Caring for the Soil as a Living System

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Number 2-06 05/15/06 http://www.vabf.org/pubs.php

Soil provides the basis of all plant, animal and human life on land. It consists of mineral matter (clay, silt, sand, gravel, stones), air- and water-filled pore spaces, organic matter (dead roots and other plant and animal remains, plus humus), and a great diversity of living organisms. In organic and sustainable cropping systems, the soil life is the engine of soil fertility and crop production, as well as the guardian of long term soil health.

Contents:

The Soil is a Living System

A living system consists of life forms, and the food, air, water, habitat and shelter they need to thrive, grow and reproduce. In the soil *organic matter* (replenished each season) becomes food; the soil's *structure* and network of *pore space* provide habitat, air and water; and *living vegetation* and *surface residues* offer shelter. Figure 1 shows approximate proportions of mineral matter, pore space and organic components in a good topsoil.

Sustainable growers tend the soil life as they would any other valuable farm livestock. Just as farmers make sure their cattle, sheep or poultry get regular food and water, and shelter from severe weather, they can keep the soil life well fed and protect it from erosion, compaction and temperature extremes.

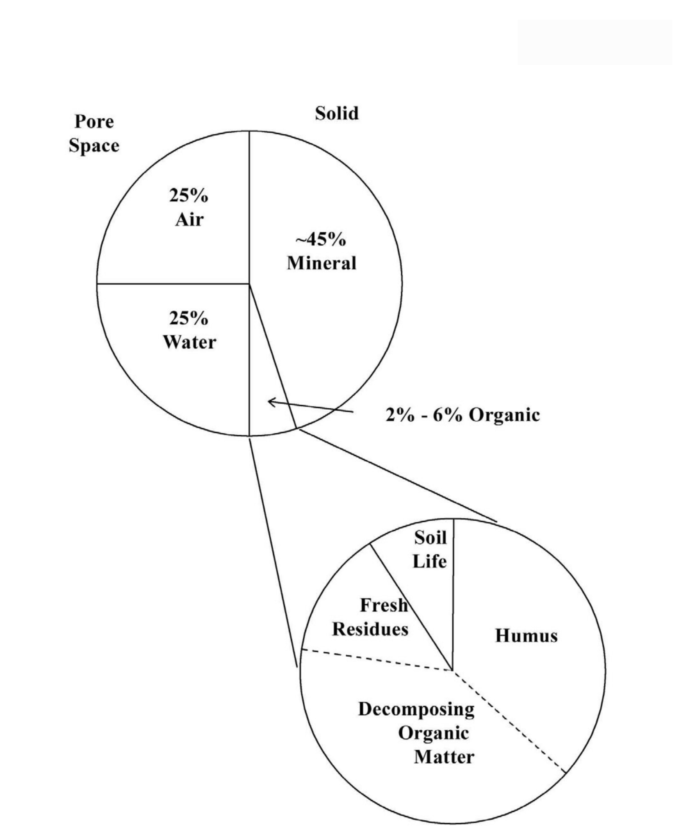

Figure 1. Approximate proportions of mineral matter, air and water-filled pore space, organic matter and living organisms in topsoil.

