The Soil Food Web

Contents

A. 1. Benefits of a Healthy Food Web

A healthy foodweb occurs when:

1. All the organisms the plant requires are present and functioning.
2. Nutrients in the soil are in the proper forms for the plant to take-up. It is one of the functions of a healthy foodweb to hold nutrients in non-leachable forms so they remain in soil, until the plant requires the nutrients, and then the plant “turns-on” the right biology to convert the nutrients into forms the plant can take-up (but which are typically very leachable).
3. The correct ratio of fungi to bacteria is present, and ratio of predator to prey is present, so soil pH, soil structure, and nutrient cycling occur at the rates and produce the right forms of nutrients for the plant.

The functions of a healthy foodweb are:

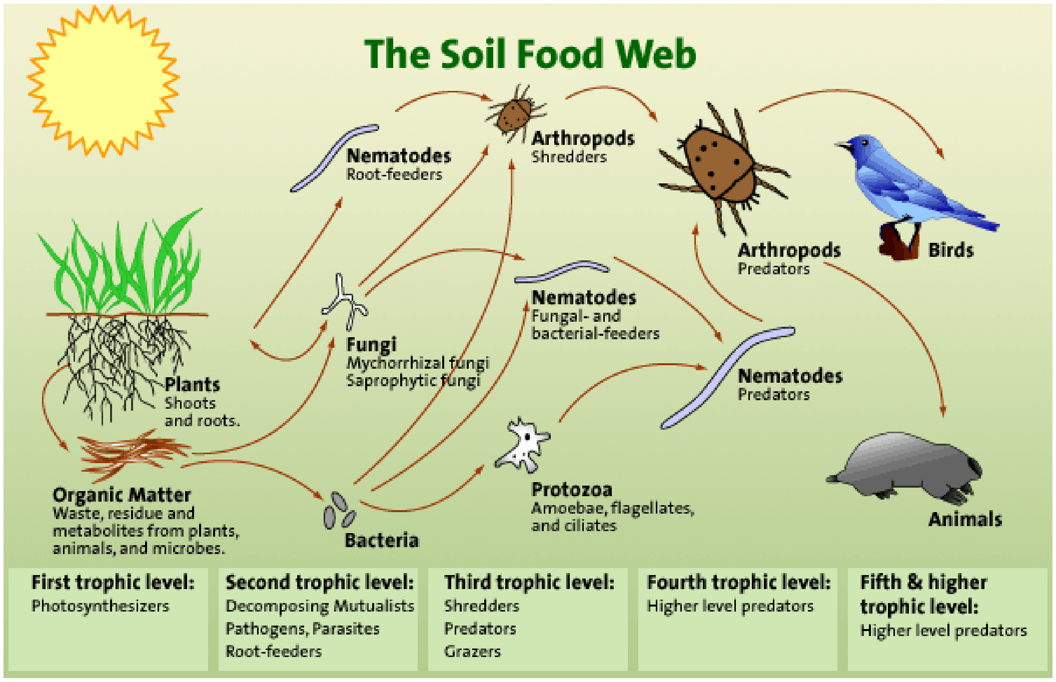
1. Retention of nutrients so they do not leach or volatilize from the soil. Reduction or complete deletion of inorganic fertilizer applications is possible.
2. Cycling nutrients into the right forms at the right rates for the plant desired. The right ratio of fungi to bacteria is needed for this to happen, as well as the right numbers and activity of the predators.
3. Building soil structure, so oxygen, water and other nutrients can easily move into the soil and into deep, well-structured root systems. Current concepts of plant root systems as being at the surface of the soil is the result of current agricultural and urban practices, not a real condition of plants. Roots should go down into the soil for at least several to 10’s and perhaps 100’s of feet, but the compaction that humans impose on soil results in toxic materials being produced, preventing good root penetration. The only way to deal with this is to have the proper biology build the structure in the soil again, so oxygen and water can move into the soil. When the biology is functioning properly, water use is reduced, the need for fertilizers is reduced, and plant production is increased.
4. Suppression of disease-causing organisms through competition with beneficials, by setting up the soil and foliar conditions to help the beneficials instead of the diseases.
5. Protection of plant surfaces, above or below ground by making certain the foods the plant surfaces release into the soil are used by beneficial, not disease organisms, making certain that infection sites on plant surfaces are occupied by beneficial, and not disease-causing organisms. And by making certain predators that prefer disease-causing organisms are present to consume disease-causing organisms.
6. Production of plant-growth-promoting hormones and chemicals can result in larger root systems, although whether forcing larger root systems on plants is a positive results needs to be understood.

7. Decomposition of toxic compounds

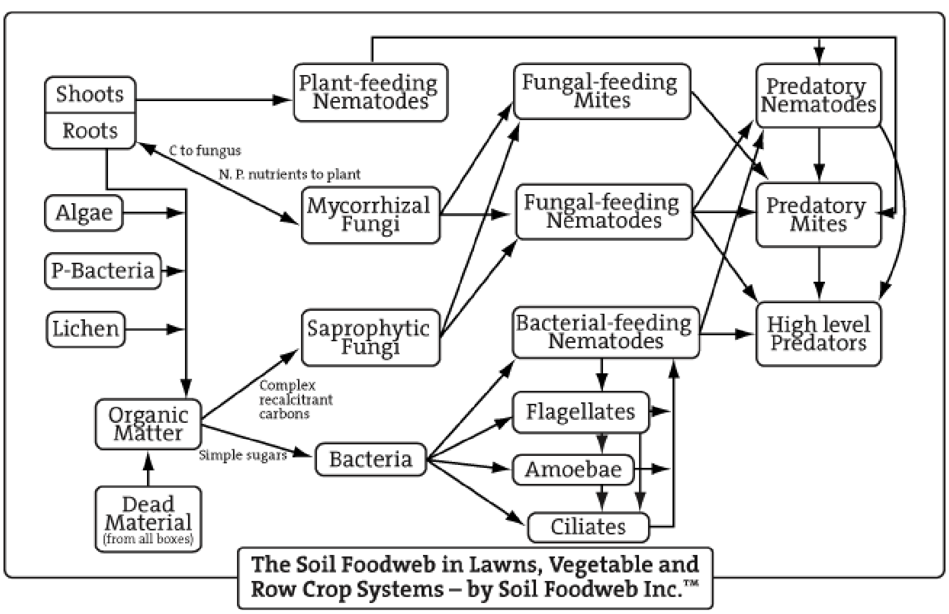
Organisms exist in populations that are

- Balanced according to optimal growth conditions for your type of plant

A.2 Soil Food Web Model in picture form



A.3 Soil Food Web Model in box and arrow form



A. 4. Compost Tea

12 steps to repairing the soil food web by Elaine Ingham, PhD

Step One

Bacteria must be present to perform their functions of competing with disease-causing organisms, retaining nutrients and making microaggregates to improve soil structure. The "correct" density of bacteria, or amount of bacterial activity has just begun to be established, based on observation of what these levels are in different soils, climates, conditions, disturbances and plant species. Seasonal variations and the requirements of different plants appear to be the most important relative factors. Again, the values for active bacteria and total bacteria are given for the season, plant type, soil type and climate in the row marked "desired range".

1. When total bacterial biomass is too low, bacteria have to be added back to the soil, compost, compost tea or to the water, if working in hydroponics, for example. Add them back by using a healthy, aerobic compost, compost tea or commercial inoculum
2. When total bacterial biomass is high, most of the time this means improved ability to perform bacterial functions, but if the balance between total bacteria and total fungi becomes inappropriate for the plant species, then the balance needs to be restored. However, you don't kill off bacteria if they are higher than the desired ratio, you improve fungal biomass instead (see Ratios).
3. On rare occasions, total bacteria may compete with fungi for food resources, and in this case, reducing bacterial foods may be a good idea, to allow the fungi to have a chance to grow. Too high bacterial biomass, combined with too low active bacteria biomass may indicate anaerobic conditions occurred, because the bacteria grew very fast, used up the oxygen in the medium so the aerobic organisms went to sleep, but the anaerobes grew well. This can be very detrimental to the aerobic organisms, and actually kill them.

Step Two

Feed the bacteria, if bacterial activity is too low. Just like any other creature, bacteria require food. Plant roots often supply the simple carbon substrates that bacteria require, such as simple sugars, proteins, and carbohydrates. Bacteria need N, P, K, Ca, and all the other nutrients as well, and obtain those from organic matter and from inorganic sources as well. Various species of bacteria can solubilize mineral elements from the mineral components of soil, but no one species can effectively solubilize ALL minerals. Diversity of species to obtain all the needed nutrients is required.

Often soil tests will indicate that some nutrient is in low supply, but merely by adding the appropriate bacterial or fungal species, these organisms will convert plant unavailable nutrients into plant available forms. Diversity is the key, however, as well as feeding that diverse set of species so they will perform their functions.

1. If activity is low, then bacterial foods need to be added to increase growth rates and improve numbers. A diversity of foods needs to be added, and thus molasses is a much better choice than white sugar. Fish hydrolysate also adds fungal foods, and N and other micronutrients. Fruit juices can be used as well, but diversity is key.
2. If activity is higher than the desired, then try to balance the ratios of the organisms by improving the organism group that is too low.
3. If active bacterial biomass is low, but total bacterial biomass is high, this is a good indicator that anaerobic conditions have occurred. In rare instances, it may be because some environmental disturbance occurred that put the majority of the bacteria to sleep, but did not kill them.

Step Three

Fungi must be present to perform their functions of competing with the more difficult disease-causing organisms, retaining nutrients especially micronutrients like Ca, and making macroaggregates which form air passageways and hallways to allow air and water to move into the soil, and to allow good drainage. This is a critical step in improving soil structure, but cannot occur without the first step of good bacterial biomass.

1. The “correct” density of fungal biomass, or amount of fungal activity, has just begun to be established, based on observation of these levels in different soils, climates, conditions, disturbances and plant species. Seasonal variations and the requirements of different plants appear to be the most important relative factors. Again, the values for active fungal biomass and total fungal biomass are given for the season, plant type, soil type and climate in the row marked “desired range”.

   When total fungal biomass is too low, fungi will need to be added back to the soil, compost, compost tea or to the water, in hydroponic situations, for example. Add them back by using a healthy, aerobic compost or compost tea. Alternatively, these fungi might be found in healthy soil, especially the humus layer of a healthy forest. But be careful not to destroy that resource by removing too much, or disturbing too much.
2. When total fungal biomass is high, most of the time this means improved ability to perform fungal functions, but if the balance between total bacteria and total fungi becomes inappropriate for the plant species, then the balance needs to be restored. However, you don’t kill off fungi if they are higher than the desired ratio, you improve bacterial biomass instead (see Ratios).
3. On rare occasions, total bacteria may compete with fungi for food resources, and in this case, reducing bacterial foods may be a good idea, to allow the fungi to have a chance to grow. High total fungal biomass, combined with too low active fungal biomass may indicate a fungal disease outbreak in progress. This can be confirmed by examining the roots for necrosis, galls, or other signs of fungal disease. 5. Beneficial fungi require aerobic conditions and if oxygen falls below
4. 5 to 6 mg oxygen per liter, then the beneficial fungi may not survive. 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.

A. 4. Compost Tea

12 steps four — eight

Step Four

Just like any other creature, fungi require food. Feed the beneficial fungi, if fungal activity is too low. Sloughed root cells and dead plant tissue often supply the more complex carbon substrates that fungi require, such as cellulose, cutins, lipopolysaccharides, complex protein-sugar-carbohydrate, and lignins. Fungi are good at condensing organic matter into ever more complex forms, such as fulvic to humic acids. Fungi need N, P, K, Ca, and all the other nutrients as well, and obtain those from organic matter and from inorganic sources as well. Many species of fungi can solubilize mineral elements from the mineral components of soil, but no one species effectively solubilizes ALL minerals. A diversity of species is needed to obtain all nutrients.

Often soil tests will indicate that some nutrient is in low supply, but merely by adding the appropriate bacterial or fungal species, these organisms will convert plant unavailable nutrients into plant available forms. Diversity is the key, however, as well as feeding that diverse set of species so they will perform their functions.

Both bacteria and fungi are important in holding nutrients in the soil when they would otherwise leach into deeper soil layers, and into ground water. The importance of microbes in forming soil structure and preventing erosion is well-known, but in order to hold the nutrients in soil, bacteria and fungi must turn them into biomass, which is not-leachable as long as the glues and strands that the fungi and bacteria use to hold themselves on any surface are not destroyed.

1. If activity is low, then fungal foods need to be added to increase growth rates and improve numbers. A diversity of foods needs to be added, and thus dead leaf material is a much better choice than purified cellulose. Fish hydrolysate also adds bacterial foods, and N and other micronutrients. Wood, sawdust, bark, paper and cardboard can be used as well, but diversity is key.
2. If activity is higher than the desired, then try to balance the ratios of the organisms by improving the organism group that is too low.

3. If active fungal biomass is low, but total fungal biomass is high, this is a good indicator that disease is either rampant, or about to be rampant. Add BENEFICIAL fungal foods and build soil structure as rapidly as possible to compete with the disease, and protect the plant roots from the disease.
4. In rare instances, it may be because some environmental disturbance occurred that put the majority of the fungi to sleep, but did not kill them.

Step Five

Mycorrhizal fungi are needed by some plants, absolutely critical for other plants, and are probably detrimental for other plants. You need to know what kind of plant you have, but in general, very early successional plant species, such as many (weeds, brassicas, mustards and kale crops do not require mycorrhizal fungal and may be harmed by mycorrhizal fungi. Annual vegetables, flowers, grasses and row crops or broadacre crops need vesicular-arbuscular mycorrhizal fungi. Most evergreen plants require ectomycorrhizal fungi, and blueberry and ericoid plants require ericoid mycorrhizal fungi.

The percentage of the root system that must be colonized has not been fully established in the mycorrhizal literature, mostly because determining benefit is relative. Mycorrhizal fungi can protect the roots from disease organisms, through simple spatial interference, by improving nutrient uptake, and by producing glomulin and other metabolites that inhibit disease. Stress in plants can be reduced because the mycorrhizal fungi can solubilize mineral nutrients from plant not-available forms to plant available forms, and translocate those nutrients to the root system in exchange for sugars provided by the plant.

Given that mycorrhizal fungi can influence so many aspects of plant growth, and documenting all these benefits is usually extremely expensive and difficult, they have not been documented. Therefore, probably the best that can be done is to say that perhaps as low as 12% colonization might be documented to be beneficial (work by Moore and Reeves in the mid-1990's), but more likely a minimum level of 40% colonization is required, as suggested by Mosse, and St. John in various publications and comments.

Early researchers found colonization as high as 80% in root systems, but most likely because they did not differentiate false-arbuscular and vesicular structures produced by disease-causing fungi from true VAM structures. Thus, colonization is rarely as high as 80% is not commonly found now that we recognize these non-mycorrhizal forms.

In the last 10 years, some researchers have suggested that some mycorrhizal fungi do not produce vesicules under all conditions, and so VA mycorrhizal fungi should be called arbuscular mycorrhizal fungi, not vesicular-arbuscular mycorrhizal fungi. Just be aware that sometimes, people say VAM, sometimes AM. Whatever.

i. If the plant does not require mycorrhizal colonization, there probably is no reason to assess the roots for mycorrhizal colonization. Although the Allens showed that one way for certain plants to exclude non-mycorrhizal plants from a community was to make sure the mycorrhizal fungi were present, because the mycorrhizal fungi pulled nutrients from the non-mycorrhizal plants. This is a probable mechanism for mycorrhizal crop plants being able to out compete weeds and earlier successional plant species.

ii. When mycorrhizal colonization is low, or less than the desired range, given that the desired plant requires VAM or ectomycorrhizal colonization or ericoid mycorrhizal fungi, then check how low the colonization is.
   - a. If less than perhaps 10 to 15%, then addition of mycorrhizal spores would be a good idea. If it is an annual plant, placing VAM spores near or on the seed or seed pieces is the simplest way to get the roots colonized as soon as the roots area produced.
      - a. With permanent turf, adding VAM spores into the compost mixed into the aeration cores gets the VAM spores into the root system without destroying the turf.
      - b. With perennial plants, verti-mulching and adding the VAM or ecto- spores into the compost mixed in the vertimulch is the simplest way to get the spores next to the root system. In cases where we have added inoculum in this fashion, roots have gone from 0% colonization to 25 to 30% within a year, and to 50 to 60% in two years, with addition of humic acids through the season to help the mycorrhizal fungi grow rapidly (see next section)

   b. If colonization is between 15% and 40%, then all that is needed is additional fungal foods to help the mycorrhizal fungi improve plant growth, reduce plant stress, and improve root protection.

