density is an indicator of low soil porosity and soil compaction. High bulk density impacts available water capacity, root growth, and movement of air and water through soil. Compaction increases bulk density and reduces crop yields and vegetative cover available to protect soil from erosion. By reducing water infiltration into soil, compaction can lead to increase runoff and erosion from sloping land or saturated soils in flatter areas. Bulk densities above thresholds in Table 1 impair root growth.

Laboratory analyses should use bulk density to adjust volume of soil to determine organic matter and nutrient content of soil. For example, a soil with a bulk density of 1.3 versus a soil with a bulk density of 1.0 would result in a 30% error in organic matter and nutrient content if the samples are not adjusted for bulk density.

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

Soil Texture	Ideal bulk densities for plant growth (grams/cm^3)	Bulk densities that affect root growth (grams/cm^3)	Bulk densities that restrict root growth (grams/cm^3)
Sands, loamy sands	< 1.60	1.69	> 1.80
Sandy 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

What management measures and practices do you think affect bulk density? Why or why not?

_____

_____

_____

What impact do you expect these practices on organic matter and soil porosity?

_____

_____

_____

Measuring Bulk Density and Soil Moisture

Materials Needed to Measure Bulk Density

____ 3-inch diameter aluminum ring

____ Wood block or plastic insertion cap

____ Rubber mallet or weight

____ Folding trowel

____ Flat-bladed knife

____ Sealable bags and marker pen

____ Scale (1 g precision)

____ 1/8 cup (29.5 mL) measuring scoop

____ Ceramic coffee cup or paper plate

____ 18-inch metal rod, probe or spade (to check for compaction zone)

____ Access to a microwave oven

Considerations – Bulk density can be measured at the soil surface and/or compacted tillage zone. Bulk density samples should be taken in same location as infiltration and respiration tests. It may be possible to use the infiltration test sample. For sticky clay soils a little penetrating oil applied to the ring makes it easier to remove soil.

Step by Step Procedure

1. Carefully clear all residue then drive ring to a depth of 3 inches (2 inches from top; see Figures 6 and 7) with small mallet or weight and block of wood or plastic cap (same process as used for infiltration test).

Figure 6. Drive ring to 3-inch depth.