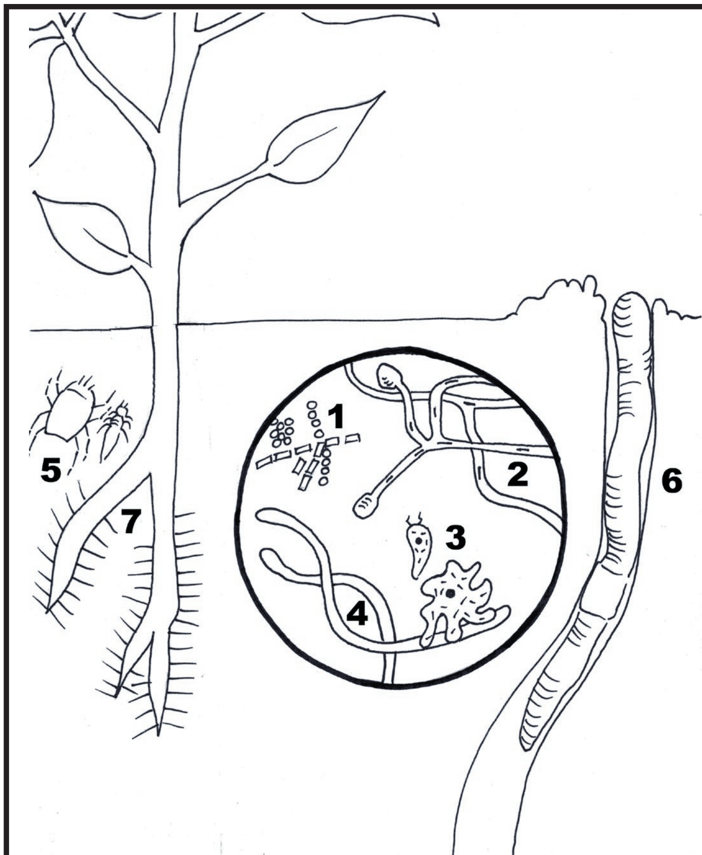

Figure 2. Main components of the soil life: (1) bacteria, (2) fungi, (3) protozoa, (4) nematodes, (5) mites, insects and other arthropods, (6) earthworms, and (7) plant roots.

One teaspoon of healthy agricultural topsoil may contain 100 million to one billion bacteria, several yards of fungal filaments, several thousand protozoa, and ten or twenty nematodes (tiny, simple worms) that together represent *thousands* of different species of microorganisms. In addition, a good soil may contain up to 100 insects, mites and other arthropods, and five to 30 earthworms per square foot, 1000-2000 lb (dry weight) of plant roots per acre, and some moles and other burrowing animals. Figure 2 shows main components of the soil food web.

This soil life is organized into a highly complex "food web." Bacteria and fungi feed on organic residues and plant root exudates; protozoa and nematodes feed on the bacteria and fungi; mites and insects feed on all of the above and on each other; and earthworms ingest soil and decomposing organic matter, absorbing nutrients released by microorganisms thereon. Some soil organisms also feed directly on plant roots, but in a healthy soil with good biodiversity, such pests are in the minority and pose little threat to vigorous plants.

In natural forest and prairie ecosystems, the action of the soil life feeding on each year's organic residues (fallen leaves, dung, dead plants and animals, etc) releases the nitrogen (N), phosphorus (P), potassium (K) and other nutrients needed for the next season's plant growth. In annual crop agriculture, crop harvest removes organic matter and nutrients from this cycle, while tillage and cultivation damage some components of the food web and accelerate the breakdown of soil organic matter. It is now widely recognized in both mainstream and alternative agriculture that the grower needs to replenish organic matter and soil life regularly, as well as mineral nutrients.

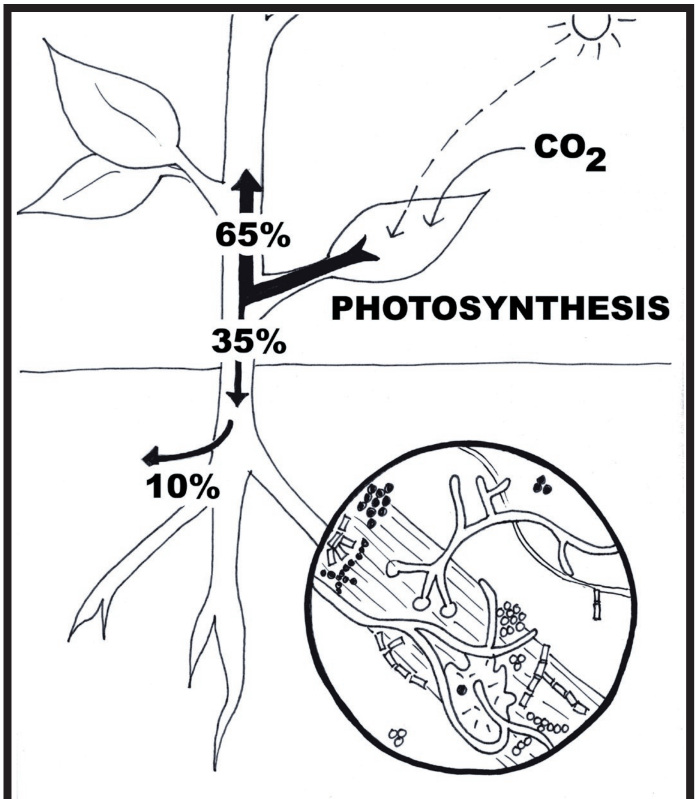

Figure 3. Plants release a significant portion of their annual photosynthetic product into the soil, supporting a vibrant microbial community in the root zone and forming a vital link between plant and soil.

Living plants are a vital part of the soil life

Living plants make a substantial contribution to soil organic matter, thereby linking soil and above-ground ecosystems. Some 25-50% of a plant's total annual photosynthate (sugars, amino acids, *etc.*, formed through photosynthesis) moves into the root system, and perhaps 10% is released into the soil as soluble *root exudates*. Root systems also slough off dead cells and fine roots throughout the season. These root deposits, which can amount to 1-2,000 lb per acre per year, support a thriving microbial community in the rhizosphere (the part of the soil adjacent to plant roots), with population densities 10-20 times that in the bulk soil. Figure 3 shows the plant-soil-life relationship.