. There is a dose response relationship to humic acids additions. Typically addition of 2 to 4 pounds of dry product, or 1 to 2 gallons of liquid product per acre are adequate to improve fungal growth. But, if there are toxic chemical residues to overcome, additional humics of fulvics may be needed. It is best to check periodically to see that colonization is improving as desired.
   a. Be aware that that most humic acid products contain 10 to 12% humic acids. If the product you are considering is less expensive, please check the concentration of humic acid. Half the concentration of the humic acid means they can drop the price, but your fungi get less benefit.
   b. Check colonization periodically to make sure the fungi are growing and colonization is increasing. Weather can cause problems with colonization, and severe drought, floods, burns, compaction causing by over-grazing, heavy machinery, herds of people walking on the lawns or turf can reduce colonization. If that happens, additional applications of fungal foods will be needed to help resuscitate the damage. Fungi are just like any other organism. If they are harmed, they need care to recover. Triage for fungi includes adding foods they love (humic acid is like chocolate to a choc-a-holic, but they'll also accept any woody, wide C:N ratio fungal food), and putting on a mulch or litter layer on the soil surface.
   c. If colonization is above 40%, then the plants are getting the help they need from the fungi. Periodically check to make sure nothing has harmed them.

d. What if colonization seems too high? This is extremely rare, but does happen, and seems to be associated with the fungi taking more than their fair share of the plant's resources. Stop applying fungal foods. Consider helping the bacteria compete with the fungi for a bit.

Steps Six, Seven, Eight

Flagellates (Six), Amoebae (Seven), Ciliates (Eight). These are the three groups of protozoa and they are critical in a bacterial-dominated soil, because the plants need a way to access all the wonderful nutrients tied up in the bacteria. Nutrients within the bacteria cannot be obtained by plant roots, so something has to eat the bacteria to release those nutrients. That's what protozoa do. Protozoa also help build the larger soil pores by pushing aggregates around as the protozoa search for and try to reach the bacteria tucked away around soil particles.

1. If the protozoa are too low in number, the nutrients remain tied up in bacterial and fungal bodies. Even if the bacteria and fungi die, they may not release the nutrients in their bodies until the protozoa come along. In many early microbial studies, microbiologists doing plate counts did not recognize that the protozoa were still in their "pure cultures", and it was the protozoa "mineralizing" nutrients, not the bacteria themselves. When protozoa are too low, and nematodes are too low as well, then inorganic fertilizer will have to be added in order to supply N, P, S etc to the plant. This is expensive and a large proportion of these nutrients will likely be lost from the soil, either by leaching or by volatilization. Until the protozoa are inoculated and brought to desired numbers, nutrient loss will continue to be a problem. Protozoa inocula are available in the form of good compost, good compost tea, or from a commercial source, Holmes Environmental, holmesenviro@comcast.net
2. If the protozoa are within the desired range, nutrients will be made available for the plants are minimal amounts over time. How much will be made available? That will be discussed in the section on Plant Available N made available to plants (see below). But reductions in fertilizer applications should be possible if protozoa are in good range.
3. If protozoa numbers are extremely high, or the different groups are very un-balanced, then nutrient cycling will be variable, and there may be periods when pulses of ammonium or nitrate may accumulate. These forms are subject to leaching and loss through gas production, and may result in weeds having the nitrate they need to germinate, grow and outcompete the crop or desired plant species.
4. If ciliates are too high, then the soil is either compacted or water-logged, and lacking oxygen. Ciliates are aerobic organisms, but prefer to consume anaerobic bacteria. They tolerate reduced oxygen conditions better than the other protozoa, so high numbers of ciliates indicate problems with the movement of oxygen into the soil, which needs to be fixed. Of course, it the soil gets too anaerobic, all three groups of protozoa will be low.
5. When ciliates are high, but flagellates and amoebae are also high suggests that one of three things may be happening:
   a. The sample has just become compacted, or flooded, and the anaerobic conditions have just been initiated. Generally the number of ciliates is not extremely high.
   b. The sample has aggregates, which are anaerobic inside the aggregates. The high ciliate signal comes from the internal parts of those aggregates where anaerobic conditions exist, but outside those aggregates, aerobic conditions exist, and thus flagellate and amoebae numbers are typically high as well. Both anaerobes and aerobes co-exist, but in very different places within the spatial structure of this sample. This is very typical of good worm compost, particularly worm compost high in castings.
   c. The sample has been anaerobic in the past, but is just becoming aerobic. Flagellates and amoebae are growing because aerobic bacteria have begun to grow. Generally, ciliate numbers will be fairly high, while flagellate and amoebae are just barely in good range. Quite often this will result in nitrate pulses and germination of weed seeds.

6. When flagellates are high and amoebae low, or flagellates low and amoebae high indicates an imbalance in nutrient cycling, with pulses of nitrate being produced, resulting in weeds being able to out-compete the desired plants.
7. What do you feed protozoa? Bacteria. So, if you have taken care of step one and two, the bacteria should be there for the protozoa to eat.

12 steps: nine — twelve

Steps Nine, Ten, Eleven

Bacterial-feeding nematodes (9), Fungal-feeding nematodes (10) and Predatory nematodes (11). The beneficial nematodes consume their prey groups, and in the case of bacterial- and fungal-feeders, release N, P, S, and micronutrients that would now be available to plants, if the majority of the cycling occurs in the root system. These nematodes also interfere with the ability of the root-feeding nematodes finding the root. The higher number of these organisms, the more nutrient cycling is occurring.

Step Twelve

Earthworms, Microarthropods.

If earthworms and/or microarthoropods are present, then the full food web is present, and if everything is in a good biomass or numbers of individual organisms, then plant health is pretty much assured, because all the processes will be functioning.

How much do I add to fix any group?

In any case, just an inoculum is required, since all of these organisms will multiply, resulting in increased numbers. Of course, the higher the initial number of individuals added, the faster the return to health. Addition of foods for the organisms will increase the rate of return to health as well.

If toxic chemicals are present in the soil, or litter material, then these materials have to be consumed by the organisms before the twelve step program can be performed. Addition of foods to help consumption by organisms will increase the rate of return to health.

Bacteria – add bacterial foods, such as simple sugars, simple proteins, simple carbohydrates. Molasses, fruit juice, fish emulsion and green plant material high in cellular cytoplasmic material feeds bacteria. The more kinds of sugars and simple substrates added, the greater the diversity of species of bacteria, and the more likely the full range of beneficials will be present.

Bacterial AND fungal inocula can be found in most good AEROBIC composts, or compost teas made with compost documented not to contain E. coli, or other human pathogens.

There are some “starter” bacterial inocula that are useful as well. What you need to look for are maximum diversity in the bacterial species. Unless you are trying to make fermentative compost, you need to avoid inocula containing anaerobic bacterial species.

There are no fungal inocula on the market. Yeasts are rarely useful fungal species in soil, or at least there is little data to support their usefulness. Some effort needs to expended to show the veracity of this view point.

Fungi – add fungal foods, such as complex sugars, amino sugars, complex proteins, soy bean meal, fish hydrolysate, fish oils, cellulose, lignin, cutins, humic acids, fulvic acids, wood, paper or cardboard. The more kinds of fungal foods that are present, the greater the diversity of fungal species will grow.

Protozoa – consume bacteria, and thus to improve protozoan numbers, bacterial biomass needs to be enhanced. Protozoa inocula are compost, compost tea, and some commercially available protozoan cultures.

Nematodes – consume bacteria, fungi and each other. Inocula of certain entomopathogenic nematodes are available, for control of certain insect species, such as root grubs and root weevils. Compost and compost tea are the only source of inocula for the beneficial nematodes.

Mycorrhizal fungi – need roots to germinate and grow successfully. Humic acids can improve germination, but then the germinated fungus has to rapidly find a root to colonize or it will die. Spore inocula exist for all kinds of mycorrhizal fungi. Make sure you have the kind needed for your plant. Make certain to get the spores into the root system of the plant, such as injecting the spore, or adding compost mix into the soil, filling soil cores with a mix of compost and spores.

A. 5. What do different plants need?

In early succession, soils are strongly bacterial-dominated, because soils have not built to the point where the fungal foods, or the structure in the soil will allow them to grow as well as the bacteria.

The first organisms that enter a sterile natural parent material (sand, silt, clay alone) are the photosynthetic bacteria. In the aerobic atmosphere, these will be photosynthetic Cyanobacteria, for example. Before the Earth's oxygen atmosphere developed, the first bacteria to exist, and the first to colonize parent material in anaerobic conditions are the photosynthetic purple or sulfur bacteria (see work on mid-ocean rift bacteria).

These first photosynthetic bacteria release waste compounds, and in succession, bacteria that could use these products evolved, while today, bacteria that use these products have to reach the material, through "taxi-cabs" of various kinds, such as wind, human movement, birds, snakes, mice, or insects for examples, carrying microbes on their feet. Every day, additional species of bacteria may arrive, depending on the distance to a source of inoculum and the ability of bacteria to disperse.

Many bacteria are really bad at dispersing. They just don't grow in places where bird feet, or earthworms, or spiders come by. If they aren't picked up by something, they don't get around very well. Especially when people are doing so much to destroy the normal set of organisms in soil or on plant surfaces, dispersal to new soils is not happening adequately. When insecticides are used, insect dependent dispersal is just about nil.

Early successional species of bacteria, or fungi, and disease-causing bacteria and fungi, have better mechanisms for dispersing. To stay alive, to maintain the species, they have to be able to find new places to grow. So, the organisms that arrive first in our agricultural soils are the diseases. They are better at dispersing than any other kind of bacteria or fungi.

As the bacterial populations increase in number, and as the number of species increases, because soil structure improves, the kinds of organic materials improve, the habitats in soil increase. And so more kinds of bacteria can find a place to live, grow and reproduce. Diversity builds. But all the nutrients will be tied up in the bacteria.

Bacteria don't mineralize nutrients all by themselves. They can't. There is no evidence that bacteria die of old age in the soil. Bacteria will become dormant, go-to-sleep, when conditions become too poor for continued growth. They don't die unless a disturbance occurs that kills them. Otherwise, they have mechanisms for surviving tough times.

Why do microbiologists say that bacteria mineralize? First, we need to understand what mineralization means. When protein is converted into carbon dioxide and ammonium or nitrate, that is mineralization. More generally, conversion of an organic material into mineral forms (carbon dioxide is a mineral form of carbon, and nitrate or ammonium are mineral forms of nitrogen) is mineralization.

What about when rock is solubilized? Rock is a mineral. You can't mineralize something that is already a mineral. Typically rock P is turned into an organic form, through the action of bacteria or fungi, and on occasion root acids, and incorporated into the biomass of these organisms. When the bacteria or fungi or plant are eaten, phosphate can be released, and since phosphate is a mineral, that would be mineralization.

But the take-home message is that soil scientists often "black-box" the processes going on in soil, and minimize the activity of the biology. They often do not take the time to learn that bacteria perform functions, but not others. Fungi do some metabolic functions, but not all things. It is critical to know what each group does. It is probably important to know what different species, or group of species do as well. Our ability to measure that level of information is limited. But differentiating bacteria from fungi is critical. They do very different things.

And up to this point in succession, fungi haven't even appeared on the scene.

At a certain point, when there is enough bacterial biomass to maintain protozoan numbers, protozoa will arrive, grow, reproduce, and maintain their populations over time. Nutrient cycling is finally present in this soil.

And now, plants can survive in this soil. But not just any plant, the plants that occupy this stage in succession are things we all would agree are weeds. The word weed has been used too generally in recent times, so let's agree that by weed, we mean something that requires high nitrate levels, poor soil structure, that produces huge numbers of seeds that disperse far and wide. We all would agree, that's a weed. And when bacterial and protozoan numbers are very out-of-whack, then the protozoa over-eat their food resources, mineralize high concentrations of N, P, S, etc, and help out the weeds that require these pulses of nutrients to germinate, and to set the stage to allow them to out-compete the later successional plant species, the things we humans like to eat.

Nematodes also arrive during this time, bacterial-feeders of course, since fungi aren't present yet in high enough levels to support fungal-feeders. Root-feeding nematodes may arrive and survive, since weeds are present. Since few competitors of the root-feeders are present, if they do arrive, they can have major impacts on weeds.

The "support matrix" is now actually soil. Soil requires life to be present, not just sand, silt and clay fractions of the mineral or parent material. Organic matter is required in order to have the organisms performing their functions in the soil. Soil structure is being built, diversity is increasing, but it is all at a very early stage of development. Plant production will improve with time, but at this stage, the plants in the system are mostly weeds. But weeds leave litter on the soil surface, contribute root biomass to the soil, as well as root exudates. So, more and more food resource is made for the bacteria.

Fungi that arrive now have a food resource to utilize, to begin to build their communities, using the cellulose the plants provide. Building soil, slowly, slowly.

As the ratio of fungi to bacteria change, the pulses of nutrients are smoothed out, and true weedy species lack the ability to out-compete the later successional plants. The early successional grass species, like Bromus, and in addition, the brassicas, the mustards, kale and cole crops do best in these soils. They develop a food web that feeds fungi a little, but mostly bacteria. But on their residues and litter, fungi get more and more food, and eventually, the soil shifts to more fungal. Not yet fungal-dominated, but more fungal relative to what came before.

And the plant species shifts, to plants that need more fungal biomass – about 2 times more bacteria than fungi, for the ryegrass related species. Some bunchgrasses, some Bermuda grass here, though many Bermuda grass species do better more bacterial. Most vegetable crop species – tomato, potato, celery, sudan grass, soybean, etc make the balance of the biology in the soil about 0.5 ratio of fungi to bacteria around their roots.

And their roots, and litter residues grow more fungi than bacteria, and again, eventually, the ratio shifts, and with it the plant species. A soil with a ratio of equal fungi to bacteria, with biomass levels above 150 ug, selects for row crops and grasses, such as corn, wheat, barley, rye, fescue, bluegrass, etc.

But again, these plant species put more fungal foods into the soil, and the soil, slowly but surely, becomes fungal-dominated. As that threshold passes, shrubs, bushes, early successional trees win in the competition for soil nutrients. Soil pH generally shifts as well. In western soils, the soil organic matter builds, soils become more and more fungal. Late success ional systems are strongly fungal-dominated. Typical ratios of fungi to bacteria observed in systems requiring few or no inorganic chemical inputs are:

Bacterial-dominated plants (most row and vegetable crops)

Lawn grass 0.5 to 1.0	Broccoli 0.3 to 0.7	Kale 0.5 to 0.8
Carrots 0.5 to 0.8	Corn 0.8 to 1.0	Wheat 0.8 t o 1.0
Lettuce 0.5 to 0.8	Tomato 0.8 to 1.0	Tobacco 1 .0 to 3.0
Turf 0.9 to 1.5		

Fungal-dominated plants

Grape 3 to 5	Deciduous trees 10 to 100	Alder 5 to 100
Apple (orchard) 10 to 50	Pine 50 to 100	Conifer 100 to 1000

How can soil organism dominance be changed? Most simply, feed the organisms that are low in number.

Bacterial Foods are: Green, high in easy-to-use sugar and nitrogen, e.g., green grass clippings, cover crops, especially legumes, molasses, compost teas, compost made with green material (high in N and simple sugars) and manures (high N) Be careful to tie up all the manure N by adding enough plant material, or plants may be burned.

Fungal foods are: brown plant materials high in cellulose, lignin, and tannin, e.g., woody fibrous materials, like straw, sawdust, compost made with woody material and small amounts of manure. Enough N needs to be present to start decomposition, but not encourage bacterial growth. Time is needed to reach the N-release stage before putting this material on plants, or planting into such material. At first, the fungi growing on organic matter high in carbon take up N from the soil, which can stress plant growth.

Those soil organisms that make N available for plants are predators of (or eat-) fungi or bacteria. Low numbers of protozoa (bacterial-feeders), nematodes (both bacterial feeding and fungal-feeding,) earthworms, or micro arthropods can be enhanced by improving their food, i.e., bacteria or fungi. Interaction of bacteria and their predators (e.g., protozoa and bacterial-feeding nematodes), or fungi and their predators (e.g., fungal-feeding nematodes and micro arthropods), produce as much as 80 % of the plant-available N that occurs in soil.

If bacterial or fungal foods, i.e., cover crops, residues, or compost can't be obtained or grown, commercial products are available to " jump start" fungi or bacteria. If spreading organic matter is difficult, a water extract of the compost can be prepared and this "tea" can be applied through the irrigation system. Compost tea can be bacterial or fungal, depending on the compost and addition of fungal foods, unless rock dust or kelp is added.

When and how to add fungal or bacterial food

Both should be placed on the surface of the soil, although if greater bacterial activity is desired, mix lightly into the top few inches of soil. Realize that plowing and compacting kills many soil organisms, and soil structure is destroyed.

