# A Fresh Look at Life below the Surface

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Too often, farming and land use practices contribute to land degradation, resulting in food insecurity and poverty. This article takes a fresh look at what is going on in the soil, especially in relation to soil organic matter and the organisms it supports; how this life in the soil is impacted by our land care practices; and how it in turn impacts the productivity of our farms.

For years, ECHO has highlighted farming practices that optimize soil organic matter (SOM) levels, as a key to improved and sustained food production. Last fall I took a week-long course on the "Soil Foodweb" led by Dr. Elaine Ingham of Soil Foodweb (http://www.soilfoodweb.com) Inc (http://www.soilfoodweb.com (http://www.soilfoodweb.com)/). The course focused on how the diversity, balance and abundance of soil organisms are foundational to healthy soil. I was amazed at the new insights and practical applications that I learned. It has helped us at ECHO understand some things we have seen on our land and suggested new approaches to how we will deal with soil and compost.

In this article, I will share the most important new insights and information that I learned that week. My goal is to help you better understand how life below ground is inter-connected with life above ground, and how to repair damaged soils through land care practices that maximize and maintain SOM and the diversity of life in what is referred to as the "soil foodweb."

Soil is often described in textbooks as rock and minerals, air, water, living organisms and decaying organic matter. Though an accurate depiction, soil biology often takes a backseat to soil chemistry and physics—soils are classified largely on the presence or absence of certain types and sizes of minerals. However, soil organisms play a huge and underestimated role in the productivity and health of soils. When a rainforest is cleared, burned, and the land subjected to annual tillage and burning, we often see this once highly productive landscape now barely able to support a maize crop. What happened? There is a growing understanding that the answers to this all too common question are found in the abundance and diversity of life hidden below the surface.

### Soil Foodweb Concept

The soil foodweb is essentially the community of organisms that live in the soil. Every agricultural field, forest, prairie, or pasture has its own soil food web with a unique set of soil organisms. Healthy soils contain massive populations of bacteria, fungi, protozoa, nematodes, soil arthropods, and earthworms (Figure 1). A teaspoon (approx. one gram) of productive soil contains between 100 million and 1 billion bacteria. It contains around 25,000 species of bacteria and 8,000 species of fungi!

Just as the plants we see above ground differ from place to place, the ratios and diversity of soil organisms change with region, climate, vegetative succession, and soil disturbance. Grasslands and agricultural fields generally have bacterial-dominated food webs while forests usually have fungal-dominated soils. Healthy, highly productive agricultural soils tend to contain about equal weights of bacteria and fungi *(Soil Biology Primer*).

Soil life is dynamic and complex. Understanding this complex soil foodweb—the life in the soil— is critical to understanding how the plant world grows and flourishes. It is the foundation for knowing how to restore damaged lands, improve agricultural production and ultimately improve the health and livelihoods of people. Soil microorganisms play a big part in supporting healthy plant life through nutrient retention and cycling, disease suppression, and improved soil structure, water infiltration, absorption, and holding capacity.

**Soil Foodweb Functions**

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**Nutrient Retention.** The ability of soil to hold nutrients is often measured by what is called cation exchange capacity (CEC)—a measure of a soil's negative charge (usually in clays and organic matter). Rarely are soil organisms mentioned with regards to nutrient retention. However, in a healthy soil foodweb, vast reserves of important plant nutrients are stored within the bodies of bacteria, fungi and other soil organisms. For example, no known organism on the planet is more concentrated in nitrogen than bacteria. Fungi are typically the second most concentrated in nitrogen (Ingham, *An Introduction to the Soil Foodweb*). Along with nitrogen they contain other critical plant nutrients—high levels of phosphorus, potassium, sulfur, magnesium, calcium, etc. Decomposition happens almost exclusively by these two sets of organisms, which in turn store nutrients from the decomposed organic matter in their own bodies, immobilizing nutrients, and thereby reducing leaching. Another example is calcium. Calcium is held incredibly tightly by fungal hyphae in the soil. Without healthy fungal biomass, calcium is easily leached through soils. The presence of decaying organic matter in soil—broken down leaves, roots, dead organisms, etc.—along with diverse populations of bacteria and fungi are key to immobilizing and storing nutrients in the soil. These nutrient-rich organisms then become the basis for the critical cycling of nutrients to plants.