Why would a plant "tithe" its energy to the soil in the form of root exudates? Certain organic acids and chelating agents in exudates help the plant absorb essential nutrients directly from insoluble minerals. Meanwhile, soil organisms thrive on the sugars, amino acids and other readily available food that comprise most of the exudates. The vast majority of these organisms are harmless, and *many are highly beneficial to the plant.* Some organisms enhance the plant's uptake of moisture and nutrients, while others protect the plant from diseases and other stresses. The proliferation of benign organisms in the rhizosphere crowds out and suppresses soil-borne pathogens (disease-causing microorganisms). Research findings now suggest that each plant species releases specific chemical signals that stimulate those organisms that are particularly beneficial to that plant.

One of the most important groups of soil fungi, the *mycorrhizae,* grow within plant root tissues and extend hyphae (filaments) some distance into the surrounding soil. Mycorrhizal symbioses expand several-fold the volume of soil from which plant roots can absorb moisture and nutrients, and strongly enhance uptake of P and trace minerals. About 80% of the world's plant species, including most food crops, form mycorrhizal associations, some investing 5-10% of their annual photosynthate in these beneficial fungi.

In some cases, root exudates will "wake up" pathogens that can harm the plant. This usually occurs when the plant is poorly adapted to the climate, season or soil type, when the plant has already been weakened by other stresses, or when the soil food web has been depleted through inadequate organic inputs. It may also occur when an *invasive exotic* pathogen is introduced in the absence of microbial natural enemies; sadly some forest trees are now threatened by such outbreaks.

Living plants also provide *shelter* for the soil surface. Bare soil is subject to intense heating and drying by direct sun, and to compaction and erosion under the impact of rainfall. After a few weeks' exposure, the top inch or so of soil may become a "dead zone," forming a surface crust that blocks aeration, absorption of rainfall and seedling emergence. A cover of living vegetation and/or organic mulch protects the biologically active top layers from desiccation, crusting and erosion.

More on the Benefits of Soil Life

Soil organisms consume fallen leaves, dung and other organic residues, converting them to *biomass* (more soil life), *active organic matter* (substances that can serve as food for other soil organisms), and *humus* (stable organic matter that contributes to the soil's long-term nutrient and moisture-holding capacities). *All* of these components, not just the humus, make up the Soil Organic Matter (SOM), and are vital to soil health. Cut off the influx of organic soil "food" and soil quality suffers within a couple of years, even though the humus level may not drop measurably until after decades of poor management.

In the initial phases of residue decomposition, soil bacteria and fungi capture and hold soluble nutrients like N so they do not leach into the groundwater. Protozoa, nematodes and other larger organisms feeding on the fungi and bacteria then release N, P, K and other nutrients – gradually, as the plant needs them. The constant activity of plant roots, bacteria, fungi and other soil life maintains an open, crumbly soil structure, enhances drainage and aeration, and reduces erosion.

Tired, worn-out soils are those in which the soil life is starving or is out of balance. The use of soluble fertilizers without organic inputs leaves the soil life nothing to live on. Soil fumigants, strong pesticides and anhydrous ammonia (a N fertilizer) kill soil organisms outright. Tillage aerates the soil, stimulates bacteria and accelerates the breakdown of organic matter. This releases crop nutrients and can enhance yields in the short run, but intensive tillage degrades soil quality in the long run.

The Sustainable Approach: Feed the Soil

In *sustainable agriculture* (including organic, biodynamic and ecological farming and gardening) the grower aims to *feed and protect the soil life,* so that the soil can support healthy crops and livestock. This is done through:

- cover cropping and green manuring
- organic mulches
- compost applications
- returning on-farm residues to the land
- crop rotation
- natural mineral or organic fertilizers as needed
- reducing intensity and frequency of tillage.

How much organic matter needs to be added each year? Here in the South, our warm humid climates promote rapid decomposition of SOM, perhaps 2,000-3,000 lb per acre per year. When fresh organic materials are added, only a fraction is converted into new soil organic matter, the rest being lost as carbon dioxide from the soil life respiration process. About 15-20% of the organic matter in fresh plant foliage, 30-40% for roots, 25-35% for manure, and 50% for compost remains as SOM at the end of one year. The annual loss of SOM might be replenished by growing a heavy cover crop, *or* by applying a 3-4 inch hay mulch, *or* 5-10 tons per acre of compost *or* 20 tons per acre fresh dairy manure. However, like humans and livestock, the soil life thrives best on a balanced and varied diet. Thus the best strategy is to add a *diversity* of organic inputs that *together* provide 5-10 tons/acre (225-450 lb per 1,000 sq ft) of organic matter annually. Note that this is on a dry weight basis; fresh manure may contain 25% organic matter (the rest is water); compost 25% (the rest is mineral matter and water); and dry hay 90%. A mature cover crop can add 3-6 tons organic matter per acre.

