



Nature Helping Science Restore the Natural Process of the Soil Food Web®

SOIL ECOLOGY & THE SOIL FOOD WEB

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Introduction

With Water becoming more and more of an issue in the Western United States, Landscapes are increasingly being targeted as one of the main culprits of water waste. The problem lies with the absolute necessity of shade and green spaces in our Southwestern High Desert Cities. Gravel is simply not a viable answer for converting or creating low water landscapes as the main criteria of function is lost. Who wants to sit in a gravel yard on a typical hot, sunny summer day? The construction of shade structures cannot replace the cooling benefit of trees over the same square footage. The second problem lies with our historical use of fertilizers to help prop up the health of our Trees and other landscape materials. You will learn by reading this paper that fertilizers result in growing all plants hydroponically or with water. In other words, the only way to keep fertilizers available to plants is to keep the nutrients in a soil solution of water with the soil always well hydrated. This contradicts what happens in nature and how plants acquire nutrients in a natural **Soil Food Web Cycle**. You cannot convert to lower water usage in a landscape and continue to use Fertilizers at the same time. Please read on and learn how the Natural Process of Nature works and how we can help you build a truly **'Ecologically Sound Landscape.'**

Why We Need a Soil Food Web

Plants depend on beneficial soil organisms to help them obtain nutrients and water from the soil, to prevent nutrient losses, to protect them from pathogens, and to degrade compounds that could inhibit growth. Each class or type of microorganism plays unique roles in these processes. Soil organisms create a living, dynamic system that can do all these things, but must be managed properly for best plant growth.

A spoonful of healthy soil contains millions of beneficial microscopic organisms of various kinds that perform vital "functions" in the root zone that can bring plants to health, if soil conditions are managed in ways that allow the microbes to live and work. These organisms include beneficial species of bacteria, fungi, protozoa, microarthropods and nematodes that never cause disease or become pests. In healthy soil ecosystems, while nutrient cycling and productivity increases, nutrient loss is minimized. What makes this possible is the complexity of the soil food web. The greater the interaction of decomposers, their predators, and the predators of those predators the more tightly nutrients cycle from stable forms in soils to plants, and back again (Coleman et al, 1985; 1992).

Effects of Pesticides, Herbicides and Fertilizers

Pesticides, which include plant killers (herbicides), bug killers (insecticides), fungi killers (fungicides) and bacteria killers (bactericides) also kill related and often beneficial organisms. While each application may impact only a few species, the cumulative effect of multiple and repeated pesticide applications is a reduction in the numbers and diversity of soil organisms.

Fertilizers do not kill many soil organisms directly. The effect of high levels of nutrients from fertilizers is that the plant is less likely to form beneficial associations with soil organisms like mycorrhizae and rhizobium. Since the plant is less able to obtain water and nutrients without their help, it becomes dependent on continuously high levels of nutrients and water. The plants are less able to tolerate water stress or low nutrient levels. Thus the landscape suffers unless both are continually applied.

Organic fertilizers, like composts and manure, have nutrients stored in the organic matter. The beneficial microorganisms are fed as the nutrients are slowly released to plants. Adding inorganic fertilizers supplies nutrients but does not feed microorganisms. The microorganisms decline in numbers and, since they aren't there in sufficient numbers to release nutrients stored in organic matter, the plants become even more dependent on repeated applications of fertilizer nutrients.

And if you don't have many beneficials then you are left with relatively high numbers of pathogens, because only the plants are present for them to feed on!

To correct this problem you need to inoculate the soil with the beneficials to make sure they are there, and then put back the food in those systems to grow and maintain these organisms.

What Happens to Soil Nutrients Without a Functioning Food Web?

When we add fertilizers containing N, some of the fertilizer will dissolve and diffuse directly to the roots and be taken up, helping the plant to grow. Much of the excess N is in danger of being leached away. Without large numbers of soil organisms that can "capture" excess N, retention in the soil doesn't happen and the nutrients can be leached into the groundwater. Other nutrients, like phosphorus, iron, manganese, zinc & copper, are rapidly converted into insoluble (less available) forms.

The solution: Protect the nutrients and cycle them! Apply the microbes that make up the food web and feed them. In return they will retain and cycle plant nutrients. And they will also do a great deal more.

What Happens to Plants Without a Functioning Soil Food Web?

Disease organisms are not suppressed; and therefore multiply and threaten plants. The loss of symbiosis with soil microorganisms results in reduced ability to take up water and nutrients. Not only are plant growth adversely affected but resistance to temperature and moisture stress is reduced as well.

The lasting solution...

Restore the health of the soil ecosystem, the soil food web.