**Nutrient Cycling**. As mentioned above, fungi and bacteria have considerably more nitrogen in their bodies than other organisms. The carbon to nitrogen ratio for bacteria is around 5:1 and for fungi is 20:1 (Ingham, *Overstory*#81). Nutrient cycling happens when other sets of soil organisms (primarily protozoa, bacterial and fungal feeding nematodes, micro arthropods, and earthworms) are present to consume the nutrient-rich bacteria and fungi and release nutrients in plantavailable forms. A healthy soil contains diverse species and huge populations of protozoa, beneficial nematodes, micro arthropods, and earthworms (Figure 1). For example, one gram of healthy soil can contain 1 million protozoa (Soil Biology Primer). A single protozoa, with a C:N ratio of 30:1, can consume 10,000 bacteria a day.

Because the protozoa need less nitrogen, the excess is excreted in the form of ammonium ions. The ammonium ions are held more tightly to the soil particles than are nitrate ions, the most common (and leachable) form of nitrogen in commercial fertilizers. This predator-prey relationship between protozoas and bacteria can account for 40 to 80% of nitrogen in plants. *(FAO Soil Bulletin #78*). A similar relationship has been documented with bacterial and fungal-feeding nematodes. With a consumption rate up to 5,000 cells/minute, these beneficial nematodes (unlike plant-feeding types such as root-knot nematodes) are thought to turn over nitrogen in the range of 20-130 kg/ha/yr, contributing immensely to plant available nitrogen. (*FAO Soil Bulletin #80*). These rapid interactions and countless exchanges of nutrients between soil organisms occur in root zones of plants where the highest concentrations of organisms exist (because root exudates provide food for the bacteria and fungi which in turn attract their predators— protozoa, nematodes, micro arthropods and earthworms). Nutrient cycling by these predators also occurs with other valuable plant nutrients such as potassium, phosphorus, calcium, sulfur and magnesium, resulting in a less leachable form than what is usually applied in synthetic fertilizers. Other soil organisms are also involved in more direct forms of nutrient cycling. Nitrogen-fixing bacteria convert air nitrogen into a useable plant form as they colonize roots of legumes. Mycorrhizal fungi colonize root systems of perennials such as coffee, staple grain crops as maize and sorghum, and vegetables like onions. In so doing, these specialized fungi cycle nutrients by secreting enzymes that solubilize calcium phosphate and pump the phosphorus directly to the plants, thus making an otherwise unavailable nutrient now available to plants (Ingham, An Introduction to the Soil Foodweb). Mycorrhizae also benefit crops by aiding in disease suppression and water absorption. In field trials at Zamorano University in Honduras, mycorrhizal fungi were applied at the time of planting and then one time a year thereafter. As a result, coffee production increased by 30%, plantain production by 23%, and jicama production by 35%. In addition, fertilizer use for avocado nursery tree production was reduced by 50% (Personal communication with A. Rueda).

### Improved Soil Structure, Air and Water Dynamics

As bacteria populations increase, they secrete glue-like, sticky materials that bind sand, silt, clay, and small SOM particles into micro-aggregrates (micro-clusters). Fungi, the largest known organism on the face of the earth (one organism can cover thousands of acres in a forest), bind the microaggregates to form larger soil aggregate structures, creating air and water passageways. Larger passageways (pores) are created by bigger organisms like nematodes, soil arthropods (e.g. sow bugs, termites, millipedes, roaches and soil mites), and earthworms that burrow through the soil looking for food. Earthworms "glaze" the passageways they create with a nutrient-rich and microbially active slime layer that greatly enhances water-holding capacity and soil structure (Ingham, *An Introduction to the Soil Foodweb*). Earthworms and many soil arthropods also shred organic matter, grazing on the microorganisms present, and then excreting the nutrients in a plant-available form. All these small channels and pores become a series of reservoirs and a transportation network for air, water, nutrients, roots, and organisms. Water use efficiency has been improved by as much as 50% in Australia by reintroducing missing soil biology—meaning the same amount of crop is grown with half of the water due to the improved soil structure and water dynamics that come with a healthy soil food web (Ingham, An Introduction to the Soil Foodweb).