Cover cropping is the cornerstone of sustainable soil management in annual cropping systems, because cover crops feed the soil both while growing and after they are tilled in, mowed or frost-killed. They also prevent soil erosion, suppress weeds and harbor natural enemies of insect pests. Legume cover crops add N, without adding P or K. This can be advantageous, as intensive agriculture often leads to a buildup of soil P and K, but rarely N, since N surpluses leach away. For more on cover crops, see the information sheet #1-06*, Cover Cropping: On-Farm, Solar-Powered Soil Building.*

Organic mulches such as hay, straw, leaves or chipped brush simulate the natural process of autumn leaves or other plant residues falling on the ground and gradually decomposing in place. The mulch breaks the erosive force of raindrops, prevents surface crusting, and maintains a favorable environment for earthworms. Nitrogen-poor materials like straw or wood chips are less likely to tie up soil N when applied as mulch than when incorporated into the soil. Note that repeated heavy mulching, especially with hay, can cause soil K to build up to excessive levels. A cover crop, grown to the full bloom stage, then mowed or rolled to form mulch in place, does not add K in this way.

Compost is mainly an inoculant rather than a food source for soil life. A well-managed composting process speeds up the soil food web in the pile or windrow, consuming most of the readily-available "food" to generate a tremendous number and diversity of desirable soil microbes. A light application of high quality compost every few years – perhaps 1-3 tons/acre (45-135 lb per 1,000 sq. ft) helps to sustain the abundance and diversity of soil life.

In the early days of organic farming compost was recommended as *the* soil food of choice and gardeners were applying an inch or more annually. Because of the labor and other costs of making compost, such heavy applications may not be feasible at the farm scale. They can also lead to soil imbalances, especially if the compost is based partly on manure. Plants utilize N and P in a ratio of about 6 to 10 parts N to one part P, whereas the N:P ratio of manure is about 2. Applying enough compost to supply the crop's N needs will lead to a buildup of P and sometimes K. This can lead to P nutrient pollution of nearby bodies of water and cause crop nutrient imbalances that reduce quality or yield. Annual compost applications of 10-20 tons per acre (450-900 lb/1000 sq ft) can restore worn-out soils low in nutrients and soil life. Once soil P and K levels have reached optimal or high ranges, compost application should be reduced, and organic inputs provided through cover crops and crop residues.

Hot composting sanitizes certain materials such as manure and crop residues that may be infested with pests, pathogens or weed seeds. The USDA National Organic Standards require that manure be composted at high temperatures (>130°F) for at least 15 days if it is to be applied within 120 days of harvest of an organic food crop. If hot composting is not feasible, manure can be spread at 5-10 tons/acre (2-4 tons/acre for poultry litter) just before sowing a *cover* crop. The fertilized cover crop will grow extra biomass and hold most of the manure N against leaching. Note that when manure is produced on-farm as part of a fairly "closed" nutrient cycle, its application to fields is much less likely to create nutrient imbalances.

Crop rotation is an essential part of sustainable soil management and not only because it reduces pest and disease problems. Different crops make different demands on the soil, support different microbial communities in their rhizospheres, and have different root structures and depths. The more diverse a crop mix, the greater the diversity of soil life, and the less probability that detrimental soil organisms will dominate and damage one or more crops.

Developing a good crop rotation is as much an art as a science and is inherently *site specific*. Research has shown that many "rotation effects" and "companion plant" effects (both favorable and adverse) relate to the rhizosphere microflora as well as root exudate chemistry. For instance, in the Northeast, microbes that frequent the root zone of red clover seem to favor potato and hurt corn. However, soil microbial communities vary with region, climate and soil type, and this interaction might look different in our region. For the dedicated grower, careful observation and on-farm selection of crop seed for several generations can point the way to crop rotations and variety selection that take advantage of beneficial crop-microbe-soil interactions, as well as minimize unfavorable ones.