A highly populated and balanced soil food web will:

1. Create humus by decomposing organic matter
2. Improve soil structure by binding particles together and creating microaggregates
3. Protect roots from diseases and parasites
4. Retain nitrogen and other plant nutrients
5. Slowly release retained nutrients to the plant
6. Produce enzymes and hormones that help plants grow and resist stress
7. Decompose pollutants that enter your soil

To do all this, the following types of organisms need to be present in sufficient numbers:

First Level

Soil organisms which capture nutrients before they are lost.

The soil bacteria and fungi form the first level of organisms - the consumers of organic matter and leftover nutrients. Nitrate nitrogen and some other nutrients can leach out and be lost unless they can be held in soils until the plant needs them. When bacteria and fungi multiply they gather up free nitrogen from the soil and convert it to protein in their bodies. Nitrogen in this form cannot be leached away or be lost as a gas.

Bacteria - the "Cows" of the soil.

Total bacterial numbers range between 5 million and 500 million per teaspoon of soil in agricultural soils, and between 20 million and 2 billion in forest soils and highly productive garden soils.

Soil bacteria are like cows in soil. They tackle the easy to decompose materials, like green yard waste and manure. These materials contain most of the nutrients. These organisms need a lot of nitrogen, and they grab it quickly (more quickly than plants!) so they often go after some of the residual nitrogen from fertilizers, if present.

They retain nutrients like N, P and S. in the soil as bacterial biomass. Productive garden soil should contain more bacteria than any other kind of organism. Bacterial waste products that cannot be broken down any further become soil humus (humic substances)

Fungi - The Goats of the Soil

A single teaspoon of healthy soil can contain up to 40 miles of fungal hyphae! The soil fungi consume the tougher, hard to decompose materials, like straw, pine needles, bark and wood. The nutrients from these types of organic matter are not lost by leaching or other processes, but are incorporated into the fungal biomass.

Just like bacteria, fungal waste products and materials that cannot be broken down any further become soil humus.

Nitrogen Retention and Organic Fertilizers

Nitrate is the most mobile (leacheable) form of nitrogen, followed by ammonium. Chemical fertilizers contain nitrogen in these forms. Even the N in urea is quickly converted to ammonium-N by the urease enzyme, which is naturally present in soils. The least mobile form is organic nitrogen in biomass and inside microbes. One advantage of organic fertilizers is that most of the nitrogen and other nutrients are bound as part of the biomass. Then, when microbes decompose the biomass, most of the N is incorporated into microbial biomass.

At this level nitrogen and other nutrients are "tied up" from loss by leaching (in bacterial and fungal biomass), but also are tied up away from plants. If there were no predators of the bacteria and fungi, the plants would not be able to get at that nitrogen. Fortunately, the soil food web contains the predator trophic level.

The Second Level

Organisms That Recycle Plant Nutrients

Once nutrients have been retained by bacteria and fungi, other kinds of soil organisms can be encouraged that feed on the bacteria and fungi. These predator organisms form the second level of the soil food web -- include protozoa, beneficial nematodes, and microarthropods. As these organisms feed on the bacteria and fungi, the excess nitrogen and other nutrients are metabolized and released back into the soil, at gradual rates that supplies plants with a steady diet of nutrients all season.

Protozoa

There are from 100 to 100,000 protozoa per teaspoon of soil. The numbers vary widely among soils, but the more the better. Protozoa -- flagellates, ciliates and amoebae, one-celled, highly mobile organisms that feed on bacteria and on each other. As protozoans eat bacteria, N and other nutrients are released, and are now available for plants to absorb. This is the primary source of mineralized N on grass and garden soils.

Nematodes - Good & Bad.

A healthy soil has from 5 to 500 beneficial nematodes per teaspoon of soil. Nematodes in soil range in length from about 0.25 to 5.5 mm (1/4 inch) long. A bacterial-feeding nematode consumes about 100 bacteria per day, and a fungal-feeding nematode consumes about 80 feet of hyphae length per day. Nematodes need less nitrogen and other nutrients than the bacteria and fungi, so the excess is released as they feed, making these nutrients available for plant growth. Well-made compost that has been cured for long periods under optimum conditions contains beneficial nematodes.

Nematodes that are pests feed on plant roots, often carrying in diseases too. However, a healthy soil has predator nematodes and microarthropods that eat these nematode pests. In addition, fungi trap nematodes then dissolve them for consumption. In addition, by having healthy colonies of bacteria and fungi that surround root systems, this makes it more difficult for root feeding nematodes to find the roots and attack them.

Microarthropods

A teaspoon of soil has several species of microarthropods. These organisms have several functions. They feed on fungi, releasing the excess nutrients locked inside the fungi. They also feed on nematodes, most importantly the plant-feeding nematodes. Microarthropods also chew the fresh (but dead!) organic material - leaves, stems and roots, into smaller pieces, making it easier for bacteria and fungi to decompose. In addition arthropods carry around an inoculum of bacteria and fungi that they apply to plant material as they chew on them!