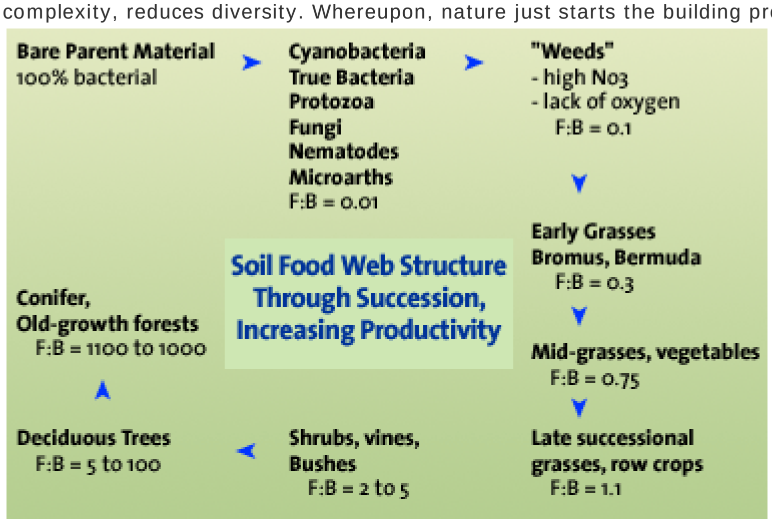
A mineral crust may then develop, decreasing water infiltration, water-holding capacity, and soil structure is destroyed. The benefit from mixing food into the soil and growing a burst of bacterial biomass may not offset all the detrimental results of the tillage. During periods of optimal moisture and temperature (spring, and fall in some areas), bacterial-food should disappear rapidly, within 2 to 9 weeks if soil organisms are diverse and healthy. Fungal-food takes a bit longer, 6 to 16 weeks for a healthy Foodweb to do it's job. If the original plant material remains identifiable, after a month or more of warm weather, some part of the Foodweb is lacking and needs to be added.

Monitor soil and compost organisms on an annual or semi-annual basis to make certain the right numbers and functions are present. Monitoring in the fall allows assessment of appropriate management through the fall into the spring when it is easiest to improve the fungal community. Organic matter additions, either as compost or as cover crops, decompose rapidly during the winter, even under the snow, if the soil Foodweb is healthy. Soil organisms growing in organic matter produce metabolic heat and will increase soil temperature in the spring. As some cover crops decompose, inhibitory compounds can be produced to so the initial flush of decomposition needs to be finished before planting the next crop. Checking the soil Foodweb in the spring allows assessment of whether beneficial are growing, or problems are developing. Assessing the Foodweb in mid-crop growth is also useful, especially for VAM colonization, pathogens, or pest problems. However, it is difficult to do much to help the current crop at mid-season, and this information is more useful determining what management is needed for the next crop.

A. 6. Succession and the soil food web

As the food web in the soil becomes more complex, the ratio of fungi to bacteria increases, plant productivity increases, and vegetative communities change. It appears that "nature" drives the successional process by continuously building more and more complex carbon compounds. This development of complex, highly-retention organic matter in soil is driven by the kinds of plant materials that are produced by higher plants, and through an ever-more complex set of metabolites being released as the biology that uses the ever-more complex carbon substrates produced by plants decompose those materials.

Another way of saying this is that as humic materials accumulate in the soil, productivity of plants increases. But the formation of humic materials is completely dependent on the biology in the soil and on plant surfaces. So, what is the chicken, and which is the egg? As Dr. David Perry explained, it's a boot-strapping process. Nature moves towards ever-more complex systems, ever-more diverse, ever-more productive. Until a disturbance happens that destroys the complexity, reduces diversity. Whereupon, nature just starts the building process again…



A. 7. Interpreting Soil Foodweb information

What information is given by which test?

- Active Bacteria/Active Fungi
- These tests measure the numbers and biomass of aerobic bacteria and fungi that are actively feeding and reproducing. Active bacteria and fungi rapidly enhance soil structure, nutrient retention, disease suppression and residue/pollutant decomposition.
- If your soil is deficient in disease suppression, you need to know whether it is because bacterial activity or fungal activity is lacking.
- If water puddles on the soil surface, perhaps the reason is that soil structure is not being maintained. If the roots of your plants only grow a short distance into the soil, it is a clear indication that the soil is compacted, and lacks oxygen. Bacteria and fungi need to grow into that soil, and build the hallways and passages ways to let water flow into the soil as well as allow oxygen to move into the soil.
- These tests are used to determine:
    1. Is nitrogen being retained at this time?
    2. Is this soil dominated by fungi or bacteria? Is it bacteria or fungi that are playing the greatest role in decomposition?
    3. Is there a decent set of bacteria to support protozoa and bacterial-feeding nematodes?
    4. Did addition of a product, compost, or compost tea, or some aspect of management cause a bloom of bacterial activity or fungal activity, or kill, harm or otherwise reduce activity of the bacteria and fungi?
    5. Did herbicides or other pesticides kill or stimulate significant numbers of organisms?

Total Bacteria / Total Fungi

- This test measures the total amount of bacteria and fungi in the sample. Total biomass includes the active populations determined in the previous tests, as well as all of the inactive (sleeping, moribund, semi-awake, just woken up, just about to go to sleep, not really wide awake yet, and dead but not yet decomposed) organisms.
- Total biomass assesses the amount of carbon or nitrogen held in these organisms, disease suppressiveness, potential benefit to soil aggregation, and relate to decomposition rates.
- There is a clear correlation between diversity and total bacteria or total fungal biomass. The higher the biomass present, the more diverse the bacterial or fungal populations. It’s not a perfect correlation, but in general it holds.
- These tests are used to determine:
    1. Are fungi or bacteria dominant or is there equal biomass of both? Are there minimum levels of fungi, or bacteria, or high levels of both?
    2. Is there a pool of retained nitrogen in the form of organisms that can be released to plants later?
    3. Is there enough fungal biomass to immobilize solution calcium so it doesn’t leach?
    4. Are fungal biomass and bacterial biomass great enough to support the organisms that graze on bacteria and fungi? These higher forms balance the population levels of bacteria and fungi and release nitrogen into the soil in the form of ammonium for plant growth.

SFI can perform morphological diversity testing. In general this is a significant improvement over plate counts, since so few species of bacteria and fungi actually grow on any plate count medium. However, it takes molecular methods to assess the full diversity of bacteria and fungi in soils. We work with other programs that are in the process of developing these methods for practical applications.

Nematode Numbers and Community Structure

- We extract all the active nematodes from 50 to 100 grams of soil or compost. We count and identify those individuals and report numbers of individuals per gram dry soil.
- Nematodes are identified to genus and placed in one of four functional group classes according to what they eat. The report differentiates root-feeding nematodes to genus. Reports list the beneficial bacterial-feeders, fungal-feeders and predatory nematodes, if any.
- Beneficial nematodes are important in preventing root-feeding nematodes from finding the roots of plants. Beneficial nematodes are a very important part of root protection, one which most agricultural soils lack.
- Identification of insect-feeding nematodes can also be performed.
- This test is used to determine:
    1. Are any root-feeding nematodes present? Are they at economic damage thresholds?
    2. Are any beneficial nematodes present?
    3. Bacterial-feeding nematodes help balance total bacteria populations and release nitrogen back to the plant.
    4. Fungal feeders balance total fungal levels, including root rot fungi, and also help release the nitrogen locked up inside fungi back to the plant.
    5. Predatory nematodes are higher-order predators that help balance all other nematodes. It is desirable to have some of these around but they are especially delicate and easily hurt by tillage.

Protozoa

- Protozoa are single celled organisms that mostly eat bacteria, although some prefer to consume pathogenic, disease-causing fungi. Protozoa are very important in recycling the nitrogen and other nutrients locked up inside the bacteria.
- Some protozoa also attack nematodes and some will attack fungi. All in all, having good populations of the right kinds of protozoa makes for a balanced soil.
- Protozoa come in three major groups, the ciliates, flagellates, and the amoebae. The relative numbers of these groups assess whether the sample is aerobic or anaerobic.
- This test is used to determine:
    1. Are enough protozoa present to cycle adequate nutrients? Will enough nutrients become plant available?
    2. Are ciliates numbers too high, indicating anaerobic conditions in the soil?
    3. All three groups of protozoa help balance total bacteria populations and release nitrogen back to the plant.

Mycorrhizal fungi (VAM)

- The kind and amount of beneficial mycorrhizal colonization on the roots is determined in this test. Mycorrhizal fungi are extremely important fungi for plants that require colonization, such as most crop, vegetable, orchard and landscape trees and shrubs.
- If you have plants in the soil, you need know the percent of the root system colonized by mycorrhizal fungi. We not only assess VAM versus ectomycorrhizal colonization of the roots, track nodulation by N-fixing rhizobia, necrosis by disease-causing bacteria and fungi, but insect and soil pest feeding on the roots.
- Please remember that we need a representative sample of roots of the plant you want to know about included in the sample. It is best to send all the roots picked from the composite soil sample (see below on obtaining the soil sample).
- This test measures:
    1. Is enough of the root system protected by mycorrhizal fungi from disease-causing organisms?
    2. Is the root system colonized enough to supply nutrients at the rate the plant requires?
    3. Would the plant benefit from improved colonization?
    4. Percent of the root being attacked by disease-causing organisms.
    5. Percent of the root being attacked by root-feeding insects

Microarthropods

This test provides information on the numbers and identification to major group of the visible soil critters. The important groups are the fungal-feeding, herbivorous, and predatory microarthropods.

Generally, soils disturbed by plowing, disking, chiseling, etc will have not significant microarthropod populations for a year or more unless mulch is placed on the soil surface. Still, many predators of pests are microarthropods, and you would want to know if you have these important bio-control organisms present in your soil.

Those microarthropods that are true soil-dwellers are usually small and inconvenient to see with the naked eye. The principal role of these creatures is to recycle nutrients and make them available for plants.

Foliage Assay: Allows determination of the area of leaf surface occupied by microorganisms such as bacteria and fungi.

- The work so far performed suggests that if 70% or more of the leaf surface is occupied by beneficial microorganisms, then foliar disease can be significantly reduced. Plants with 70% or more of the leaf surface occupied by beneficial microorganisms also appear to have higher leaf tissue concentrations of important nutrients.
- More work is needed to determine which species of bacteria or fungi will be most suppressive and whether different cultivars of plants will respond in different ways.

Review the **Organism Biomass Data** table in a seperate window

Dry Weight: All three composts have moistu sre in good range. If the soil is too wet, aeration will be a problem and roots will be killed. Too dry and organisms cannot grow.

Active bacterial biomass: Control is in good range. HH is in good range, not significantly different from the control. In Biol, bacterial activity is low, resulting in poor decomposition, poor nutrient retention, a lack of soil structure building and limited disease suppression. Need to add bacterial inoculum, or bacterial foods to wake up the bacteria that are present (see total bacterial biomass).

Total Bacterial Biomass: Control has adequate total bacterial biomass but both treatments have low total bacterial biomass, for different reasons. Fungal growth is probably out-competing bacterial growth in Plus HH, while something in Bio1 is detrimental to bacteria. In all samples, sleeping, dormant organisms are present (active subtracted from total). Some unknown percentage of these dormant, sleeping organisms would grow on plate counts.

Active Fungal Biomass: Active fungi low in the control and in the Bio1 sample. Plus HH has in desired range activity. Disease suppression, nutrient retention, and soil building will be present in HH, not in the control or in the Bio1 samples. Need to add a fungal inoculum and fungal foods to these two samples.

Total Fungal Biomass: Both control and Bio1 too low, and therefore fungal diversity is lacking. Need to add fungal foods to get fungal decomposition going. Fungal foods are, for example, humic acids, many fulvic acids, dry, brown leaf materials, wood chips, sawdust, paper, cardboard. May need to add a fungal inoculum as well. The HH treatment has adequate fungal biomass, showing that just by adding humic acid that fungal biomass can be resuscitated.

Hyphal Diameter: As indicated by the footnote on the table, the diameter of the hyphae observed in these samples indicate typical soil fungi, a mix of beneficials and not-so-beneficial are present in the control and in the Bio1 treatment. In the HH treatment, this amendment has provided food for the beneficial fungi and they grew in preference to the less beneficial fungi. This is a very good result for any soil.

Sample #	Treatment	Protozoa # per gram			Nematodes # per gram
		F	A	C	
91046	Control	580	2,798	84	0.07
91047	Plus HH	61	1,486	38	1.71
91048	Plus Bio 1	2,689	844	329	0.05

Protozoa: All too low, in all samples. Need to add an inoculum of protozoa, which is typically found in compost with higher moisture, compost tea, or in commercial products (see www.soilfoodweb.com for list). Note the variability in this assessment method. All three values of flagellates are probably not significantly different one for the other. How is this determined? From replicate sampling from a set of soil samples.

Nematodes: All too low numbers, low diversity. This is the hardest component of the foodweb to return to healthy conditions once the food web has been destroyed. An inoculum of beneficial nematodes is needed to re-establish this group of the soil foodweb.

Review the **Fungal to Bacterial Biomass** table in a seperate window

Total Fungal to Total Bacterial Biomass: Control and Bio1 both on the bacterial-dominated side, while HH is fungal-dominated. Need to add more fungal foods and possibly need fungal inoculum in control and Bio1 samples. Control and Bio1 samples reveal foodwebs appropriate for vegetables, annual plants. The HH sample has a ratio appropriate for bentgrass and other productive pasture or lawn grasses.

Active to Total Fungal Biomass: Only HH has decent levels of active fungi. Neither the control nor the Bio1 sample have enough active fungi to protect the plant against disease-causing organisms. An inoculum of beneficial fungi would be wise, but certainly fungal foods are needed.

Active to Total Bacterial Biomass: Both the control and HH have adequate active bacteria relative to total bacteria, but the Bio1 treatment has reduced the active bacterial component severely. This amendment is detrimental to both active and dormant bacteria,

Active Fungi to Active Bacteria: Which microbial group is winning? Bacteria are in the control, so the soil will become even more bacterial over the next few weeks. In the HH treatment, the beneficial fungi were enhanced and the ratio shows that the soul will become more and more fungal with time. In the Bio1 treatment, the bacteria were killed, so this ratio is very fungal. Because active bacteria were harmed more than the fungi, the ratio is quite skewed. Fungi will grow in this soil more than bacteria, until conditions change, but it may well be un-desirable fungi because the bacteria are not performing their jobs.

Plant Available N: Low in all three soils. Need a protozoan inoculum.

Nematodes: No root-feeders detected, but no beneficial nematodes found either. Need a beneficial nematode inoculum. Nematodes are the most difficult group to get re-established.

For additional questions, please e-mail Soil Foodweb Inc.

Soil Foodweb Inc. 1128 NE 2nd St. Ste 120 Corvallis, OR 97330 Phone: 541-752-5066 FAX 541-752-5142 E-Mail: info@soilfoodweb.com							**Soil Foodweb Analysis** Client: Soil USA Soil Type: Unspecified Desired Foodweb: Assume Equal bacteria and fungi
Organism Biomass Data (Bold means value lower than desired range)							
Sample	Treatment	Dry Weight	Active	Total	Active	Total	
#		of 1 gram	Bacterial	Bacterial	Fungal	Fungal	Hyphal
		Fresh	Biomass	Biomass	Biomass	Biomass	Diameter
		Material	(µg/g)	(µg/g)	(µg/g)	(µg/g)	(µm)
91046	Control	0.72	17.9	195	**5.21**	**127**	2.5
91047	Plus HH	0.73	18.2	**146**	24.5	235	3
91048	Plus Bio1	0.72	**0.41**	**135**	**1.99**	**101**	2.5
Desired		0.45 -	See A	See B	See A	See B	
Range		0.80	15 - 30	150 - 300+	15 - 30	150 - 200+	C

A - Immature compost can have activity ranging from 10 to 100%.

Mature compost should have activity between 2 to 10%.

B - Desired fungal activity and biomass depends greatly on the plant being grown.

Desired range given here is for a 1:1 compost.

C - Hyphal diameter of 2.0 indicates mostly actinomycete hyphae,

2.5 indicates community is mainly ascomycete, typical soil fungi for grasslands,

diameters of 3 or higher indicate community is dominated by beneficial fungi

Season, moisture, soil and organic matter must be considered in determining optimal foodweb structure.

A. 8. The Nitrogen Cycle and the Soil Food Web

A complete understanding of the nitrogen (N) cycle is necessary in order to comprehend why the soil foodweb is so important in being able to predict N cycling. Most people with little or no understanding of environmental microbiology do not do justice to the role of biology in N cycling. So, we need to go through this with most people.

Start with atmospheric N

The predominant form of N on this planet is nitrogen gas in the atmosphere. Seventy-five percent of the atmosphere is nitrogen gas, so the trick is getting that nitrogen into a form that plants can use.

N fixation

Back before life on Earth started, most of the N was fixed through the action of lightening, enough to get life started. After life started on earth, most of the nitrogen fixed is by microorganisms, and indeed, all N fixation requires the help of bacterial enzymes. Most people know about N-fixing bacterial genus, Rhizobium, on the roots of legumes. These bacteria make the plant form nodules to house them, allowing the bacteria to exclude oxygen, allowing the N-fixing enzymes to perform their function of converting N-gas into biomass.

But a number of other N-fixing bacteria abound in certain environments. Cyanobacteria form filaments, and are typically photosynthetic, so the bacteria fixing their own carbon from carbon dioxide also fix N inside those filaments, in many different extreme environments.

Free-living N-fixing bacteria, such as Azotobacter and Azospirillum, also fix N in the root systems of many different plants. The plant supplies the sugars that these bacteria need, in the amounts they need to perform N-fixation. So, while not truly symbionts, these bacteria usually are most active in the rhizosphere.