Natural mineral and organic fertilizers or soil amendments can play an important supporting role in a living soil. Just as individual people may require specific vitamin or mineral supplements to improve or maintain their health, most soils will need some supplementation. In particular, heavy-feeding, cool-season vegetables like broccoli, spinach or lettuce may need supplemental N in all but the most biologically active soils. A good soil test and proper interpretation will identify what fertilizers or amendments might be needed. For more on soil testing and amendments, see the information sheet, *How to Use a Soil Test.*

Till with care- the less the better! Judicious, soil-conserving tillage practices are critical for maintaining soil life and organic matter. This is especially true on sloping land, where conventional tillage practices can lead to the loss of 10-100 tons of topsoil annually. Such erosion also robs a disproportionately large fraction of the organic matter. Steeper slopes should be left in perennial cover such as pasture or orchard. Even in flat fields, simply converting from conventional tillage to no-till has led to net accretions of nearly 1000 lb SOM per acre per year in some southern US soils. SOM can increase a full percentage point in 20-30 years. More important, the *active organic matter* component, which is closely correlated with soil quality and productivity, rebounds faster (within a few years), in response to reduced tillage. *Continuous* no-till is not feasible in organic annual cropping systems in which herbicides cannot be used to control weeds. However, the intensity and frequency of tillage can often be reduced, and least-destructive implements can be used. Moldboard plowing, which inverts and buries the biologically-active surface layer, is particularly destructive to SOM and soil life. Repeated disking or rotary tillage can pulverize soil crumbs, kill off fungi and create hardpan. Chisel plowing provides deep tillage and relieves hardpan without soil inversion, and the new rotary and reciprocating spaders can break hardpan, incorporate residues and cover crops, and leave a good seedbed without seriously degrading soil structure. As soil structure improves in response to better care of the soil life, less and less tillage will be needed to form a seedbed.

Tillage does the least harm when the soil is moderately moist, neither dry and dusty nor wet enough to compact or stick together under the impact of the tillage implement. Subsoiling or chisel plowing should be done to a depth just an inch or so below the hardpan, and when the soil is dry enough that the shank fractures the hardpan rather than simply carving through it. Shallow ($\leq$1 inch) cultivation is useful for breaking a surface crust while knocking out small weeds and leaves most of the soil profile undisturbed. When weed pressure or other circumstances necessitate intense or repeated tillage, growing vigorous cover crops can help minimize net losses in SOM.

Soil "Metabolism" and Site-Specific Soil Care

Each soil is unique and requires a site specific approach for optimal results. Like people, some soils have a fast metabolism and others have a slower metabolism. The warmer the climate and the sandier and faster-draining the soil, the faster the soil life consumes organic matter, and the lower the "steady state" SOM levels. Thus in a sandy loam with 75-80% sand, a 2% SOM level on a soil test might reflect a healthy, well-fed soil food web and excellent soil management. On the other hand, the soil life in a clay-loam in the cooler Appalachian region works much more slowly on added organic residues, and a 2% SOM level might indicate a virtually dead soil. Under good management, this cool, heavy soil should eventually reach 5% SOM, which will in itself improve drainage and aeration.

Soil type can also inform tillage decisions. Tillage acts as a stimulant to the soil life, much like coffee for a person. Reducing tillage to the absolute minimum on the Tidewater sandy loam will help slow the burn-up of organic matter and help match the release of nutrients to crop need. In contrast, the Appalachian clay loam may benefit from appropriate non-inversion tillage prior to crop planting, in order to aerate the soil, stimulate soil life and release nutrients in a more timely fashion for crop production. No-till plantings in cool, heavy soils often cannot give optimum yields without applying soluble N. Over time, farmers learn from experience what management practices work best for their particular soils.

Resources

ATTRA offers several thorough information bulletins, including Sustainable Soil Management, Drought-Resistant Soils, Sustainable Management of Soil-borne Diseases, Compost Tea and other relevant topics. Visit *www.attra.ncat.org/soils.html* to view a listing and download bulletins.

Magdoff & Van Es, 2000. *Building Soils for Better Crops*, 2nd ed. Sustainable Agriculture Network, USDA, 240 pp. Available through *www.sare.org/publications/index.html*.

Soil Biology Primer – USDA-Natural Resources Conservation Service, Soil Quality Institute. *www.statlab.iastate.edu/survey/SQI/sqihome.shtml.*

Soil Quality – Agronomy Technical Notes. A series of information sheets on practical methods for enhancing soil life, organic matter and soil quality published by the Natural Resources Conservation Service's Soil Quality Institute, 411 S. Donahue Dr., Auburn, AL 36832, tel. 334-844-4741, ext. 177; web *http://soils.usda.gov/sqi*.

Fred Magdoff & Ray R. Weil, 2004. *Soil Organic Matter in Sustainable Agriculture*. CRC Press, 2004, 398 pp.

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