The Top of the Soil Food Web

There are even higher-level predators, such as millipedes, centipedes and earthworms! These keep the nematodes and protozoa from exploding in population and over-eating the fungi and bacteria. The net effect to plants is a slow, sustained release of nutrients, with little danger of losses by leaching.

The insects and earthworms are preyed upon by rodents and birds, and these in turn may be eaten by mammal predators like foxes and raccoons -- for a total of six trophic levels, all starting from plant-produced organic matter!

SPECIAL SOIL ORGANISMS

Earthworms!

Earthworms will not colonize soils to any significant degree unless sufficient organic matter is present, because they digest the organic material present in the soil they eat. Earthworms create channels for water, air and plant roots as they tunnel through the soil. They also release much of the nutrients locked into the organic matter they eat. Many pesticides and the salt effect from heavy fertilizer additions kill earthworms.

Symbiotic Bacteria

Mutualistic bacteria and fungi can be critically important for plants. For example, the nitrogen-fixing bacterium on legume plants. The plants feed the bacteria that inhabit the roots, and the bacteria capture atmospheric nitrogen and convert it to plant usable forms. In fact, the whole landscape ecosystem benefits when the high-N organic matter of legumes is decomposed, and the N is later released.

Studies have also shown that if soil nitrogen levels are high, due to chemical fertilizer additions, the plants will **not** form the symbiotic association with N-fixing bacteria. Because of this, they become dependent on regular nitrogen fertilization to grow.

Free-living Nitrogen Fixers

Free-living nitrogen fixers, like blue-green algae, and several species of bacteria, can capture atmospheric nitrogen and convert it into plant-usable forms. For the support of the bacteria a good source of organic matter in the soils is needed. This support may come indirectly from plant root secretions. Regular organic matter additions to soils will also help maintain these populations.

Mycorrhizae

Vesicular-arbuscular mycorrhizal (VAM) fungi are very important for most plants because they help plants scavenge for water and nutrients in the soil. Studies have shown, so far, that over 90% of all plant species form a symbiotic association with mycorrhizae in natural soils. After the mycorrhizae "infect" the plant roots, the plants feed the mycorrhizae. The mycorrhizae benefit plants by sending mycelial threads far out into the soil, penetrating the spaces too small for plant roots. These threads capture water and plant nutrients that were not available to plant roots. The greater nutrients use efficiency that result means that fertilization requirements go way down. In addition, your plants can tolerate drought a lot better if they are mycorrhizal, because mycorrhizae also bring in water.

A number of studies have indicated that the lack of mycorrhizae fungi can result in poor plant growth, due to the reduced ability to survive under nutrient and water stress conditions. In situations where soil degradation has been severe, it may not be possible to maintain a successful planting of several plant species without mycorrhizal inoculation.

Studies have also shown that if soil nutrient levels are very high, due to regular chemical fertilizer additions, the plants **will not** form the symbiotic association with VAM fungi. Because of this, they become dependent on regular and frequent watering and fertilization to continue living and growing.

The presence of at least 1 to 5 spores per gram of soil is adequate for most planted areas. When the number of spores falls below one per gram, then inoculation of VAM spores generally results in positive effects.

A new and even more exciting discovery in recent years is the real soil builder – Glomalin. When plants are Mycorrhizal, production of Glomalin in the soil occurs. Sara F. Wright, a soil scientist with the USDA's **Sustainable Agricultural Systems Laboratory** in Beltsville, Md., discovered glomalin in 1996 and named the substance after Glomales, the taxonomic order of the fungi that produce the sticky protein.

The Glomus genus of Mycorrhiza fungi living on plant roots, use the plants carbon to produce glomalin. As the roots grow, glomalin sloughs off into the soil where it acts as a "super glue," helping sand, silt and clay particles stick to each other and to the organic matter that brings soil to life. It is glomalin that helps give good soil its feel, as smooth clumps of the glued-together particles and organic matter flow through an experienced gardener's or farmer's hands.

How Soil Organisms, Control Root Diseases and Parasitic Nematodes.

A healthy soil that contains a broad diversity of microbial types contains species that kill, inhibit or suppress the kinds of fungi and bacteria that cause root rots and the species of nematodes that attack roots.

Up to one-third of the plant's carbon flows down below ground and is pumped into the soil through the roots. These root exudates are the food resources for soil microbes near the root surface: sugars, proteins, carbohydrates. Through this process, each plant is attracting the right kinds of microbes to colonize the area right around the root system. These microorganisms will produce enzymes and growth hormones, and protect the plant against pathogens.