N is in bacterial biomass after N-fixation occurs

There is a mis-conception that Rhizobium, or the free-living N-fixing bacteria “dump” nitrate into the soil. They do no such thing. These bacteria require a great deal of energy to fix N. Fixed N does not get made into nitrate, or any other inorganic form of N. The bacteria fix N for themselves first, and is put into protein in the bacterium before anything else occurs. If the bacterial colony fixes enough N rapidly enough so the bacterial demand is met, then protein is provided to the plant, in the case of Rhizobium. The free-living bacteria are not in the plant, but in the rhizosphere, so all the fixed N remains tied up in bacterial biomass, in the form of protein mainly.

No inorganic N is dumped into the soil then, in this first step of fixing N. The plant may receive some N, but the plant isn’t going to give away N for no reason. Only when the plant dies will it lose N, and that N is in the dead plant litter, roots, seed, fruit, etc. This organic matter is elevated in protein N, but that form is not usable by other plants. It has to be decomposed by bacteria and fungi before anything else can happen.

No inorganic, plant-available N is released into soil through the process of N-fixation. The dominant form of fixed N is protein. How does that form of N get converted into ammonium, nitrite or nitrate?

Bacteria don't die of old age in the soil. Neither do fungi. Empty hyphal strands may be left behind, but there is extremely little N in cellulose, or mannin, or chitin, or the other structural cell wall materials left behind as the empty tubes of fungal biomass. There is no evidence that in healthy soil any of these organisms die just because they get old. In lab cultures bacterial colonies will get old and the toxic metabolites that accumulate in the Petri dish will kill the bacteria in the colony. But that doesn't happen in the real world. Water washes away the metabolites in the real world, or another kind of bacteria, or fungus, or other organisms eats that waste metabolite. So the colony doesn't get stuck dying from it's own excrement. The major reason bacteria or fungi die in soil is because someone eats them.

The Mineralization Step

Predator-prey interactions in soil are no different than in the aboveground world with cats and mice, hunting dogs and birds, tigers and water buffalo, lions and gazelle. Bacteria get eaten by protozoa, nematodes, earthworms, microarthropods, etc. When bacteria, with a C:N of 5 get eaten by a protozoan with a C:N of 30, possibly higher, then N, P, S, etc will be released in plant available forms.

If you are unfamiliar with these interactions, please read some of the reference materials in the reading list, or on Dr. Ingham's list of publications, or attend some of her classes, or other soil ecologist classes.

When fungi are eaten by protozoa, nematodes, microarthropods and earthworms, N is released in a mineral form into the soil. The majority of this process of making plant-available N occurs in the rhizosphere of the plant. But mineralization occurs only because of biological processes.

Want to predict how much N will be mineralized? You have to understand how much N is being tied-up by the bacteria and fungi in non-leachable forms, how much will be leached and lost from the root system, and how much prey (bacteria and fungi) will be consumed by the predators (protozoa, nematodes, microarthropods, earthworms, etc). There are different flow rates for different organisms, so the relationship is not straightforward.

But if you do not understand biology, and do not know how much of whom is present, or how active they are, prediction of N-mineralization is impossible. It remains a black box, highly variable and head-scratching in its inability to be understood or predicted.

Initially N is in the form of ammonium

The predators of course release predominately ammonium, a nutrient that plants can take-up. But ammonium is not a good nutrient for ALL plant species. In general, ammonium is the right form of N for perennial plants, although all perennial plants that have been tested can take up nitrate and possibly a little nitrite as well.

But perennial plants growing with mostly nitrate in the root zone are HIGHLY prone to disease. Nitrate in high concentrations stresses these plants, and result in an never-ending battle with disease, requiring the use of high amounts of fungicide, nematode, antibiotic, and herbicide applications to combat the organisms being selected and enhanced by the high nitrate present.

Annual plants are best at using nitrate, although there is evidence that nitrate in high concentrations is harmful to continuing root function even with annuals. Annuals can take up ammonium, but generally help the equilibrium shift from ammonium to nitrate so the form of N they like is at least present, so they can preferentially take that form up.

How do you maintain ammonium as ammonium? Or convert it to nitrate?

Conversion to nitrite and then nitrate

In soil where the nitrifying bacteria are able to grow, these bacteria convert ammonium to nitrite and then nitrate. But nitrifying bacteria have some significant constraints on where they will grow. They need reduced oxygen conditions to do best. They typically reduce oxygen around their colony, so the bacterial individuals in the middle of the colony are in reduced oxygen conditions. Or they grow in the rhizosphere, where the rapid growth of all those other bacteria sets the stage for a small colony to be at the oxygen level they need. Nitrifiers take the hydrogen ions from ammonium and replace them with oxygen. Ammonium is first converted, by the action of bacterial enzymes, to nitrite (NO2) and then another set of bacteria converts nitrite to nitrate (NO3). It is an oxidation step of the nitrogen.

But this is not a mineralization step. Ammonium is already a mineral form of N, and so conversion to nitrite and then to nitrate is merely a shift in the form of inorganic N.

Nitrifying bacteria require particular habitats in order to grow and perform their nutrient cycling processes. These bacteria need the hydrogen ions in order to generate energy through their metabolic pathways. They remove H from the medium. What does that do to soil pH?

Nitrifying bacteria remove ammonium, and produce nitrate. They aren't taking up the N, that are just using it to deal with the electrons they need to get rid of in respiration. In order to grow and perform their function, they will drive a soil more alkaline. As they utilize H ions during metabolic functions, the soil will become more alkaline.

Some scientists say that bacteria couldn't possibly have that much effect on soil. Each individual bacterium is so small, how could bacteria have much effect on anything in soil? These people clearly don't understand soil, or how many bacteria are in soil. In a healthy soil, there are 600,000,000 individual bacteria per TEASPOON, or gram, of soil. In conventional ag soil, there may be only 1,000,000 individual bacteria per gram of soil.

Consider that the only reason there is enough oxygen in the atmosphere of this planet for aerobic organisms to function is because anaerobic bacteria produced enough oxygen as a waste product to change the composition of gases in the atmosphere. Humans exist only because those tiny creatures performed their functions.

Why is it not possible that bacteria could alter soil pH? They altered the atmosphere of this planet. Why not soil?

Consider the real world, not a greenhouse or lab soil. Nitrate doesn't exist in soil without the biology present and functioning. Without the organisms to alter the form of N, plants won't grow. Now, when people add ammonium to the soil, they alter the normal flow of nutrient cycling. When people say plants take up ammonium, what you need to say back, right away, is, "But is that the form of N that will keep that plant healthy?"

What form of N do different plants need? Some scientists say that N is N, it doesn't matter where it came from. Could that possibly be true? Think about yourself. What form of N do you need? What if you consumed your N in the form of nitrate? You'd be dead in a very short time because your kidneys would go into failure. If you didn't consume enough nitrate to kill you that way, you'd starve to death. People can take up nitrate, but it will kill us. Is the form of N important? Can people consume ammonia? You'll die even faster if you try that form of N.

Is the form of N important? Of course it is. Plants have similar requirements. If all you give a plant is nitrate, it will take up nitrate. But is that the correct form for that plant to grow without stress?

If the only thing you give your plant is ammonium, will that plant take-up that form of N? Yes, but is the plant growing in a healthy fashion? If the plant now needs fungicides, insecticides, herbicides, etc in order to grow, this is not healthy. All inorganic N is highly leachable. Stop destroying water quality by putting these leachable forms of N in your soil or potting mixes.

Some plants do best taking up nitrate, others do better with ammonium.

Is there a generalization we can use to say what kinds of plants do best with the different kinds of N? Annual plants, in general, do better with nitrate. Perennial plants do best with ammonium. "Do best" means not stressed, less subject to disease, stronger cell walls, higher production. Annual plants can use ammonium, for example, but they are not healthy, and require much more pesticide in order to stay alive.

Nitrifying bacteria produce nitrate which is the preferred form of N for annual plants in normal soil – no inorganic fertilizer applications needed. Nitrifying bacteria require and maintain alkaline conditions. That means that terrestrial annual plants grow best in alkaline soils. And they do, in general.

The form of nitrogen is very important then, is it not? When bacteria and fungi grow in the soil, what form of N are they taking up? They probably prefer protein, but they will also take up nitrate, nitrite and ammonium – all of the inorganic forms of N can be taken up by these organisms. But not all species use all kinds of N. Presence of high concentrations of NO3 will select for certain communities of bacteria, or fungi. Nitrite selects for other species, ammonium for other species.

Look at a picture of the root of an annual plant taken with a microscope. In the book called "The Ultrastructure of the Root", by R. Fosterm the most noticeable thing you will see is the deep layer of "slime" present on root surfaces, and the soil around the root. Everything is embedded in the slime produced by bacteria.

Recent work from the USDA in Beltsville show that mycorrhizal fungi also produce significant glues to hold the fungal hyphae on the root, and which help form macro-aggregates in the soil. The pH of these glues are alkaline. When we deal with row crop plants, with most mid-to-early successional grasses, with most terrestrial weeds, and most early successional terrestrial plants, the pH around the roots is alkaline.

But given that the slime layer, the glue around aerobic bacterial cells is alkaline, and there are millions of bacteria per gram of healthy soil, they have to have a large role in influencing soil pH, especially if the soil is bacterial-dominated.

Don't over-extrapolate to wetland plants, riparian plants, hydroponic situations, or high production ag conditions. Different things are going on there. Think about the fact that most plants in high production ag fields are extremely sick, very stressed, and not functioning normally. If they were healthy, they wouldn't need all those pesticides, and they would be able to establish and out-compete the weeds. So, any example based on conventional ag cannot be used. Seriously different things are going on there. And pH is being jerked around all the time by high lime, or gypsum or anhydrous ammonia, or other additions.

Humans alter pH with very little effort. So, you can't use pH as a meaningful measure of anything if pesticides, high level of fertilizers, or compaction have been imposed on soil. And what intensive agricultural soil has not had pesticide, herbicide, high levels of inorganic fertilizer, and severe compaction imposed on it?

But how can normal soils have lower pH than neutral? Different organism dominance. Fungi produce organic acids as major components of their metabolism, but not the STRONGLY acidic organic acids that occur in anaerobic conditions. So, when we test soils that are aerobic, and fungal-dominated, the pH is always somewhere between 5.5 and 7.

This means the nitrifying bacteria are not major players in converting ammonium to nitrate, and so ammonium stays ammonium in fungal-dominated, pH 5.5 to 7.0, healthy forest soils.

What happens in compacted soils?

Compaction destroys the air passageways and water infiltration hallways in soil. If possible, the aerobic organisms start re-building the structure immediately, but their activities may use up the oxygen faster than oxygen can diffuse into the soil. When that happens, the soil loses oxygen, and may move into the facultative anaerobic and finally into the anaerobic zone of metabolism.

How rapid is the loss of oxygen? Depends on how active the organisms are, and how limited the diffusion of oxygen into the soil. Do a soil penetrometer reading. Look how far down the roots of your plants grow.

Take a look at some of Steiner's and Pfiffer's drawings of how far down roots went into soil just a mere 50 or 60 years ago. And now look at what current soils books tell you about root depth.

Something has happened. Roots of plants today don't seem to go down as far as they used to go down.

Look at the USDA definition of soil depth. In the 1940-s and 1950's, soil was defined as material in which you can grow plants. That depth was determined by how far down roots went, and in the 1930's, that depth was defined as 4 to 6 inches. In the mid-1980's, soil depth was re-defined as going down to 12 to 18 inches. In 1994, soil was re-defined again as going down 4 ft. Below those zones, in any time period, you could not get plants to grow in ag that soil. Except for tap roots, roots would not grow deeper than those depths.

How can that be? You have to understand tillage equipment. In agriculture, up to the 1970's, most soils, especially in the Midwest were tilled with mold-board plows which turn the soil to a depth of 4 to 6 inches. With continuing tillage, the soil became so compacted at that depth that water and air could not move through it. The "soil" below that point was anaerobic, salt problems occurred. Water would hold up and not penetrate further into the soil. In the spring, that pan would prevent water from moving into the soil, and then erosion occurred, taking soil downhill.

The solution to this was an engineering approach. Have a hard pan? Break it open physically. Plow deeper. Chisel and disc plows go down to, 12 to 18 inches. The hardpan at 4 to 6 inches was broken up, but the compaction zone was then imposed at 12 to 18 inches, depending on your equipment. Within a few years, the hardpan was so bad at those depths that deeper tilling equipment was invented. We need to break open the compaction zone at 12 to 18 inches, by deep-tilling, or sub-soiling. We shatter the soil down to 4 feet, and so we develop two compaction zones. One at 4 feet, and the “normal” ones at 12 to 18 inches.

As compaction occurs, oxygen movement slows, aerobic organisms go to sleep. Anaerobic organisms start to grow. In aerobic conditions, the bacteria making alkaline slime were predominant. But as anaerobic bacteria, and yeasts (which are fungi, but are not normally functional in soil in aerobic conditions), begin to win in competition with aerobes for the food resources.

Consider the metabolites produced in anaerobic conditions. Alcohols are a major component of anaerobic conditions and are among the most phytotoxic materials that we know. In anaerobic conditions, the roots will be killed.

Unless it’s a riparian or wetland plant. Then these roots have mechanisms for dealing with and getting rid of alcohol. They have the plant world’s equivalent of livers. Enzymes are produced which destroy alcohol, or they pump oxygen into the root system, for example.

What else is produced in anaerobic conditions? Some very toxic organic acids, such as acetic acid, proprionic acid, butyric acid, valeric acid, and a host of other low pH organic acids, only produced in anaerobic conditions. So, what happens to soil in anaerobic conditions? The pH can fall into very low levels. These severely low pH organic acids are strictly produced by anaerobic organisms, and become the dominant determinant of soil pH when the whole soil profile, or a major part of the soil, becomes anaerobic.

Some really nasty phenols are also produced under anaerobic conditions. More killing power in these anaerobic conditions.

What happens to ammonium, or nitrate in anaerobic conditions? They are lost as volatile gas, ammonia. Ammonia is a product of anaerobic microbial metabolism. What happens to sulfur in anaerobic conditions? Lost as hydrogen sulfide. What happens to phosphate in anaerobic conditions? Lost as phosphine gas. Can’t smell it, but you can see it. The anaerobic organic acids metioned above, and of course ammonia and hydrogen sulfide, you can smell. If it stinks, there’s anaerobic metabolism occurring.

Can you grow plants in something where N, P, S has been lost, or at least significantly reduced? Certainly not going to grow well.

Will you be able to grow healthy plants in something where plant-toxic materials have been produced?

Can you grow plants in something where the nutrient-cycling organisms have been killed, or at least put-to-sleep by the lack of oxygen, to say nothing of the toxic effect of alcohol, low pH organic acids, and phenols, or the loss of the exudates from the root systems?

So, at low pH, the soil is in serious trouble. Below pH 4.5, terrestrial plants are not going to do well. Riparian plants? Wetland plants – different story, as explained above.

So, closing the nitrogen cycle requires anaerobic conditions, which results in nitrate or ammonium being blown off as a gas, ammonia, nitrous oxide, or nitrogen gas. And nitrogen is back where we started – in the atmosphere, where our biggest reserve of N is.

Please see the books and CD's by Dr. Elaine Ingham to hear more about the N cycle, microorganisms, and plant growth.

A. 9. Repairing the Soil Food Web

The soil food web is a complex, interdependent, mutually beneficial group of organisms ranging in size from bacteria, to fungi (the largest organisms on the planet) to protozoa, to nematodes, microarthropods, worms and beetles. The foodweb develops good soil structure by binding pieces of soil (clay, sand, silt, organic matter, roots) together and by building airways and passageways through the soil. Good movement of air and water are vital to the health of plants and the soil food web itself. While it seems contradictory, good soil structure both allows water to drain from too wet soil and helps soil to hold water when soils start to dry out.

When considering living organisms, it is true that "everything eats, everything excretes, and everything is food for something". Bacteria and fungi feed on plant residues, breaking them down and holding nutrients (e.g. nitrogen, calcium, iron, potassium, phosphorus, etc.) in their bodies, glued and bound to soil particles, preventing loss of nutrients through leaching. The nutrients bound in the bacteria and fungi are not available to plants, until protozoa, nematodes, small microarthropods, and earthworms consume individuals of bacteria and fungi and release nutrients in plant available forms. The nutrients are released when and where the plants need them, in the form and amounts that plants need. Plants excrete foods for bacteria and fungi from their roots, which are foods for the beneficial species, protecting the root from pathogen and pest attack.

In the process of feeding on plant materials and each other, these organisms also produce hormones that plants need, and consume or break down pollutants in the soil. The soil food web protects all plant surfaces from disease-causing organisms and other pests, often by out-competing them for food, sometimes simply by eating them, by occupying the plant surfaces so the pathogen cannot gain access, and at other times by altering the soil conditions so the disease-organisms cannot thrive.

So much of what modern agriculture has done is to destroy these beneficial organisms in the soil, and on plant surfaces. The goal was to destroy specific pathogen and pest organisms through the use of toxic chemicals, but the beneficial, protective organisms were also killed. And the boom-and-bust-life-style, disease-causing organisms came back faster from those toxic applications. It takes a number of toxic chemical applications, and typically several different kinds of toxic chemical applications have to be made, to wipe out the whole set of beneficial bacteria and fungi, protozoa and nematodes, but it has been done. In typical conventional agriculture fields, bacterial numbers have been reduced from several thousand billion in the root zone, to only a million per gram. Species diversity has been lost, and the disease-selected, the beneficials destroyed. No wonder disease and pests are impossible to control after 30 to 50 years of warfare against the normal set of organisms in soil.