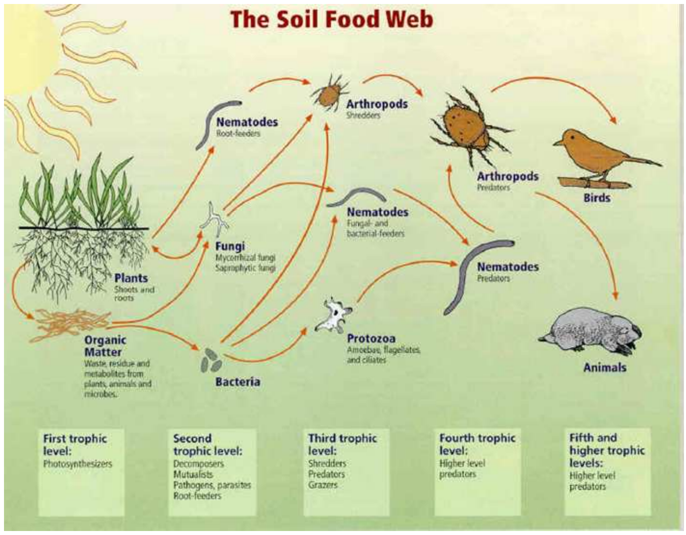


Figure 1: The Soil Food Web. From Ingham, E., et. al. 2000. Soil Biology Primer pg.5. Used with permission of Soil Foodweb, Inc. and Dr. Elaine Ingham.

**Pest and Disease Suppression.** Soil organisms break down toxic compounds in the soil, produce plant-growth promoting hormones and chemicals, out-compete and suppress disease causing organisms, and buffer soil pH. When there is a healthy balance and abundance of soil organisms in the foodweb, pests and diseases can be out competed or preyed upon. One of our worst pests in Florida (and on the ECHO farm) is the root feeding nematode. This pest has numerous predators in the food web—bacteria like Pasteuria and Burkholderia, predatory nematodes, and multiple nematode-eating fungi species such as Trichoderma (Guerena, M. Nematodes: Alternative Controls). Commercial formulations of these biocontrols are increasingly available. When a balance is not maintained (for example, if fungal diversity and biomass is reduced), micro arthropods and fungal-feeding nematodes whose main food source is normally fungi foods may attack plant roots instead. Most of us are aware of beneficial organisms like ladybugs, spiders, and wasps that attack crop pests above ground. There are far greater concentrations of organisms in the soil. Maintaining a healthy soil foodweb is essential for long-term, sustainable crop health and production. A mature healthy soil with sufficient organic matter and a full supporting cast of diverse soil organisms reaps vast untold benefits. Some excellent, highly recommended resources are listed in the online version of this EDN issue. Having laid the groundwork, we will now focus on topics that might be most relevant to your practical, hands-on work.

### Where does one begin in trying to apply the soil foodweb approach?

Understanding soil organism habitat is key. Bacteria, fungi, protozoa, nematodes, soil mites, earthworms, etc. need food, air, water, and a "home" in which to live. The suitable food depends on the species, but the base of the soil food chain is diverse bacteria and fungi breaking down leaves, stems, roots, and dead organisms. Without crop residues or some added organic matter, there is little food to feed this web of life. Consequently, soil organism populations, along with all their soil-building benefits, decline. Organic matter is the long-term food resource for bacteria and fungi.

I mentioned earlier how plant roots benefit from the air and water passageways. Those same pores provide open spaces for air and water that organisms require. Microorganism, earthworm, and insect populations decline with reduced oxygen levels, often caused by soil compaction, water logging and poor soil structure in the absence of sufficient SOM and soil life. During dry seasons, covered soils remain more moist than bare soil. Many organisms "go to sleep" during intense dry seasons, but when the rainy season comes, microbial activity immediately intensifies, resulting in nutrient cycling and flushes of available plant nutrients to newly planted crops. In terms of a "**home**," healthy soils (e.g. in a forest or no-till field) are covered by an organic litter (mulch) that provides an umbrella and sanctuary against extremes in temperature and moisture, and buffers the impact of raindrops. Below the litter roof is an amazing transportation network—an underground city—of tunnels, micro and macro pores that carry both **air** and **water**. Ideally, a soil would have 50% of its volume in pores alone, 45% mineral composition and around 5% organic matter (comprised of decaying matter and living organisms). (Coder, K.D. Soil Compaction and Trees) Usually, soil habitat that is good for roots is also good for soil organisms.

**How is this soil foodweb habitat impacted by farming practices?**

The habitat and food resources for soil biology improve when there is 1) minimum disturbance of soil; 2) maintenance of a soil cover; 3) rotation of crops; and 4) avoidance of excessive fertilizer and pesticide use (ACT Info. Series No. 1). Cover cropping, leaving crop residues, and planting diverse polyculture systems also positively impact the soil biology.

