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).

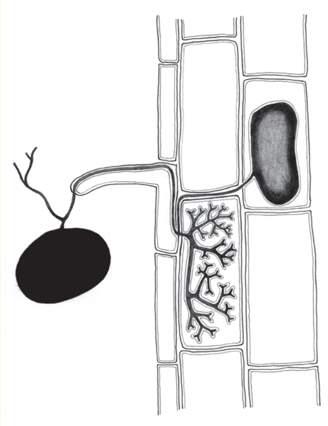
The 'soil factory' workers can be most productive when they have a good working environment with an ample supply of energy. When they are most productive, the farmer is most profitable.

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.

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.

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

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.

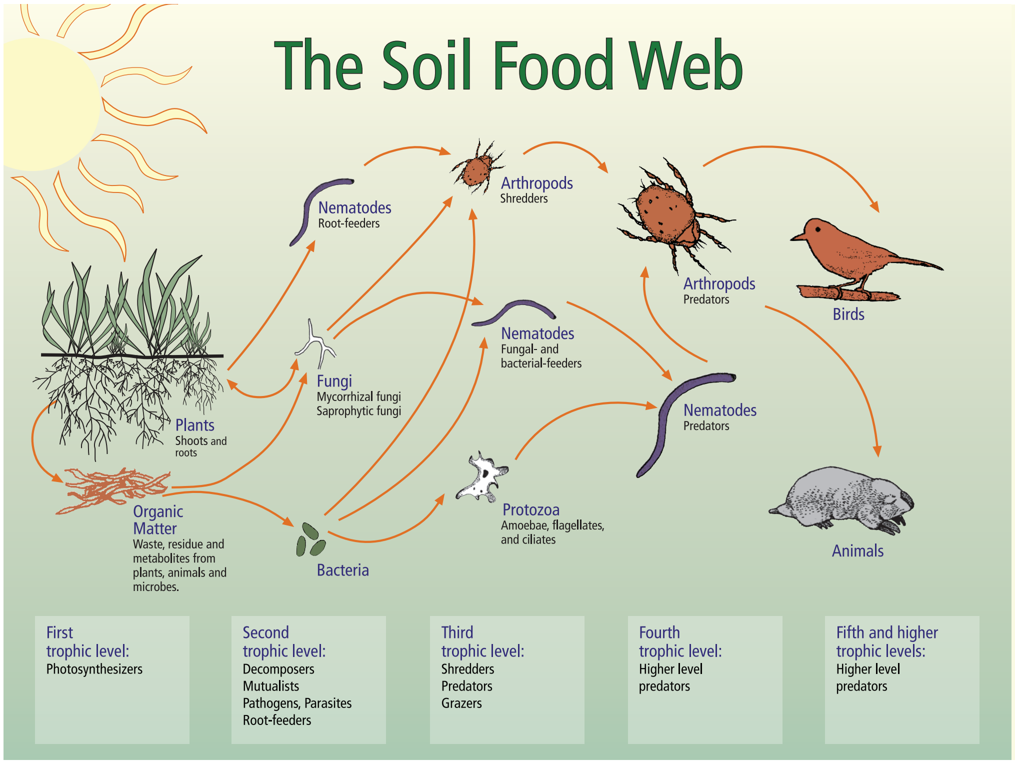
Living plants maintain a rhizosphere, an area of concentrated microbial activity close to the root. The rhizosphere is the most active part of the soil factory because it is where the most easy to eat food is available, and it is where peak nutrient and water cycling occurs. Microbial food is exuded 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.



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.

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

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.

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.

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 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.

November 2012

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