But how do you fix the problem? We didn't know we were harming things so badly, and so nearly everyone has inadvertently caused serious problems in their soils. How do we get the right biology back into the soil?

Step One: Bacterial Diversity Adequate?

Bacteria must be present to perform their functions of competing with disease-causing organisms, retaining nutrients and making microaggregates to improve soil structure. The "correct" density of bacteria, or amount of bacterial activity has just begun to be established, based on observation of what these levels are in different soils, climates, conditions, disturbances and plant species. Seasonal variations and the requirements of different plants appear to be the most important relative factors. The correct values for active bacterial biomass, and total bacterial biomass are given on a Soil Foodweb report, based on season, plant type, soil type and climate, in the row marked "desired range".

1. When total bacterial biomass is too low, bacteria have to be added back to the soil, compost, compost tea or to the water, if working in hydroponics, for example. Add them back by using a healthy, aerobic compost, compost tea or commercial inoculum.
2. When total bacterial biomass is high, most of the time this means improved ability to perform bacterial functions, but if the balance between total bacteria and total fungi becomes inappropriate for the plant species, then the balance needs to be restored. However, you don't kill off bacteria if they are higher than the desired ratio, you improve fungal biomass instead (see Ratios).
3. On rare occasions, total bacteria may compete with fungi for food resources, and in this case, reducing bacterial foods may be a good idea, to allow the fungi to have a chance to grow. Too high bacterial biomass, combined with too low active bacteria biomass may indicate anaerobic conditions occurred, because the bacteria grew very fast, used up the oxygen in the medium so the aerobic organisms went to sleep, but the anaerobes grew well. This can be very detrimental to the aerobic organisms, and actually kill them.

Step Two: Feed the Bacteria

Feed the bacteria, if bacterial activity is too low. Just like any other creature, bacteria require food. Plant roots often supply the simple carbon substrates that bacteria require, such as simple sugars, proteins, and carbohydrates. Bacteria need N, P, K, Ca, and all the other nutrients as well, and obtain those from organic matter and from inorganic sources as well. Various species of bacteria can solubilize mineral elements from the mineral components of soil, but no one species can effectively solubilize ALL minerals. Diversity of species to obtain all the needed nutrients is required.

Often soil tests will indicate that some nutrient is in low supply, but merely by adding the appropriate bacterial or fungal species, these organisms will convert plant unavailable nutrients into plant available forms. Diversity is the key, however, as well as feeding that diverse set of species so they will perform their functions.

1. If activity is low, then bacterial foods need to be added to increase growth rates and improve numbers. A diversity of foods needs to be added, and thus molasses is a much better choice than white sugar. Fish hydrolysate also adds fungal foods, and N and other micronutrients. Fruit juices can be used as well, but diversity is key.
2. If activity is higher than the desired, then try to balance the ratios of the organisms by improving the organism group that is too low.
3. If active bacterial biomass is low, but total bacterial biomass is high, this is a good indicator that anaerobic conditions have occurred. In rare instances, it may be because some environmental disturbance occurred that put the majority of the bacteria to sleep, but did not kill them.

Step Three: Fungal Biomass Adequate?

Fungi must be present to perform their functions of competing with the more difficult disease-causing organisms, retaining nutrients especially micronutrients like Ca, and making macroaggregates which form air passageways and hallways to allow air and water to move into the soil, and to allow good drainage. This is a critical step in improving soil structure, but cannot occur without the first step of good bacterial biomass.

The “correct” density of fungal biomass, or amount of fungal activity, has just begun to be established, based on observation of these levels in different soils, climates, conditions, disturbances and plant species. Seasonal variations and the requirements of different plants appear to be the most important relative factors. Again, the values for active fungal biomass and total fungal biomass are given for the season, plant type, soil type and climate in the row marked “desired range”.

1. When total fungal biomass is too low, fungi will need to be added back to the soil, compost, compost tea or to the water, in hydroponic situations, for example. Add them back by using a healthy, aerobic compost or compost tea. Alternatively, these fungi might be found in healthy soil, especially the humus layer of a healthy forest. But be careful not to destroy that resource by removing too much, or disturbing too much.
2. When total fungal biomass is high, most of the time this means improved ability to perform fungal functions, but if the balance between total bacteria and total fungi becomes inappropriate for the plant species, then the balance needs to be restored. However, you don’t kill off fungi if they are higher than the desired ratio, you improve bacterial biomass instead (see Ratios).
3. On rare occasions, total bacteria may compete with fungi for food resources, and in this case, reducing bacterial foods may be a good idea, to allow the fungi to have a chance to grow. High total fungal biomass, combined with too low active fungal biomass may indicate a fungal disease outbreak in progress. This can be confirmed by examining the roots for necrosis, galls, or other signs of fungal disease.
4. Beneficial fungi require aerobic conditions and if oxygen falls below 5.5 to 6 mg oxygen per liter, then the beneficial fungi may not survive. 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.

Step Four: Fungal activity adequate?

Just like any other creature, fungi require food. Feed the beneficial fungi, if fungal activity is too low. Sloughed root cells and dead plant tissue often supply the more complex carbon substrates that fungi require, such as cellulose, cutins, lipopolysaccharides, complex protein-sugar-carbohydrate, and lignins. Fungi are good at condensing organic matter into ever more complex forms, such as fulvic to humic acids. Fungi need N, P, K, Ca, and all the other nutrients as well, and obtain those from organic matter and from inorganic sources as well. Many species of fungi can solubilize mineral elements from the mineral components of soil, but no one species effectively solubilizes ALL minerals. A diversity of species is needed to obtain all nutrients.

Often soil tests will indicate that some nutrient is in low supply, but merely by adding the appropriate bacterial or fungal species, these organisms will convert plant unavailable nutrients into plant available forms. Diversity is the key, however, as well as feeding that diverse set of species so they will perform their functions.

Both bacteria and fungi are important in holding nutrients in the soil when they would otherwise leach into deeper soil layers, and into ground water. The importance of microbes in forming soil structure and preventing erosion is well-known, but in order to hold the nutrients in soil, bacteria and fungi must turn them into biomass, which is not-leachable as long as the glues and strands that the fungi and bacteria use to hold themselves on any surface are not destroyed.

1. If activity is low, then fungal foods need to be added to increase growth rates and improve numbers. A diversity of foods needs to be added, and thus dead leaf material is a much better choice than purified cellulose. Fish hydrolysate also adds bacterial foods, and N and other micronutrients. Wood, sawdust, bark, paper and cardboard can be used as well, but diversity is key.
2. If activity is higher than the desired, then try to balance the ratios of the organisms by improving the organism group that is too low.
3. If active fungal biomass is low, but total fungal biomass is high, this is a good indicator that disease is either rampant, or about to be rampant. Add BENEFICIAL fungal foods and build soil structure as rapidly as possible to compete with the disease, and protect the plant roots from the disease.
4. In rare instances, it may be because some environmental disturbance occurred that put the majority of the fungi to sleep, but did not kill them.

Step Five: Roots colonized by the "goods guys"?

Mycorrhizal fungi are needed by some plants, absolutely critical for other plants, and are probably detrimental for other plants. You need to know what kind of plant you have, but in general, very early successional plant species, such as many (weeds, brassicas, mustards and kale crops do not require mycorrhizal fungal and may be harmed by mycorrhizal fungi. Annual vegetables, flowers, grasses and row crops or broadacre crops need vesicular-arbuscular mycorrhizal fungi. Most evergreen plants require ectomycorrhizal fungi, and blueberry and ericoid plants require ericoid mycorrhizal fungi.

The percentage of the root system that must be colonized has not been fully established in the mycorrhizal literature, mostly because determining benefit is relative. Mycorrhizal fungi can protect the roots from disease organisms, through simple spatial interference, by improving nutrient uptake, and by producing glomulin and other metabolites that inhibit disease. Stress in plants can be reduced because the mycorrhizal fungi can solubilize mineral nutrients from plant not-available forms to plant available forms, and translocate those nutrients to the root system in exchange for sugars provided by the plant.

Given that mycorrhizal fungi can influence so many aspects of plant growth, and documenting all these benefits is usually extremely expensive and difficult, they have not been documented. Therefore, probably the best that can be done is to say that perhaps as low as 12% colonization might be documented to be beneficial (work by Moore and Reeves in the mid-1990's), but more likely a minimum level of 40% colonization is required, as suggested by Mosse, and St. John in various publications and comments.

Early researchers found colonization as high as 80% in root systems, but most likely because they did not differentiate false-arbuscular and vesicular structures produced by disease-causing fungi from true VAM structures. Thus, colonization is rarely as high as 80% is not commonly found now that we recognize these non-mycorrhizal forms.

In the last 10 years, some researchers have suggested that some mycorrhizal fungi do not produce vesicles under all conditions, and so VA mycorrhizal fungi should be called arbuscular mycorrhizal fungi, not vesicular-arbuscular mycorrhizal fungi. Just be aware that sometimes, people say VAM, sometimes AM. Whatever.

1. If the plant does not require mycorrhizal colonization, there probably is no reason to assess the roots for mycorrhizal colonization. Although the Allens showed that one way for certain plants to exclude non-mycorrhizal plants from a community was to make sure the mycorrhizal fungi were present, because the mycorrhizal fungi pulled nutrients from the non-mycorrhizal plants. This is a probable mechanism for mycorrhizal crop plants being able to out compete weeds and earlier successional plant species.
2. When mycorrhizal colonization is low, or less than the desired range, given that the desired plant requires VAM or ectomycorrhizal colonization or ericoid mycorrhizal fungi, then check how low the colonization is.
    a. If less than perhaps 10 to 15%, then addition of mycorrhizal spores would be a good idea. If it is an annual plant, placing VAM spores near or on the seed or seed pieces is the simplest way to get the roots colonized as soon as the roots area produced.
        i. With permanent turf, adding VAM spores into the compost mixWed into the aeration cores gets the VAM spores into the root system without destroying the turf.
        b. With perennial plants, verti-mulching and adding the VAM or ecto- spores into the compost mixed in the vertimulch is the simplest way to get the spores next to the root system. In cases where we have added inoculum in this fashion, roots have gone from 0% colonization to 25 to 30% within a year, and to 50 to 60% in two years, with addition of humic acids through the season to help the mycorrhizal fungi grow rapidly (see next section)
        b. If colonization is between 15% and 40%, then all that is needed is additional fungal foods to help the mycorrhizal fungi improve plant growth, reduce plant stress, and improve root protection.
    . There is a dose response relationship to humic acids additions. Typically addition of 2 to 4 pounds of dry product, or 1 to 2 gallons of liquid product per acre are adequate to improve fungal growth. But, if there are toxic chemical residues to overcome, additional humics of fulvics may be needed. It is best to check periodically to see that colonization is improving as desired.

i. Be aware that that most humic acid products contain 10 to 12% humic acids. If the product you are considering is less expensive, please check the concentration of humic acid. Half the concentration of the humic acid means they can drop the price, but your fungi get less benefit.

ii. Check colonization periodically to make sure the fungi are growing and colonization is increasing. Weather can cause problems with colonization, and severe drought, floods, burns, compaction causing by over-grazing, heavy machinery, herds of people walking on the lawns or turf can reduce colonization. If that happens, additional applications of fungal foods will be needed to help resuscitate the damage. Fungi are just like any other organism. If they are harmed, they need care to recover. Triage for fungi includes adding foods they love (humic acid is like chocolate to a choc-a-holic, but they'll also accept any woody, wide C:N ratio fungal food), and putting on a mulch or litter layer on the soil surface.

c. If colonization is above 40%, then the plants are getting the help they need from the fungi. Periodically check to make sure nothing has harmed them.

d. What if colonization seems too high? This is extremely rare, but does happen, and seems to be associated with the fungi taking more than their fair share of the plant's resources. Stop applying fungal foods. Consider helping the bacteria compete with the fungi for a bit.

Steps Six, Seven, Eight: Adequate protozoa to cycle nutrients?

Make air passageways? Flagellates (Six), Amoebae (Seven), Ciliates (Eight). These are the three groups of protozoa and they are critical in a bacterial-dominated soil, because the plants need a way to access all the wonderful nutrients tied up in the bacteria. Nutrients within the bacteria cannot be obtained by plant roots, so something has to eat the bacteria to release those nutrients. That's what protozoa do. Protozoa also help build the larger soil pores by pushing aggregates around as the protozoa search for and try to reach the bacteria tucked away around soil particles.

- 1. If the protozoa are too low in number, the nutrients remain tied up in bacterial and fungal bodies. Even if the bacteria and fungi die, they may not release the nutrients in their bodies until the protozoa come along. In many early microbial studies, microbiologists doing plate counts did not recognize that the protozoa were still in their "pure cultures", and it was the protozoa "mineralizing" nutrients, not the bacteria themselves. When protozoa are too low, and nematodes are too low as well, then inorganic fertilizer will have to be added in order to supply N, P, S etc to the plant. This is expensive and a large proportion of these nutrients will likely be lost from the soil, either by leaching or by volatilization. Until the protozoa are inoculated and brought to desired numbers, nutrient loss will continue to be a problem. Protozoa inocula are available in the form of good compost, good compost tea, or from a commercial source, Holmes Environmental, holmesenviro@attbi.com
- If the protozoa are within the desired range, nutrients will be made available for the plants are minimal amounts over time. How much will be made available? That will be discussed in the section on Plant Available N made available to plants (see below). But reductions in fertilizer applications should be possible if protozoa are in good range.
- If protozoa numbers are extremely high, or the different groups are very un-balanced, then nutrient cycling will be variable, and there may be periods when pulses of ammonium or nitrate may accumulate. These forms are subject to leaching and loss through gas production, and may result in weeds having the nitrate they need to germinate, grow and outcompete the crop or desired plant species.
- If ciliates are too high, then the soil is either compacted or water-logged, and lacking oxygen. Ciliates are aerobic organisms, but prefer to consume anaerobic bacteria. They tolerate reduced oxygen conditions better than the other protozoa, so high numbers of ciliates indicate problems with the movement of oxygen into the soil, which needs to be fixed. Of course, it the soil gets too anaerobic, all three groups of protozoa will be low.
- When ciliates are high, but flagellates and amoebae are also high suggests that one of three things may be happening:
    - The sample has just become compacted, or flooded, and the anaerobic conditions have just been initiated. Generally the number of ciliates is not extremely high.
    - The sample has aggregates, which are anaerobic inside the aggregates. The high ciliate signal comes from the internal parts of those aggregates where anaerobic conditions exist, but outside those aggregates, aerobic conditions exist, and thus flagellate and amoebae numbers are typically high as well. Both anaerobes and aerobes co-exist, but in very different places within the spatial structure of this sample. This is very typical of good worm compost, particularly worm compost high in castings.
    - The sample has been anaerobic in the past, but is just becoming aerobic. Flagellates and amoebae are growing because aerobic bacteria have begun to grow. Generally, ciliate numbers will be fairly high, while flagellate and amoebae are just barely in good range. Quite often this will result in nitrate pulses and germination of weed seeds.
- When flagellates are high and amoebae low, or flagellates low and amoebae high indicates an imbalance in nutrient cycling, with pulses of nitrate being produced, resulting in weeds being able to out-compete the desired plants.
- What do you feed protozoa? Bacteria. So, if you have taken care of step one and two, the bacteria should be there for the protozoa to eat.

Steps Nine, Ten, Eleven: Adequate nematodes numbers, and are they the right kinds to help nutrient cycling, and build passageways to let water and air into the soil?

Bacterial-feeding nematodes (9), Fungal-feeding nematodes (10) and Predatory nematodes (11). The beneficial nematodes consume their prey groups, and in the case of bacterial- and fungal-feeders, release N, P, S, and micronutrients that would now be available to plants, if the majority of the cycling occurs in the root system. These nematodes also interfere with the ability of the root-feeding nematodes finding the root. The higher number of these organisms, the more nutrient cycling is occurring.

Step Twelve: The bigger critters home?

Earthworms, Microarthropods.

If earthworms and/or microarthoropods are present, then the full food web is present, and if everything is in a good biomass or numbers of individual organisms, then plant health is pretty much assured, because all the processes will be functioning.

How much do I add to fix any group?

In any case, just an inoculum is required, since all of these organisms will multiply, resulting in increased numbers. Of course, the higher the initial number of individuals added, the faster the return to health. Addition of foods for the organisms will increase the rate of return to health as well.

If toxic chemicals are present in the soil, or litter material, then these materials have to be consumed by the organisms before the twelve step program can be performed. Addition of foods to help consumption by organisms will increase the rate of return to health.

Bacteria – add bacterial foods, such as simple sugars, simple proteins, simple carbohydrates. Molasses, fruit juice, fish emulsion and green plant material high in cellular cytoplasmic material feeds bacteria. The more kinds of sugars and simple substrates added, the greater the diversity of species of bacteria, and the more likely the full range of beneficials will be present.

Bacterial AND fungal inocula can be found in most good AEROBIC composts, or compost teas made with compost documented not to contain E. coli, or other human pathogens.