Conversely, tillage operations 1) infuse tremendous oxygen into soils resulting in rapid decomposition of SOM, 2) slice and dice delicate, thread-like fungi resulting in the soils being dominated by the smaller single-celled bacteria, 3) damage soil structure (significantly reducing arthropod and earthworm populations), and 4) often cause hardpan, a compaction zone created by the smearing action at the bottom of the plough, that reduces root growth, oxygen and water infiltration into lower soil levels. Most ploughed fields have a period during which they are bare and sun-exposed. To various degrees, the land becomes subject to erosion by water and wind, hot surface temperatures, and sealing from the "hammering" impact of raindrops that results in water and soil runoff. Continued mono-cropping also reduces SOM levels and soil biology.

Removal of crop residues by burning is especially injurious to soil biology. Many soil organisms are killed and the food for the decomposers is eliminated. Once again, the ground is left bare and exposed. Fertilizer is well-documented to positively impact yields. However, fertilizer contains a mixture of salts, and damages soil biology if applied in too high concentration. Also, nitrogen fertilizers, such as urea and ammonium phosphates (e.g. MAP and DAP), are converted rapidly into nitrate by bacteria, resulting in a release of acids and an increase in acidity at the soil surface (FAO Soil Bulletin #80). If soil acidity is already a problem, both crop production and the diversity of soil biology may be reduced (at pH values less than 5). Pesticides, most notably broad-spectrum and fumigation types like methyl bromide, kill both good and bad life in the soil.

**Why are aerobic conditions (plenty of oxygen) so important in the soil?**

This is directly related to soil organism habitat. All kinds of problems arise when soils become compacted or waterlogged and anaerobic (i.e. oxygen levels become very low). Soils become compacted when aeration-pores (macro-pores) are destroyed and soil volume is reduced, resulting in reduced oxygen levels (Coder, K.D.). Anaerobic conditions (beginning at less than 16% oxygen levels in soils) favor an entirely different set of organisms, many of which are disease-causing bacteria and fungi, e.g. Pythium and Phytophthera root rots. Dr. Elaine Ingham writes, "Anaerobic bacteria attack and consume fungi in these low oxygen conditions. Disease causing fungi are benefited by anaerobic conditions, either because they no longer have competition from the beneficials, or because they require anaerobic conditions for best growth. In either case, anaerobic conditions select for and allow the disease-causing organisms to "win" in the fight for plant tissues." (*The Soil Foodweb Approach*).

Another serious problem in anaerobic soils is that some plant nutrients under low oxygen conditions can be reduced (chemically changed) into forms that volatilize into the atmosphere and thus become useless to plants and soil organisms. Nitrogen contained in inorganic compounds, for example, can be changed into ammonia that evaporates into the atmosphere. The anaerobic decomposition of manure in feedlots and poultry houses results in massive losses of valuable nitrogen in the form of ammonia gas, not to mention the noxious smell. The same is true for sulfur and phosphorus, which are respectively released as hydrogen sulfide (rotten egg smell, resulting in a black layer in soil that is toxic to plant roots) and phosphine gas.

Organic acids (e.g. acetic, valeric, butyric acids) are produced under anaerobic conditions and lower the pH. This may injure soil biology and make certain nutrients less available. Other toxic substances such as alcohol, formaldehyde, and phenols are also produced in anaerobic soils and compost. These are capable of destroying membrane functions in soil organisms.

There are also direct implications for plants as they become confined to a "steadily diminishing aerobic layer." Dr. Kim Coder in *Soil Compaction and Trees* explains, "… as the anaerobic layer expands toward the surface, the physical space available for living roots declines. The consequences of having smaller volumes of [space for roots to grow means that] roots and their resources are subject to much greater fluctuation in water, heat loading, and mechanical damage. Drought and heat stress can quickly damage roots in this small layer of oxygenated soil." Weeds—which typically have shallow root systems and short life cycles—can be increasingly favored under these conditions.

### Can damaged soils be restored?

Yes, if farming practices are changed to favor increased SOM and soil biology. In addition to what has already been mentioned (minimizing soil disturbance, leaving crop residues, keeping the soil covered, practicing rotation, using pesticides and fertilizers in moderation), soil biology habitat can be restored. Missing soil biology can be returned to fields and gardens through quality compost.

### What is meant by quality compost?

Compost is the result of aerobic decomposition of organic matter by bacteria and fungi. However, contrary to the common current understanding of compost, compost is much more than a fertilizer with nutrients, enzymes and hormones. In addition to all these, *quality compost is an inoculum* of beneficial soil organisms foundational to healthy soils. Quality compost is the outcome of a diverse, active microbial population.