In a healthy soil, there should be at least 100 million organisms per gram of soil. But in the zone close to the root, the plant can support up to a **trillion** organisms per gram -- which creates what scientists call a "rhizosphere" of soil organisms in a symbiotic relationship with the plant.

Mycorrhizal fungi play an important role in disease suppression. These fungi wrap its mesh of hyphae around the root system, so root-feeding nematodes can't penetrate the network. In addition, mycorrhizal fungi secrete compounds that are antibiotic and inhibitory to many pathogenic microbes.

Organisms That Build Soil Structure

Good soil structure allows for water, mineral nutrients and air to move to the plants easily. Both bacteria and fungi improve soil structure. Bacteria produce glues that attach to soil colloidal surfaces, causing the small particles to stick together. Fungi grow hyphae strands around soil particles and groups of soil particles, binding them together into what are called microaggregates. Soils high in microaggregates have a loose, crumbly structure - like earthworm casts. In the spaces between the "clumps" of soil particles, water and air can penetrate, and plant roots grow down between the clumps.

In addition, larger organisms like nematodes, earthworms, millipedes and other arthropods create passages for air, water and roots as they push through the soil. But these organisms are sensitive and easily disturbed by pesticides and heavy fertilizer additions.

Organisms That Decompose Toxic Compounds

These are primarily the bacteria and fungi at the first trophic level. However, most require regular organic materials to eat along with the toxic compounds. This process is called co-oxidation. It's a bit like eating salad dressing (toxic compounds) along with the salad (organic materials). The dressing is consumed along with the salad, but we rarely eat the salad dressing all by itself! So you have to have both the organisms and a good food supply available for the organisms present in order for them to decompose the toxic compounds.

Organisms That Produce Plant-Growth-Promoting Hormones and Enzymes

All plants depend on the presence of certain species of soil microorganisms in the root zone to produce various hormones and other chemical "signals" that stimulate growth and development. The plant growing in healthy soil will exude food for these microorganisms, and the microbes in return secrete enzymes and growth hormones not made by the plant itself.

How to Keep the Soil Food Web Healthy?

Bacterial numbers are maintained by mixing high-N, easily digestible plant material into the soil. But the bacteria eat this material rapidly, so additions are required every year. Materials that will feed this process include a diverse blend of Proteins from both animal and vegetable sources mixed together using the correct amino acid ratios, by a reputable company that can control the quality of the ingredients, a high quality compost*, grass clippings (a mulching mower does this on the fly), etc.

Letting litter accumulate on the soil's surface or by adding low-Nitrogen fibrous organic materials, like mulch, straw, brown leaves, etc can maintain fungi.

Do not apply pesticides or synthetic fertilizers*. The former kills soil organisms and the latter breaks the relationship between plants and soil organisms.

* Additional Important Notes of issues that can hurt the establishment and maintenance of a healthy Soil Food Web, or just simply cost lots of money with no benefit.

- **Beware of poor quality Compost!** In the Southwest where rainfall is limited and evaporation is high, avoid compost products that are high in salts. Often compost made from the manure of farm animals such as cows and horses can be high in salts and contaminants such as Anti-Biotics, De-Wormers and other unwanted chemicals. As manures are composted or aged, the salt concentration goes up, not down and the product can do damage in soils where excess salinity and alkalinity is already a problem. In the Southwest, excess soil salts, sodium and alkalinity are difficult to manage as our minimal rainfall does not leach these materials.
- **Beware of Manipulated Compost products!** One example of this is taking poor quality compost and trying to enhance it with Humate - a mined Oxidized Lignite material or acids. The manufacture claim is that the Humate being acidic will lower the pH of your soil, yet when the manufacture adds Humate to the compost at 10 percent by volume, it does not even change the pH of the compost. Compost has a low buffering capacity which means it's easy to lower the pH, so the question is raised as to why the Humate failed to work for that particular claim?
- **Do not try to change the pH of your soil!!!** The buffering capacity of the soil can be immense which means it would take a huge amount of acid to change the pH of an alkaline soil just a tiny amount and the results could be harmful to yourself and the soil. Products that manufacture's claim to change the pH of soils to a significant plant root depth of 6 inches would require many thousands of pounds of strong acids on a per acre basis to really make that change. It's not economically feasible, nor is it safe for you or the Soil Food Web.
- **Beware of Mine Tailings being sold as Iron and Soil Acidifiers!** Some of these products have been shown to have extremely high levels of Lead and Arsenic, which can compromise the health of you and your family.
- **Beware of common commercial fertilizers!** These are salt based in-organic products that will damage a healthy soil and its food web of Soil Microorganisms.