There are some “starter” bacterial inocula that are useful as well. What you need to look for are maximum diversity in the bacterial species. Unless you are trying to make fermentative compost, you need to avoid inocula containing anaerobic bacterial species.

Fungi – add fungal foods, such as complex sugars, amino sugars, complex proteins, soy bean meal, fish hydrolysate, fish oils, cellulose, lignin, cutins, humic acids, fulvic acids, wood, paper or cardboard. The more kinds of fungal foods that are present, the greater the diversity of fungal species will grow.

There are no fungal inocula on the market. Yeasts are rarely useful fungal species in soil, or at least there is little data to support their usefulness. Some effort needs to expended to show the veracity of this view point.

Protozoa – consume bacteria, and thus to improve protozoan numbers, bacterial biomass needs to be enhanced.

Protozoa inocula are compost, compost tea, and some commercially available protozoan cultures.

Nematodes – consume bacteria, fungi and each other. Inocula of certain entomopathogenic nematodes are available, for control of certain insect species, such as root grubs and root weevils. Compost and compost tea are the only source of inocula for the beneficial nematodes.

Mycorrhizal fungi – need roots to germinate and grow successfully. Humic acids can improve germination, but then the germinated fungus has to rapidly find a root to colonize or it will die. Spore inocula exist for all kinds of mycorrhizal fungi. Make sure you have the kind needed for your plant. Make certain to get the spores into the root system of the plant, such as injecting the spore, or adding compost mix into the soil, filling soil cores with a mix of compost and spores.

This is just a start to understanding how to get the right biology back into the soil. You need to test your soil and figure out where your soil is, with respect to the right biology, and then make a plan on how to get the right biology back. Once you think you have achieved the goal, test again to see if you have achieved a healthy soil condition for your plants.

B. 1. Compost Food Web Information

All of the information in this section applies to compost made by thermal composting, by worm-driven processes (cold-composting), or by static composting. Differences in microbiology between these different ways of reaching the same end-product, as far as the plant is concerned, are in The Biology of Compost book, written by Dr. Elaine Ingham. Please see our product page for information about the book.

Compost is used for one of the following reasons, generally:

1. To add organisms to the soil. This is not just bacteria, but fungi, protozoa, nematodes and often microarthropods. Compost serves as an inoculum of all these organisms, if the compost is made correctly.
2. To add foods to feed bacteria, fungi, protozoa , nematodes and microarthropods.
3. To add structure to the soil. Many composts contain physical structure components like kor (cocnut fiber), clay, fiber, and chunks of wood. These impart physical structure that allows oxygen to move through the material. It is very important to maintain these air passageways into the compost.

Many people think of compost as a source of enzymes, hormones, and plant growth promoting materials. But while those materials are important, they do not last long in soil, or in compost.

What is the "life-expectancy" of enzymes, hormones and other good-food resources for bacteria or fungi to consume in compost, or soil? Unless the organic matter is absorbed on the surface of clay or organic matter – and thus protected from uptake by the plant or more difficult for the bacteria or fungi to access – these nutrient-rich compounds will be consumed by something within minutes. One more caveat - normal biology has to be present. If the enzymes has been separated into sterile conditions, then of course it won't be used as food. But as soon as any protein or sugar (all enzymes are proteins, all hormones contain sugars and/or protein in their structure) is put into a habitat where bacteria or fungi are actively growing, that food is going to be gone.

What makes enzymes, hormones, and plant-growth-promoting materials? The bacteria, fungi, protozoa, nematodes and microarthropods. So, really, what you want to be adding is the biology, because they will make more of the enzyme you want. Or the hormone. Make certain that the compost contains the right set of bacteria, fungi, protozoa and nematodes so the process you want will occur. If you buy really good compost, the microarthropods will be present too.

There is a “best food web” for each combination of crop type, climate, region, soil type, amount of organic matter and water supply. The ideal food web balance for row crops in Arizona is different than the ideal balance for fruit trees or grapes in California (see SFI Approach, Succession and the Soil Foodweb) LINK

So, make or buy compost that will make a habitat appropriate for your plant to grow. In general – and this is a huge generalization – annuals need bacterial-dominated soil to maintain pH, form of N, soil structure, and nutrient cycling correct for those plants. Perennials need fungal-dominated soil to maintain pH, form of N, soil structure and nutrient cycling correct for the long-lived plants. Exceptions? Sure. But in general, this holds true everywhere we are looking at this all over the world.

Now, if growing plants in soils where the biology isn’t right, you can get plant growth, by using the toxic chemicals to try to overcome the diseases that will attack the stressed plants, by using chemical salt inputs to try to feed the plants the inorganic nutrients they need. But the plant is not healthy, it is stressed, and the food it makes is not the best for human consumption.

Can we increase production of plant material in un-healthy systems? Sure. But at what cost to water quality? What cost to human nutrition? To the quality of our lives? The long-term impacts are going to be staggering.

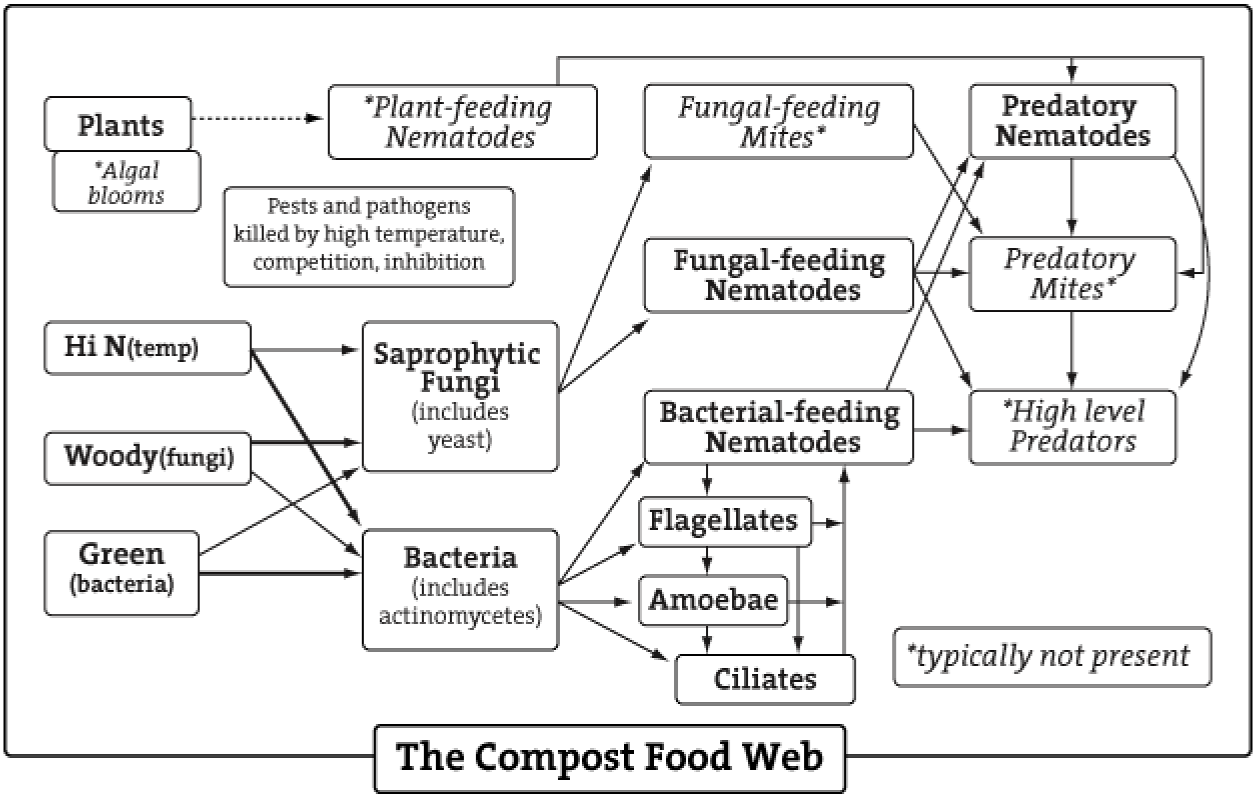
So, when trying to decide what compost is needed, and when trying to determine what compost to buy, understand your purpose in using compost very clearly.

The tests you need then should be come clear.

- For example, if you want to know what organisms you need, you need to do a full foodweb analysis. If you don’t know what part of the food web may or may not be “out of whack”, you have to figure that out first.
- You also need to know if the biology is lacking, or a chemical lack is preventing plant growth. Biology can’t solve the plant’s problems if all the calcium in your soil has leached away, or is tied up on the carbonates, clays, or organic matter in your soil. You might need to add some form of calcium first, and get the biology back to make sure that calcium STAYS in your soil.
- If you have done a foodweb analysis in the past, and know your soil lacks fungal activity, for example, then all you need to assess is fungal activity and total fungal biomass. Perhaps mycorrhizal colonization as well, since this assay includes disease encountered on the root system, as well as insect feeding damage.
- If your problem has been root-feeding nematodes in the past, then perhaps you just need to assess whether addition of the biology has out-competed, inhibited and consumed those root-feeders.

B. 2. The Compost Food Web

< back - note: please scroll down to read the explanation



Compost organisms perform a number of important processes during composting. But their importance doesn't stop there – those organisms survive and live in soil, on leaf surfaces, and around roots, leaves, stems, blossoms, etc. They can create a protective layer on leaves, stems, blossoms, fruit and any above-ground as well as below ground surface.

Bacteria and fungi – the WHOLE diversity of these organisms, not just one or five or 20 species, but the whole 25,000 or more that could potentially be present in good compost - retain nutrients in the compost, and ultimately, in your soil too. Or on your leaf surfaces, if you could somehow get compost to stick to leaves. Except, that is possible, if you turn the compost into compost tea – see the sections on compost tea!

Protozoa and nematodes – the good guy nematodes only please! – then mineralize nutrients from the retained nutrients held by the bacteria and fungi. In compost, these mineralized nutrients serve to help other organisms grow and utilize the carbons sources in the organic matter put in to the compost pile.

Bacteria and fungi build micro- and macro-aggregates in the compost as well, and the protozoa and nematodes help build the larger pores in compost, so within a week or so, if you have the right biology in the compost, air passageways and water-infiltration-hallways have been built by the organisms. Turning becomes less and less critical as the biology grows and forms structure for you.

If the compost pile can be left alone, and you have a good set of local microarthropods or earthworms that can move into the pile, then they will move into the pile and set up housekeeping too, stimulating the growth of the fungi, and building structure, improving aeration, aggregation, and taking care of any pathogens in the pile.

Vermicompost, or composting using worms instead of heat, shifts the species of bacteria, fungi, protozoa and nematodes as compared to thermal composting, and generally, worm-compost contains some extremely beneficial bacterial and fungal species that are in lower densities in thermal compost. The worms quite clearly enhance certain beneficial bacterial and fungal species. Worm compost is also generally much higher in protozoa, and often have quite complex aggregation patterns that result in a great range of food resources for the beneficial species in the compost.

The dynamic, living system in compost is very influenced by the foods you choose to put into the compost pile, by the biology on the organic matter going into your pile, and by rain, wind, heat, sunlight, and pollution that occurs while you are composting. Only if some disturbance harms the community of beneficial organisms in compost will disease be able to get foothold in the pile.

Understanding compost health requires knowing:

1. what organisms should be present (community analysis),
2. how many are present (total biomass of each group), and
3. how many should be functioning (active biomass).

If anything has been harmed or reduced, or put out-of-balance during the composting process, you either have to start over again, or use a good compost tea to replenish the lost organisms.

Plants depend on beneficial microorganisms in the following ways:

1. to protect them from pathogens,
2. to retain nutrients in the soil so they do not leach from the root zone,
3. to cycle nutrients into plant available forms (both predator-prey and mycorrhizal fungi function to these ends),
4. to improve uptake of soil or foliar nutrients,
5. to break down pollutants in the soil, on on aboveground plant surfaces or around the roots, and
6. to build the air passageways, hallways, lving rooms, dining rooms, kitcnes, and swimming pools that allow air and water to move into the soil, and to be retained so roots can grow as deep into the soil as physiologically possible, and obtain water and nutrients all year long, regardless of drought.

If the organisms that perform these benefits are missing, they need to be replaced.

The food web in compost will not contain many of the higher level predators if the compost is turned often. But as time from last turn increases, and there is a source of the beneficial organisms to colonize the pile, the higher trophic level, predator organisms will colonize, survie and grow in the compost pile.

Pests in the compost pile need to be discouraged by the habitat built by the biology in the pile. A good compost should be resistant to any diseases moving into the pile, because the beneficials have fully occupied the pile. If something happens to favor the growth of pests, however, then diseases or pests may be selected, and take over the pile. Biology is always a process, never totally stable, never something you can just ignore.

Factors important in making compost:

1. The starting materials
    a. Commercial composting
    a. i. Quality
        b. ii. Quantity
        b. Back-yard composting
        . i. Quality
        a. ii. Quantity

2. Moisture
    3. Aeration – chunkiness and aggregation
    4. Mixing/Turning
        . Commercial composting
        a. Back-yard composting

The Starting Materials

Do you want the final compost to be bacterial, or fungal? Are you making thermal compost, or worm compost? Do you want to be finished in 6 weeks, or can you take more time?

You have to know these answers in order to select for the right kinds of starting materials. We can reach the same end-point – from the plant's point of view – with any composting approach you want to take. From the point-of-view of the microbiology of the compost, each stick of wood, each leaf of each plant, each different kind of material you add in will change the species composition of the compost pile.

Diversity

From a human point of view, what level of resolution do we need to know?

We don't need to know the precise names of all the organisms in the compost pile. Just like a human city, we don't need to know the first and last names of each human in the city in order to be able to know if that city is a good place to live. Is it functioning properly?

We need to know if the diversity of bacteria is adequate, if there is enough bacterial activity so the functions of nutrient retention, disease-competition and microaggregate building are going to be performed adequately. Fungal diversity needs to be adequate too, so the functions of the fungi are carried out properly. So, we need to know active bacterial biomass, total bacterial biomass, active fungal biomass, and total fungal biomass in order to know if the compost is good for the plant we want to grow.

Activity

There are minimal levels of activity and total bacterial biomass, active and total fungal biomass that are needed regardless of plant type, and then we can change whether the compost will be more fungal or more bacterial, by adding in foods that shift fungal or bacterial growth, just as you put the compost out on the soil, or use it to make compost tea.

To heat or not-to-heat?

Heat in a thermal pile is the result of the growth of bacteria and fungi. The more rapidly bacteria and fungi grow, the faster the pile will generate heat. You have to have the right ratios of carbon and nitrogen, but all the rest of the nutrients must be adequate so these other nutrients are not limiting either. But generally, in plant material, all the other nutrients are in good amount, it is the C:N ratio that will determine how hot the pile will get.

These ratios, the proper way to alter the relative amounts of high nitrogen plant material to not-high nitrogen plant material to low nitrogen plant material is explained in the compost book.

The compost biology book also explains why with back-yard composting, the ratio of high N to not-high N to low N has to be different. With back-yard composting, we only have to turn once after the pile has gotten started, but with commercial composting, we have to turn more often.

The need for proper "chunky" material is also explained, as well as how to aerate the pile. Again, back-yard is quite different from commercial conditions.

There are any factors that can be worked with to make compost be what your plants need, and that will help you reduce, and most likely end entirely, your reliance on toxic chemicals in order to raise high yields of fruits and vegetables. Let us help you do that. Check out the Compost Biology book *available June 2004*.

B. 4. How to Tell Good Compost

Compost Standards

Use the chart below(in development) to determine whether the compost you have can successfully transfer the minimum organism biomass for each of the different groups in the soil or compost food web to the soil.

Your soil needs the right biology in order to grow the plants you want, without the use of toxic chemicals. If your soil, potting mix, hydroponics medium, or compost lacks the minimum set of organisms, steps need to be taken to re-establish the right set of organisms.

First, you need to establish what biology is present in your soil, and what biology is in the compost or compost tea you will add to the soil. The fastest way to do this is to send in a sample of both the soil and compost or compost tea to determine the biology present.

Second, you need to determine who you adding the compost or tea to the soil. Directly on the surface may mean a time period while the organisms move into the soil. Typically, bacteria and fungi need to be carried deeper into the soil by protozoa, nematodes, earthworms, and/or microarthropods. If you don't have these larger predator organisms, then you have to physically move the organisms into the soil, by tillage (which will harm the predators an fungi), or by coring and re-filling the core holes with compost, or a mix of compost and sand.

The alternative to using microbial assays to fix your soil is use of cover crops and organic matter additions to try to move the biology in the right direction. If you have time and an observant eye, you can use plant responses as an indicator that the additions you made last year, or earlier in this year are moving the biology in the correct direction. This approach takes time and patience, and may result in the loss of a crop or two before you learn to recognize what the plants are trying to tell you about the management you perform.

The compost you use needs to have the right biology. That's the answer, the right biology.