**Explain the compost process.**

Think of compost like making bread. The soil organisms, then, are the yeast, and the dried grass stalks, leaves, and manure are the flour, eggs, and sugar. The right "food" for the organisms, the right conditions, and the right biology needs to be present. Bacteria and fungi rapidly consume the high concentration of simple sugars and proteins in compost piles, generating heat as they grow and multiply at enormous rates As those "super" foods are consumed, microbial activity and multiplication can become so great that oxygen levels are depleted, requiring the pile to be turned to keep it from becoming anaerobic. The time to turn a pile can be determined by carefully monitoring the temperature inside the pile. If possible, check temperatures daily. The temperature inside the pile should not exceed 160°F (71°C). In the absence of soil thermometers, farmers may need to be trained by feeling the temperature of a long stick placed in the pile. A pile may need to be turned four or five times if a lot of high nitrogen foods are present or only once or twice if less nitrogenous material is used. Try to achieve 135°F (57°C) for at least three days, to kill seeds and pathogens.

Once the high concentrations of simple foods are consumed, compost piles stabilize while the more complex compounds like fats, cellulose and lignin continue to be decomposed. A stabilized pile means a healthy foodweb is present with minimal nutrient loss due to leaching or volatilization. Maximum diversity is achieved after about six months. Compost can be stored well over a year, but biology and nutrient levels then begin to decline.

Maintain moisture levels around 50%. This is monitored by the "squeeze test." Grab a handful of soil and squeeze. One or two drops of moisture should come out. If you are working on a compost pile during the rainy season or extreme dry season, the pile may need to be covered to achieve proper moisture levels. Too much water will fill air pores, cause anaerobic conditions, and negatively impact microbial activity.

In the ideal compost pile, no more than 5% of the particles in the pile should exceed one inch (2.5 cm) in diameter, but varying textures and sizes are important to provide the initial aeration pores. It requires a lot of machete work to create small size materials (unless, of course, you have a chipper or lawn mower to run over the material), but you will be rewarded for your work. When the compost process is finished, you should be unable to recognize the original plant material (Ingham, *An Introduction to the Soil Foodweb)*

**How do you know what type of compost to make?**.

According to Dr. Ingham, "There is a 'best foodweb' for each combination of crop type, climate, region, soil type, amount of organic matter and water supply." (*The Soil Foodweb Approach*) Tree crops in general prefer fungi-based soils, vegetable crops like brassicas (e.g. cabbage, collards and broccoli) and carrots prefer more bacteria-based soils, and field crops like maize and wheat prefer soils that have about equal amounts of fungi and bacteria (Ingham, *The Soil Foodweb Approach*). Maximizing diversity and selecting for organisms best suited to crop needs is achieved by carefully choosing the types and ratios of foods added to the compost pile. Bacterial foods are generally green, with simple sugars, high in nitrogen and easily digested. These include manure, legumes, thin succulent stems, food scraps, coffee grounds, green grass and leaves. Fungal foods are usually brown plant materials that are woody or fibrous like dried corn stalks, dried weeds, sawdust, straw, shredded newspaper and wood chips.

For a bacteria-based compost, on a volume basis: mix 25% high-nitrogen materials (manure, legume plants), 45% green materials (diverse materials of grass, leaves, succulent stems), and 30% woody material (brown plant material). For fungal compost, mix 25% high-nitrogen, 30% green, and 45% woody material.

Material is added in these ratios and this order. For example, if making a bacteria-based compost for growing cabbages, you would take one shovelful (25%) of high-nitrogen material like manure. Follow this with two shovels (45%) of green matter like fresh cut grass or finely cut succulent weeds. Next, a heaping shovel (30%) of brown woody material like coarse grass or weeds is added. This pattern—high-nitrogen, green, brown—is repeated over and over. With larger amounts (e.g. wheelbarrow or larger), it is best to mix the layers.

**What are some different compost methods?**

1) *Thermal composting* is a quick approach, used to produce quality compost in as short as one month. This is most often used for commercial scale production. Usually a high-nitrogen recipe is used to generate the necessary heat for killing off weed seeds, plant and human pathogens, and plant-feeding nematodes. Once made, the pile quickly heats up beyond 135°F (57°C), the temperature necessary for death of most weed seeds and pest and disease organisms. When the pile approaches 160°F (71°C) (usually on day two or three), it is turned (i.e. contents thoroughly remixed) and the cycle repeats itself. This is done four or five times, and the time between turns steadily increases until the simple sugars and proteins are consumed and the temperature no longer spikes. The piles are often constructed in long windrows and must be a minimum of 3 feet (1 m) tall to generate adequate heat. Ideally, aim for 5 feet (1.5 m), but make piles no taller than 8 feet (2.4 m).