With the right set of organisms, disease organisms will be prevented from having unrestricted access to your plants. Nutrients will be retained in your soil, instead of ending up in your drinking water, surface waters and the ocean, killing the organisms there as the result of toxic accumulations of nutrients. Nutrients will be cycled into the proper forms at the proper pH, at the proper time, for the growth requirements of your desired plant, if the right biology is present. Soil structure will be improved, and typically, pesticide use falls to practically nil when the biology sets the conditions in your soil to select for the growth of your desired plant. Water use decreases, because you retain water in the soil instead of having it wash right through the soil. Organic matter is important, but the biology on that organic matter are the real keys. Together, the right biology and the foods to feed them will allow the plant you want to grow to the exclusion of other plants.

Desired levels of organisms (direct microscopy) **in aerobic compost or vermicompost** (measured in fresh weight compost, but expressed per gram dry weight of compost).

In the past, these values were considered to change slightly through the year, but as we realized that good compost has to reach temperature regardless of ambient temperatures. That means you can compost in Minnesota in the middle of the winter – you just have to have the starting materials at 60 to 65 or higher for the first three days to get things going.

Bacteria

- 15 to 25 or more µg active bacteria /g dry weight compost
- 150 µg (fungal compost) to 300 or more µg (bacterial compost) total bacteria /g dry weight compost
- 15,000 - 25,000 or more bacterial species (using molecular methods), minimum total bacterial biomass using direct methods

Fungi

- 15 to 25 µg or more active fungi /g dry weight compost
- 150 (bacterial compost) to 300 or more (fungal compost) µg total fungal biomass/g dry weight compost
- Hyphal diameters should on average be 2.5 micrometers or greater than 2.5 µm
- 5,000 to 8,000 or more fungal species (using molecular methods), minimum total fungal biomass using direct methods

Protozoa

- 50,000 or more protozoa per gram dry weight compost
  25,000 or more flagellates
  25,000 or more amoebae
  50 - 100 ciliates. Higher numbers indicate anaerobic conditions resulting from compaction, water-logging, discontinuities in soil

Nematodes

- 20 to 100 BENEFICIAL nematodes per gram dry weight of compost
  10 - 15 bacterial-feeders
  5 - 10 fungal-feeders
  1 - 5 predatory nematodes
  No root-feeding nematodes

Mature Compost

- < 10% activity of bacteria and fungi indicates a mature compost

Habitat requirements for beneficial bacteria, fungi required to obtain thermal death of pests and pathogens

Thermal Compost

- Maintain 5.5 ppm O2 (dissolved gases) or higher during compost cycle
- Pleasant Smell
- Moisture 45 to 75%
- For thermal compost: Temperature of 55 C or higher for at least 3 days in all parts of the compost: No greater than 70 C. Compost must be turned to achieve adequate temperature throughout pile. Turn compost every time compost approaches 68 to 70 C to maintain adequate air throughout pile.

Vermi-compost

• For vermicompost: At least 75 to 80% of the material in the worm bin must actually pass through the worm digestive system. No weed seed can be added or materials must be pre-composted

Testing Requirements

- Starting materials used must be stated
- Chemistry and Pathogen Testing must meet local standards (city, county, state, Federal).
- Test each batch for organisms for the first three months or until tests show three consistent sets of compost produced at or above levels given above
- Once initial testing passed, test each 3 months, or each set of different starting materials.

Thermal compost

- For thermal compost: Turning times, daily temperature, end moisture, and daily CO_2 or O_2 data must be submitted for each batch of compost

Vermi-compost

- For vermicompost: Number of worms per unit volume must be assessed, temperature, and oxygen data must be submitted

Sampling requirements for healthy foodweb assessment

Thermal compost

- At 5 feet height above ground, dig directly toward the hottest center of the compost (measure temperature and CO_2 or O_2), remove sample 2 feet into the pile. Place in clean container.
- Repeat 5 to 10 times at equidistant spacings on both sides of the compost pile
- Mix with clean utensil.
- Remove approximately 500 g of compost, place in clean plastic, sealable bag and send overnight to SFI lab. Send with completely filled out sample submission form
- Match the fungal:bacterial ratio to the requirements of the plant; give a clear indication of intended use requirements
- Date to be used by, and required storage conditions to assure maintenance of beneficial organisms must be on the bagging materials.

Vermi-compost

- Mix material removed from worm bin in clean container.
- Remove approximately 500 g of compost, place in clean plastic, sealable bag and send overnight to SFI lab. Send with completely filled out sample submission form
- Match the fungal:bacterial ratio to the requirements of the plant; give a clear indication of intended use requirements
- Date to be used by, and required storage conditions to assure maintenance of beneficial organisms must be on the bagging materials

C. 1. Understanding Compost Tea

1. Why Use compost tea?

Compost tea is used for two reasons: To inoculate microbial life into the soil or onto the foliage of plants, and to add soluble nutrients to the foliage or to the soil to feed the organisms and the plants present. The use of compost tea is suggested any time the organisms in the soil or on the plants are not at optimum levels. Chemical-based pesticides, fumigants, herbicides and some synthetic fertilizers kill a range of the beneficial microorganisms that encourage plant growth, while compost teas improve the life in the soil and on plant surfaces. High quality compost tea of will inoculate the leaf surface and soil with beneficial microorganisms, instead of destroying them.

What is compost Tea?

Compost tea is a liquid produced by leaching soluble nutrients and extracting bacteria, fungi, protozoa and nematodes from compost. The brewing process is performed at constant temperature, although the growth of the organisms may elevate temperature as a result of their reproductive heat produced.

Tea production is a brewing process, and as easy as making beer or wine. But we all know that wine or beer brewing isn't that easy. Brewing compost tea can be fraught with problems. But if you think about what you are doing, and pick out the right tea-making machine, making compost tea that will help your plants is easy as flipping a light switch. What is your purpose in making tea? If you want to inoculate a highly beneficial group of bacteria and fungi, protozoa and possibly nematodes, buy good compost that has these organisms, and make Actively Aerated Compost Tea. There are a number of excellent tea makers on the market (see How to make AACT).

Benefits of using of compost tea containing the WHOLE foodweb include:

- Improve plant growth as a result of protecting plant surfaces with beneficial organisms which occupy infection sites and prevent disease-causing organisms from finding the plant,
- Improve plant growth as a result of improving nutrient retention in the soil, and therefore reduce fertilizer use, and loss of nutrients into ground- and surface waters
- Improve plant nutrition by increasing nutrient availability in the root system as predator-prey interactions increase plant available nutrients in exactly the right place, time and amounts that the plant needs,
- Reduce the negative impacts of chemical-based pesticides, herbicides and fertilizers on beneficial microorganisms in the ecosystem
- Improve uptake of nutrients by increasing foliar uptake as beneficial microorganisms increase the time stomates stay open, while at the same time reducing evaporative loss from the leaf surface,
- Reduce water loss, improve water-holding in the soil, and thus reduce water use in your system,
- Improve tillage by building better soil structure. Only the biology builds soil structure, and ALL the groups in the foodweb are required to be successful. You can't have just bacteria, you must have fungi, protozoa, nematodes and microarthropods as well! Please be aware that plate count methods don't tell you about the whole foodweb.

What is in compost tea?

Tea contains all the soluble nutrients extracted from the compost, but also contains all the species of bacteria, fungi, protozoa and nematodes in the compost. Not all the individuals in the compost, but representatives of all the species in the compost are found in the compost tea. Making sure only beneficial species are present in the compost is therefore critical.

Outdated methods of assessing numbers of organisms in samples might lead you to believe compost tea doesn't have much diversity. But, consider that species diversity in soil is much, much greater than plate count data would lead people to believe. Plate counts miss 99.99% of the bacterial and fungal species in soil. You need to use molecular methods to understand true species diversity in compost.

Plate count assessments of diversity in compost and tea, and soil should not be used. They are misleading about the true diversity, or even as an indicator of diversity in soil, compost or compost tea. Good, aerobic compost contains a huge diversity of organisms.

Foods extracted from the compost, or added to the tea, grow beneficial organisms. A large diversity of food resources is extracted from compost. The species diversity of organisms in the tea is much higher than those hundred or so species of bacteria that grow on the food resources added by people. Together, the beneficial bacteria and fungi growing on the compost foods, and on the added foods, result in a many individuals of many different species. Molecular diversity analysis is required, however, to assess even a small portion of the species present in compost tea.

Only aerobes are desired. Anaerobes make alcohols that kill plant tissues very rapidly. Putrifying organic matter, which is anaerobic, also contains organisms, just not organisms that do anything beneficial for your plants.

Most introductory microbiology books can answer most questions about the controversy between direct enumeration and plate count approaches. Reading the sewage treatment literature also points out clearly the conditions that allow E. coli to grow, which means reduced oxygen atmosphere. In full aerobic conditions, only if the beneficial bacteria have been killed or harmed can E. coli win in competition with aerobic organisms.

The list of papers specific to compost tea and compost have been summarized by Steve Diver, and are listed on the ATTRA website, www.ATTRA.org

When buying a tea machine, you should ask the manufacturer to provide information about oxygen during the tea brewing cycle in the compost basket or bag. You should insist on being given molecular analyses of diversity, and total and active bacteria and fungi, and protozoa, present in the tea made under standard conditions.

The METHOD is critical in making tea

In order to have the organisms in the tea, brewing conditions must be correct to produce the end product desired.

The biology that is active and performing a function will be very different, depending on:

- temperature of brewing,
- the foods added to the brew,
- oxygen concentrations in the brewer during production,
- the initial compost used, and therefore which species are present to be extracted,
- The length of time tea is brewed.

Temperature

Temperature during brewing should be related to the temperature of the soil, or of the leaf surface. If tea is applied in the late autumn, when temperatures are cool, it may be wiser to apply a tea where the organisms are mostly asleep, or that are selected to grow on plant residues. Selection for this ability would be enhanced by addition of plant material to the brew, such as oatmeal, alfalfa meal, feathermeal, etc.

Foods

Foods added to a brew will select for particular species that can use those foods. Do you want a bacterial tea? Add sugars, simple proteins, simple carbohydrates. If a fungal brew is desired, add more complex foods, such as plant material (oatmeal, soybean meal, flour), humic acids, fulvic acids (which will release bacterial foods after fungi begin the process of decomposition). Predators can be enhanced by adding hay (cut green and dried), or by soaking hay for a few days and adding the water to the tea brew.

Oxygen

Oxygen is perhaps the parameter that has been least understood in centuries of tea-brewing. Most beneficial organisms, the organisms that promote the processes that plants need in order to grow without stress, and therefore with greatest resistance to disease, are aerobic organisms. To enhance this community of beneficials, tea must remain aerobic.

Fermentative microorganisms are organisms which can grow in aerobic as well as reduced oxygen conditions. Since these organisms have dual metabolic abilities, they have to maintain the genetic material for both sets of enzymes. They have an energetic load that means they are not as competitive with true aerobes, when oxygen is in fully aerobic concentrations. They are not as competitive when in competition with true anaerobes at low oxygen concentrations. They do best in the conditions where oxygen is fluctuating in the intermediate aerobic – anaerobic range. These organisms can make very interesting waste products when growing in anaerobic conditions. These materials are known to have significantly inhibitory effects on a variety of less-desirable organisms.

The problem is maintaining the conditions exactly correctly so that the desired organisms grow. This knowledge is not public domain, and remains proprietary. Until attention is directed to understanding what products result from different aerobic – anaerobic conditions, with which foods, and with different temperature regimes during brewing, fermentative compost teas remain in the questionable realm. These teas don't produce the same effects time-after-time, which is the reason that compost teas have languished in the "snake-oil", and "voo-doo-juice" category for so long. If the tea you brew today has one effect, but the tea you brew tomorrow has a different, and possibly negative effect, that lack of reliable results will destroy the reputation of a product. It is most important to clearly maintain production conditions when making tea.

Anaerobic conditions (below 2 to 4 mg oxygen per L for example) during brewing can result in the growth of some quite detrimental microbes and production of some very detrimental metabolites. It is best to avoid extremely low oxygen concentrations during brewing, or if low oxygen concentrations occur, brewing must continue until the organisms stop growing on the added foods, such that oxygen will diffuse back into the brew. Only after the brew returns to the aerobic conditions should it be used on plants or soil.

If you want to make a mix of unknown, but possibly quite anti-bacterial, or anti-fungal materials, then a fermentative approach might be best. The specific conditions needed for production of a consistent mix set of inhibitory substances are not well-documented. More work is needed to understand production parameters for this kind of tea.

Is compost or compost tea "better" if it is aerobic or anaerobic?

Bacteria that cause human diseases almost invariably require anaerobic or reduced oxygen conditions in order to survive in competition with aerobic organisms. Only in reduced oxygen, or anaerobic conditions, can human disease-causing organisms out-compete the normal set of beneficial bacteria or fungi growing in soil, compost or compost tea.

If you've done a good job choosing or making your compost, the compost will not contain any human disease organisms. The tea will not contain human pathogens if there were none in the compost. What do you need to know in order to be assured that the compost contains no human pathogens? The temperature cycle of the compost. Insist on getting that data from the compost maker. What do you care about the amount of nitrate, if there are human pathogens in the "compost"?

If the compost was kept fully aerobic, and temperatures between 135 F and 155 F were maintained for 10 to 14 days, or the compost was processed by adequate numbers of earthworms, the likelihood of human pathogens in the compost is just about nil. Contamination of finished compost by something else containing pathogens is possible so be aware that this can be a problem too.

If the compost wasn't processed correctly and disease-causing organisms weren't destroyed by temperature, competition with beneficial organisms, or passage through earthworms, the probability is reasonable that disease-causing organisms will grow rapidly and be in high numbers in a tea that goes through reduced oxygen, or anaerobic, conditions.

If the tea was made with good compost (high numbers of beneficial bacteria, fungi, protozoa, nematodes; good soluble nutrients) using aerobic conditions, there is little likelihood that human pathogens could grow, because not only are conditions not correct for their growth, but they will be out-competed and inhibited by the aerobic bacteria and fungi growing in those aerobic conditions.

It is critical to know that the tea maker you are using can maintain aeration rates greater than the rate the bacteria and fungi use up the oxygen.

Oxygen or carbon dioxide can be monitored to determine whether aeration is adequate throughout the whole brewing cycle, and in all parts of the machine. Please be aware that the data needed are from the inside of the compost basket, or inside the compost bag. Currently, all national level compost tea manufacturers display SFI data on their websites, with only two exceptions. People who bought machines from these two companies have sent data to SFI showing that either inside the compost baskets or the bags, the tea went anaerobic during tea brewing, or serious anaerobic bio-films develop in places that you can't see or can't reach easily during cleaning.

Oxygen in the tea should not fall below 5.5 to 6 ppm dissolved oxygen, which is typically about 70% dissolved oxygen, or 15 to 16% oxygen when measuring total atmospheric gases. These values change based on altitude and temperatures, so make sure the oxygen probe comes with information on typical maximum oxygen levels, which is where your water in your tea maker will start out.

You can't tell whether oxygen use, or carbon dioxide production, was performed by bacteria or by fungi. Since you need to know, at least occasionally, the ratio of fungi to bacteria your tea, you need to test your teas so you can be certain you are making disease suppressive tea.

Fungi grow very well indeed in compost tea.

For good fungi in tea, first of all, fungi in the compost have to be extracted adequately. This is a function of two things, presence in fungi in the compost, and rapid enough water movement through the compost to pull the fungi off the compost particles. Work with Bruce Elliott of EPM (sales@composttea.com) has shown how easy it is to get great extraction and growth of fungi in the tea.

The EPM, KIS, WormGold, and BnBrewer machines in the US, Tea-riffic® in Canada, the Compost Tea machine in New Zealand, and Compara in Europe, in do excellent jobs of extracting fungi from the compost and allowing it to grow in the tea. Testing, over one to two years, shows that these machines continue to make good tea. Machines with hidden surfaces that develop biofilms do not maintain good tea production over time.

Sales people from companies that cannot pass SFI standards like to say that "fungi don't grow in tea", or "there are lots of fungi in the soil already". Please realize that what they are actually telling you is that the machines they sell do a poor job of extracting fungi and growing fungi. Fungi can be extracted and grow quite well in tea.

When soils have been treated with fungicides, including copper sulfate, or sulfur, the soil cannot possibly maintain normal levels of beneficial fungi. Adequate beneficial fungal biomass does not occur in any field treated with fungicide, insecticide, bactericide, nematicide, herbicide or high levels of inorganic fertilizer.

Fungi require foods to feed them

If the compost contains complex food resources, that can be enough to feed many fungal species, but usually additions of humic acids, and complex nutrient resources enhance the growth of beneficial species. People involved in making tea often research nutrient food resources. Hendrikus Schraven Landscaping (gina@hendrikusorganics.com), EPM (sales@composttea.com) and Leon Hussy at KIS (www.simplici-tea.com) make some outstanding food resources for bacterial and fungal teas. Many ideas for foods for bacteria and fungi can be found on the compost_tea list serve, www.compost_tea@yahoogroups.com

Species diversity

Species diversity is the same in compost and the tea made from that compost. Species diversity in compost is higher than fumigated or sick soil. But at least one plate count microbiology lab is giving out data suggesting that compost has lower diversity than bad soil and that “ok” tea has less diversity than bad compost. It is clear that plate count “diversity” methods are not effective in assessing species diversity, or species richness, in soil, compost or compost tea. Molecular methods tell us that species diversity in soil, tea, and compost, can number in the thousands and tens of thousands per gram.