2) *Worm composting* is a "cold-composting" method that depends on worms to turn the pile as they shred organic matter and consume bacteria and fungi. Their nutrient rich waste (called casts) is left behind, and the organic matter reappears in smaller fragments inoculated with microorganisms from the gut of the worms. This process increases microbial activity as the organic matter surface area increases. Large populations of worms are needed to produce significant amounts of compost. Worm composting is usually done in confined structures (large crates, raised beds) and in cool, shaded areas. Worms prefer a higher moisture content (60-70%) than standard compost piles (approx. 50%). Food comprising 50% green and 50% brown material (often shredded newspaper) is usually applied in thin layers at the surface. Frequency and amount depend on worm populations. Too much food in the bin can result in anaerobic conditions. Worm composting does not kill seeds, so avoid adding weeds with seeds.

3) *Small back-yard composting* is a type of thermal composting more appropriate for farmers who do not have soil thermometers and may not need to produce compost in such a short time. This method requires a lower nitrogen ratio and minimal turning. The recipe is 10% high-nitrogen, 45% green, and 45% woody. The pile should still achieve at least 135°F (57°C) for 3 days to kill seeds and pathogens. When it reaches 160°F (71°C), the pile should be thoroughly turned. With the lower nitrogen ratio, the pile is turned usually only once, but several months are needed

to achieve quality compost. The back-yard compost method can be made in long windrows as well. We are currently experimenting with this method at ECHO. Our main challenge thus far is finding enough high nitrogen and green material to get the temperature above 135°F for more than 3 days. It is possible to add small quantities of urea or ammonium nitrate to piles without harming soil biology to get the needed high-nitrogen percentage up to kill off the weed seed and pests and pathogens, but we do not know the recommended rate.

**How can you tell if a compost pile has become anaerobic?**

Color and smell are excellent indicators. Compost should be rich brown, not black. It should have a pleasant earthy smell. Rotten-egg, sour milk, putrid or vomit-like smells are the result of acids formed under anaerobic conditions. Hopefully, in finished compost, you will see thick fungal strands growing through the pile.

**What can you do to maximize soil organism diversity in the compost process?**

At the initial construction of a compost pile, beneficial organisms can be added for multiplication, just like yeast in dough. Numerous products can be purchased and/or collected locally to improve soil and plant health. For example EM, or effective microorganisms, are a set of beneficial facultative anaerobes (can grow in both aerobic and oxygen-limiting conditions) that provide a host of well-documented benefits to crops. When anaerobic conditions exist, these facultative anaerobes can out-compete disease-causing anaerobes. Smallscale farmers who cannot afford expensive inputs can add material from other quality compost sources, as well as numerous soil samples collected from healthy landscapes, both locally and afar. At ECHO, I have already added soil samples from various forest soils to our compost pile. Maximize diversity!

Multiple species of endoand ectomycorrhizal fungi can be added to finished compost. Endo-mycorrhizae grow within root cells and are associated with grasses, row crops, vegetables, and shrubs while ecto-mycorrhizae grow on root surfaces and are commonly associated with trees. Both greatly help in disease suppression and water and nutrient uptake, especially phosphorus. (*FAO Soil Bulletin*#80) Because the mycorrhizae spores are killed in the thermal compost process and are also consumed by worms, they should be added at the end of the compost process just before field application (Ingham, *An Introduction to the Soil Foodweb*).

A company called Mycorrhizal Applications (http://www.mycorrhizae.com/), Inc sells mycorrhizae spores, and gives referrals if they themselves are unable to supply the product due to restrictions (http://www.mycorrhizae.com (http://www.mycorrhizae.com/))

**How can you really know whether or not there is adequate diversity and numbers of soil organisms in your soil or compost?**

Laboratories can test soil and compost to determine the actual soil biology present, but the cost (several hundred dollars, due to labor intensive microscope work) make it impractical for most readers of EDN. However, a commitment to farming practices that increase SOM will provide the habitat needed for diverse and abundant soil organisms. Farmers can then focus on maximizing diversity through shared and collected soil and through production of quality compost.

### How much compost do I need to make?

This will take time and experimentation to determine, as every field and farming operation is different. Rates vary from 1 to 10 tons/acre/year for vegetable, grain, orchard, and pasture applications. Remember, compost is both a fertilizer and an inoculum, and remember that the primary benefit at modest levels is the inoculant you are adding, not the fertilizer. This makes field applications a real possibility, whereas previous thinking suggested that this may have been impractical. Ideally, apply compost at least once a year, well in advance of planting.

### What are some compost application methods?

There are many ways to apply compost. It is great as a starter media for vegetable transplants or nursery stock, if weed seeds can be eliminated. If available and possible, it is especially advantageous to mix in mychorrizal spores selected for the target crop to your potting soil. Another simple, but effective method of using compost is mixing maize seeds or potato seed pieces with compost in a bag just before field planting to inoculate them with good soil biology, just as one would inoculate legume seeds with selected nitrogen-fixing bacteria before planting. Compost can be applied in furrows or placed on top of a vegetable bed in a layer up to two inches (five cm) deep. At ECHO, we are experimenting with applying 250-500 grams of manure, worm compost, and/or regular compost in holes directly below a vegetable transplant and maize planting station. So far, the results are promising. In our most recent trials we have been substituting worm compost in place of fertilizer, placing the compost below the surface and laying down a thick mulch (e.g. cut vetiver grass, wood chips, leftover stems and leaves from our goat feed) at the surface of most all our plantings. This targeted below-plant application of compost and surface mulching has resulted in decent vegetable (carrot, squash, tomato, and bean) yields and is consistent with the successful maize production system promoted in southern Africa called Farming God's Way, which will be featured in an upcoming EDN issue.

### How does the soil foodweb relate to acid soils, aluminum toxicity, and phosphate fixation?

Many soils, especially in the southern tropical belt, tend to be acid by origin (Haynes and Mokolobate, 2001). This often results in aluminum toxicity and limited phosphorus availability. The standard recommendation is to use huge amounts of lime and phosphorus based fertilizers to achieve satisfactory crop production. Such inputs are expensive and out-of-reach for small-scale farmers and high rates of lime are injurious to soil fungi. There are, however, numerous examples where conservation farming methods have increased soil organic matter, reduced Al toxicity and increased P availability (Haynes and Mokolobate, 2001). One explanation is that organic matter, particularly humic substances that have been created through many different soil organisms, has an enormous capacity to interact with metal ions, oxides, hydroxides, mineral and organic compounds forming water soluble and water-insoluble complexes. Aluminum is complexed with these humic substances, rendering it nontoxic to crops and positively influencing nutrient availability (*FAO Soil Bulletin* #80).

### What are the implications (of these microbial dynamics) for reforesting denuded hillsides?

At the beginning I mentioned a scenario where a tropical forest was cleared for an agriculture field, but after one or two seasons, the land could barely support a maize crop. So what happened? For centuries, there existed a dynamic forest system that never once needed any fertilizer, lime, or other chemical input. Under the forest's tall giant canopies, in the deep shade and protection of leaf litter, the soil was teeming with an abundant, diverse balance of soil organisms. Nutrients at the surface were rapidly recycled; complex humic substances were formed; an extensive mychorrizal fungi biomass was present; and countless other species were present to perform all the necessary and important life-supporting functions that exist in mature forest systems.

With the disappearance of the forest, removal of the litter layer, and rapid oxidation of the remaining organic matter due to damaging agricultural practices, the number and diversity of soil organisms dramatically declined. Their habitat and food were gone. The soil remained exposed to the sun and impact of rain, further limiting the potential for restoration. With declining organic matter and soil biology, and with continued bad practices of fire, tillage, and exposure, the ground became increasingly compacted. Anaerobic conditions developed, resulting in further soil acidification and toxic compounds being produced. With the biology largely missing, the soil became defined by the leftover mineral composition of the soil—low CEC, low pH, low water-holding capacity, low fertility, etc. Chemical inputs now become the norm and a devastating cycle of dependence develops. Hope is described as the next fertilizer or lime subsidy.

If we only knew that life below the surface is what supports life above the surface, many would find that in a short time, damaged lands can be restored to their productive potential without expensive inputs. Land care practice would change to be truly that, care for the land, patterned after the marvelous and elaborate design in the meadows and prairies and forests, that causes them to flourish.

### Final thoughts

During the week-long course, Dr. Elaine Ingham claimed that of the over 100,000 soil samples she has analyzed from around the world, "there [was] no shortage of any mineral in any soil necessary for plant growth." Most modern soil tests only reveal the soluble and/or exchangeable forms of nutrients present, not the total extractable nutrient pool. These extractable forms of nutrients, which can exist as enormous reserves in soil, are often only made available through the soil organisms. When soil biology is missing, then soils will largely be defined by the chemical and physical structure and texture.

What I have learned about the soil foodweb strongly indicates that the measure of a healthy soil should include the presence of organic matter and of a full supporting cast of bacteria, fungi, protozoa, beneficial nematodes, worms and arthropods. Organic matter is the food. Soil biology is the life that makes it happen. The remedy for so many damaged agricultural lands, especially in the tropics where solar radiation is intense throughout the year, is to keep the soil covered, minimize tillage, practice rotation, maximize organic matter and reintroduce needed soil biology to bring breath and life back into the soil.

**Life** in the soil is deeply connected to **life** above the soil. I marvel how God uses what appears to be the small (very small in the case of bacteria and fungi) and lowly things (bugs and worms) of the world to accomplish mighty things such as the growth of a giant redwood tree or tropical rainforest. This is great news—it is possible to move toward a diverse soil food web, in which microbes, insects, and worms fulfill their role in the creation to improve soils to support abundant life above the ground.

**Selected References and Recommended Publications**


African Conservation Tillage Network—ACT *Information* _Series_ No. 1-9. These short publications are extremely welldone and I highly recommend those working with farmers to take the time to read this material. Available on-line (English). http://www.act-africa.org/

Coder, K. D. 2000. *Soil Compaction & Trees: Causes, Symptoms & Effects*, University of Georgia. I found this publication very helpful in explaining the finer points of soil compaction and how serious a problem it is. Available on-line (English).

*Conservation agriculture: Case studies in Latin America and Africa*, FAO Soil Bulletin 78. Lots of helpful case studies with an incredible appendix about the soil foodweb. Available online (English). http://www.fao.org/DOCREP/003/Y1730E/y1730e00.htm#… (http://www.fao.org/DOCREP/003/Y1730E/y1730e00.htm#P1_0)

Cooperband, L. R. 2000. *Composting: Art and Science of Organic Waste Conversion to a Valuable Soil Resource. Laboratory Medicine*. Vol. 31:283-290. This is a good general guide about composting available on-line (English).

Guerena, M. 2006. *Nematodes: Alternative Controls*. http://attra.ncat.org/attra-pub/nematode.html. This particular article (in English) was helpful for the portion on nematodes. ATTRA is an incredible source for information related to sustainable agriculture. This has been one of the most useful websites for help in managing ECHO's farm. http://attra.ncat.org/ (website includes information in English and Spanish)

Haynes, R.J., Mokolobate M.S. 2001. "Amelioration of Al toxicity and P deficiency in acid soils by additions of organic residues: a critical review of the phenomenon and the mechanisms involved." *Nutrient Cycling in Agroecosystems*. I included this because I used it as a reference for the portion on soil acidification. Though I only had access to the abstract, I still found this brief summary very helpful. Available on-line (English). http://www.springerlink.com/content/g52v9p31n67285… (http://www.springerlink.com/content/g52v9p31n6728582/)

*The Importance of Soil Organic Matter: Key to Drought Resistant Soil and Sustained Food Production, FAO Soil Bulletin* 80. This is one of FAO's conservation farming publications. It is not as detailed as I hoped, but still contains useful information emphasizing SOM from a reputable source. Available on-line (English). ftp://ftp.fao.org/agl/agll/docs/sb80e.pdf

Ingham, E. *The Soil Foodweb Approach*. This is the official Soil Foodweb, Inc. website (English). It is a good place to start for information and see when future courses are taught. http://www.soilfoodweb.com

Ingham, E. *The Overstory*#81, The Soil Food web: Its Role in Ecosystem Health. This is a concise summary of the soil food web approach. Available on-line (English). Overstory #81, Soil Foodweb (http://www.agroforestry.net/overstory-back-issues/182-overstory-81-the-soil-foodweb-its-role-in-ecosystem-health)

Ingham, E. 2002. *An Introduction to the Soil Foodweb*, CDs 1 and 2. Excellent audio recording of Elaine teaching, available through web-site.

Ingham, E. 2001. *The Compost Foodweb*. CDs 1 and 2. Excellent audio recording of Elaine teaching, available through web-site.

Soil and Water Conservation Society (SWCS). 2000. *Soil Biology Primer*. Rev. ed. Ankeny, Iowa: Soil and Water Conservation Society. This short book can be purchased or read on-line. It explains well the different roles and functions of the major soil organism groups. Extremely well done USDA publication (in English). http://soils.usda.gov/sqi/concepts/soil_biology/biology.html

 