Use of methods that tell you that soil contains only a few 5 to 10 species, or that compost contains only 8 to 15 species need to be viewed with a great deal of incredulity. Plate methods are missing only about 99.9% of what is actually present!

Do plate counts or direct counts assess tea quality? The clear answer is that direct counts assess tea quality, while plate counts do not. Take a look at the results (below) from a test where two different teas were used to control blight on tomato plants.

Compost bags

Multi-layer fabric, or felt, bags are a poor idea, because the hyphae get held in the fabric, and mildew grows in the damp material. Single layer, nylon or netting bag material is necessary.

Time to brew

Small, well-aerated, well-mixed compost tea makers can give great tea within 10 to 12 hours. The KIS machine gets great organism extraction and growth of the beneficial organisms in 12 hours, based on direct counts of the individual bacteria, measurement of biovolume of fungal hyphae, enumeration of protozoa and nematodes from those teas.

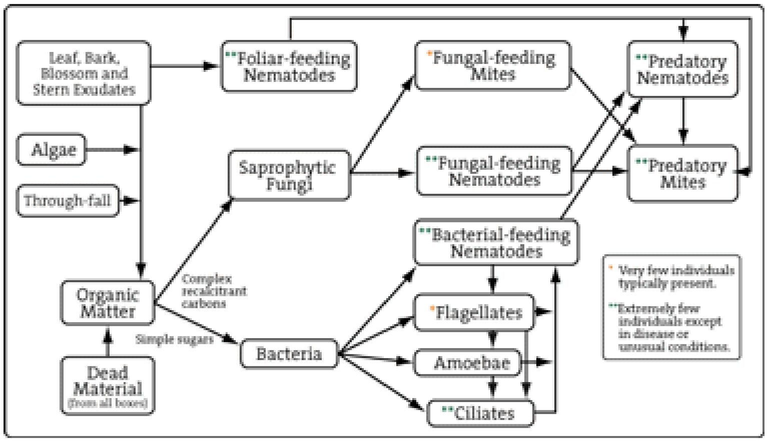
Pay attention when you buy a machine or develop a design. Different tea machines take different amounts of time to brew good tea. Especially those machines that take 48 hours or more to brew a decent level of organisms in their tea, the salespeople tend to be very reluctant to tell you exactly how long the tea takes to reach a certain organisms-in-the-tea level. For example, some machines take a minimum of 48 hours to brew the tea, and as a result, tend to have more problems with becoming anaerobic.

Several “tea-brewer” manufacturers have no data about maximum bacterial or fungal production with their machine, and certainly no clue at all about protozoa or nematode numbers. Their salespeople will tell you their tea is ready in 24 hours, but they don’t have any data to prove this to you. Buyer beware!

What is the shelf life of compost tea?

The shelf life is short in high quality tea with active organisms necessary to attach to lead surfaces and not be washed off. In the research that we have done with 24 hour brewing cycles, after just 6 hours without any aeration, the oxygen levels are lowered by over 300 %. If the compost tea is not used within that time, aerate, agitate and add more food to the tea to feed the micro-organisms.

C. 2. How does the Foliar Food Web affect plants?



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Foliar organisms create a protective layer on leaves, stems, blossoms, fruit and any above-ground just as happens in the soil, around roots.

This dynamic, living system on the aboveground parts of plants is constantly impacted by rain, wind, heat, sunlight, and pollution. Often disease can gain a foothold after some disturbance harms the community of beneficial, plant-surface dwelling organisms.

Understanding foliar health requires knowing:

1. what organisms should be present (community analysis),
2. how many are present (total biomass of each group), and
3. how many should be functioning (active biomass).

Healthy Leaves, Soil, or any System requires:

1. Organisms that cycle nutrients into the right forms at the right rates need to be present on the foliage in the right diversity, in the right number, in the right places (growing on the exudates plant surface release) with the right level of activity,
2. Organisms to prevent disease-causing organisms from being able to find a foot-hold on leaf or plant surfaces,
3. Organisms that cause plant stomates to open and remain open longer so nutrients added with the microbes will be pumped into the leave surfaces more rapidly, when the plant is supplying foods to make microbial activity occur,
4. Organisms to degrade toxic materials, especially air-borne pollutants,

Aren't organisms present in the soil, or on leaves, or in compost just automatically?

NO, they are not. Consider all the toxic chemicals human beings release on a daily basis. Consider air pollution. If air pollution is killing human beings, think of the damage to smaller, less well-protected individuals. Dust, and toxic pesticides and salts are being poured out onto soil, onto plant surfaces, each day. Natural disturbances (freeze, thaw, wet, dry, fire, and compaction) can kill critical organisms as well. We need to learn the impact of all disturbances, whether human-generated or natural occurrences. We need to learn how to replace, encourage and select for the presence of the appropriate organisms.

If nature kills organisms through natural disturbance, we need to know how to return to what is needed for the crops we want, just as we need to know how to return the organisms to what is needed after we use any chemical, for whatever reasons. It would be better not to let disturbance kill the organisms we want, but sometimes, we just don't have any choice. We have to learn how to nurture the right biology and bring it back.

If anything has been harmed or reduced, or put out-of-balance, the appropriate organisms must be returned to the plant surfaces if they have been harmed or reduced in diversity or biomass. If the organisms that perform these benefits are missing, they need to be replaced.

The foliar food web will not contain the higher level predators. In unusual disease or pest outbreaks, such as ants farming aphids on foliage, it may be necessary to discourage the ants from this behavior by adding some ant-pathogenic fungi into their nests, or adding the fungi to the tea brew so the ants pick up the fungus and take it home with them on their feet.

Foliar pests can be discouraged by the smell, the taste, or the tackiness of the leave surface that foliar compost tea brews leave behind. The precise mechanism needs to be determined for why this works.

Bacteria are typically the dominant microbe on leaves, twigs, branches, blossoms and bark. Decomposer or saprophytic fungi are also present. Both bacteria and fungi use the exudates produced by the plant, by algae or lichen growing on plant surfaces or deposited by through-fall or other deposition processes. Maintenance of the proper coverage of organisms on the leaf surfaces is critical to maintaining disease suppression in the foliage of any plant.

How can the Soil and Foliar Food Web be assessed?

Methods have been developed that allow the numbers, types and activity of each important group in the soil and on plant surfaces to be quickly assessed. The kinds of assessments used are:

- Number of individuals or biomass of each group
- Type of organisms present and who is dominant
- How active the organisms are
- Relation of soil organisms to plant available nutrients

All of these methods need to be performed by direct microscopy, not by plate counts, enzyme assays, or other in-direct assessment methods.

C. 3a. How to make Actively Aerated Compost Tea

Aeration must be adequate to extract the maximum amount of soluble nutrients, and to maintain oxygen in aerobic concentrations in order to produce a tea high in aerobic bacteria and fungi, and with maximum extraction of protozoa and nematodes. The more diverse the community of microorganisms extracted and grown under aerobic conditions, the greater the disease suppression and the better nutrient retaining the tea will be. The greater the concentration of nutrients extracted, the more food there is to grow beneficial bacteria and fungi in the tea during the brewing cycle and after the tea is sprayed out.

It is CRITICAL to understand that tea must remain aerobic. If too great a concentration of food resources for the bacteria and fungi are added, the growth of the organisms will be so rapid, that they will consume oxygen more rapidly than oxygen can be added into the tea. The tea will go anaerobic, and then human pathogens can grow in the tea.

Any compost tea machine can be caused to go anaerobic, if too much microbial food is added, too much compost, and aeration is lacking.

Compost tea is used to add bacteria, fungi, protozoa and nematodes to the soil or onto foliage. Compost tea also contains soluble nutrients that feed the organisms in the tea and may feed plants. Use compost tea any time organisms in the soil or on the plants are lower than optimum levels. Chemical-based pesticides, fumigants, herbicides and some synthetic fertilizers kill the beneficial microorganisms that encourage plant growth, either in the soil or on foliage. Compost teas improve the life in the soil and on plant surfaces and help plants take-up the nutrients they require, and suppress diseases at the same time as building soil structure, and reduce erosion and loss of nutrients into drinking water. High quality compost tea of will inoculate the leaf surface and soil with beneficial microorganisms, instead of destroying them.

Given a good set of organisms (see Compost Tea Standards for what those numbers are), the following benefits can be brought about:

- Improved plant growth
- Reduced application rates of chemical pesticides, herbicides and fertilizers
- Reduced impacts of chemical-based pesticides, herbicides and fertilizers on beneficial microorganisms in the ecosystem
- Occupation of infection sites on the plant surface so pathogens cannot infect the leaf
- Improved uptake of plant nutrients through influences on stomata,
- Increased numbers of organisms on and around plants to compete with disease-causing organisms, reducing disease incidence,
- Retention of microorganisms in soil or on leaf surfaces, resulting in an increase in retention of nutrients,
- Increased plant nutritional quality,
- Production costs are reduced
- Reduced application of toxic chemicals, thus reducing run-off into lakes and streams,
- Reduced toxic impacts on humans and pets.

Step-by-step Approach to Making AACT

One, choose a compost tea machine that has documented ability to extract and grow the beneficial organisms from the compost you are using.

Here’s a list of brewers on the market in the US. We will be putting up a list of brewers from outside the US in a short period of time.

Demonstrated to Make Good Compost Tea, Grow Beneficial Fungi in the Tea Maker. These are **not** in any particular order!

- EPM, Earth Tea Brewers – 100 ($3,500) and 500 gal Excellent extraction (compostea.com)
- KIS brewers – 5 ($99) and 25 gal Good extraction, easy to clean!!!!! (simplici-tea.com)
- Alaska Giant – 1 ($40) and 5 ($80) gal, good extraction, soaker hose (alaskagiant.com)
- Ground Up – 50 gal and larger
- Worm Gold (www.wormgold.com)
- Compara
- Sottilo - JAMSOT@aol.com Brewers made to order

Demonstrated to grow bacteria, and usually only anaerobic bacteria

SoilSoup – 6.5 gal ($400), 30 gal, 250 gal (soilsoup.com)

Growing Solutions – 25 ($1300), 100 ($5000) and 500 ($12,000) gal (growingsolutions.com)

Figure out the amount of tea you need to put out at any one time. If you can put out 5 gal today, and 5 tomorrow, and 5 the day after, why buy a machine that makes 50 gal? If you own 10,000 acres, ok, you need a big machine. If you own an acre or less, a 5 gal machine will likely do fine.

Read and ask questions on the compost-tea list serve (http://groups.yahoo.com/) put 'compost_tea' in the search box, relative to each brewer you are considering.

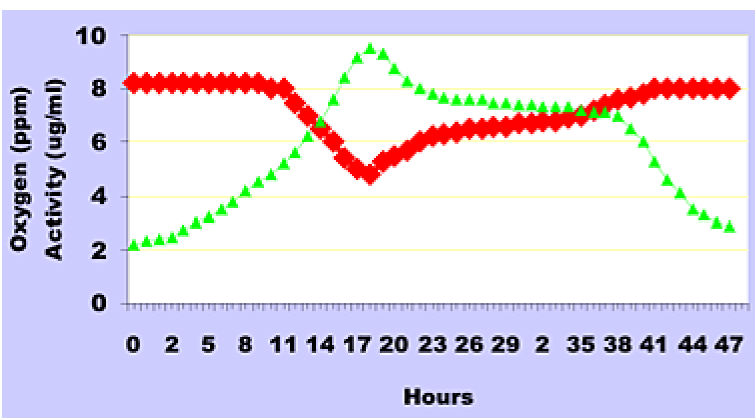
You need a tea brewer that the seller can document oxygen remains in the aerobic range!

Here's a graph showing the type of information you need.

In this case, the red line is oxygen concentration in the water (in ppm or mg oxygen per L of water), and the green line is the active biology in the tea (micrograms of active bacteria and active fungi per ml of tea). When the organisms are growing the most rapidly, activity peaks (after about 16 hours in most brewers, although about hour 8 in small brewers).

The reason for the peak is that the microorganisms have maximized use of foods, and after that peak, their activity slows down, because they are running out of food. Activity usually stabilizes about 24 hours, so it is safe to take the tea out of the max aeration brewer and put it into a sprayer tank that has just re-circulation.

If the aeration is turned off, it typically takes some time for the organisms to use up the air, and plunge into anaerobic conditions. A truly stable tea would only slowly use up oxygen and go anaerobic, usually in about 5 to 6 hours. But if the tea is not in a stable condition, then when aeration is turned off, oxygen levels will plunge within mere minutes to low, anaerobic levels.



Two, find a GOOD source of compost! Ask the compost maker for documentation of the bacteria, fungi, protozoa and nematodes in the compost. If they don't have the data, they have probably tested, and couldn't show that their compost really is compost. Lack of data often means they can't make the grade. You have to have the beneficials in the compost in order to make good tea. You may want to read over the compost section of this website to find out the desired levels of the different organism groups.

Three, decide on the foods you want to use to grow the beneficial organisms in your tea. The company you bought your tea maker from has a proprietary blend of foods that go with their tea machine, balanced already for the oxygen-use of that set of foods, and the ability of the machine to replenish oxygen during the growth of those organisms. It is critical that aeration be adequate. Alternatively, you can design your own tea recipe, but this will take some testing to make sure you are NOT adding too much food, and reducing oxygen, through the growth of the beneficial organisms, below aerobic levels. Foods that should be considered are:

- a diversity of sugars for bacterial growth, but realize that often the compost itself contains adequate bacterial foods to grow a great set of bacteria. Addition of more bacterial foods can just cause problems.
- Citric acid to help buffer pH to the right level, as well as feeding beneficial bacteria
- Cold-water kelp (higher in nutrients) to serve as a source of micro-nutrients (K, Co, B, etc, please check the label of the product you buy to make sure you are adding micronutrients you need. How do you know micronutrients are needed? A soil chemistry, or plant tissue test might be a good idea)
- Humic acids fro fungal growth, but realize that you want data to show you that this material can actually help grow fungi. Harsh extractants can make the humic materials very difficult for fungi, or anything else, to use.

Four, you need a means of transferring the tea from the tea brewer to the soil, or to the foliage of your plants. With small size tea brewers, pouring the tea into a sprayer works well. But with larger volumes of tea, you will need a transfer pump to move the tea into the sprayer unit. You need to talk to your tea machine maker and find out the testing that they have done to make certain that the pump doesn't destroy the organisms in the tea as it is being transferred.

There is a tea maker on the market, clearly one not recommended by SFI, where the transfer pump kills about 50% of the organisms in the tea. So even though that company posts plate count data showing there is bacteria in the tea made by that machine, moving the tea out of that machine into your sprayer will kill about half the organisms in the tea. Please be aware of these kinds of snake-oil salesmen!

Five, you need a sprayer that will distribute the organisms evenly on the leaf surface. Typically any sprayer meant to apply pesticide will evenly apply tea organisms. The only thing that needs to be checked is that the sprayer re-circulates tea while the tea is in a large size tank (back-pack sprayers or smaller don't need this, it typically doesn't take hours to apply tea in small amounts), and that the pump used by the sprayer doesn't kill organisms either. Talk to the tea machine makers about their lines of spray equipment.

Factors affecting Compost tea Quality

- Compost source – make sure it contains the organisms your plant needs
- Compost tea bag or container – the simpler the better, but opening sizes have to be right
- Brewing time – longer is not better
- Brewing temperature – make it right for the system the tea will be sprayed on!
- Water source – get rid of chlorine, chloramines, sulfur, other preservatives
- Extraction – the organisms have to be ripped off the compost, but not harmed in the process!
- Amount of tea applied to the soil or to the foliage – 5 gallons per acre for each 6 feet of foliage height, 20 gal per acre for the soil applications are the latest test results using EPM, KIS, BnBrewer, Clarke, AG, CT Brewer (NZ), and WormGold brewers.

The Pump

If you are going for the bigger machines, pay attention to the kind of pump on the machine. Did the manufacturer check to see if his pump kills organisms? Where are his data? Don't accept "trust me". There's a machine on the market that we demonstrated to the manufacturer that his pump to take the tea from the brewer into a holding tank was reducing numbers of fungi and bacteria by 50%. Keep that in mind, when buying something. How are you getting large volumes OUT of the tank?

Ease in cleaning is important.

Can you get to the bottom of the tank? Are there square corners in the pipes, knowing that in a month or so, that corner will be bio-film filled. It isn't right away that the problem develops. With the commercial Microb-Brewer, altered from the original design we tested at OSU, the pipes and pumps were changed to make the machine look prettier. The numbers on the changed machine were similar to the original, not-pretty design for the first couple of runs, but then, look out, the numbers dropped terribly as the bio-film developed. The manufacturer claimed that our methods had gone awry, that we didn't know what we were doing, because the numbers were coming out lower. It wasn't us, it was bio-film. But the manufacturer got mad at me. Stopped speaking to me all together. Called me all sorts of bad things.

SFI just tests the tea, we don't have to know why the numbers are coming out poorly. Usually I try to figure it out, and with the Microb-Brewer, we did figure it out. But not until after the damage was done. The Microb-Brewer is no longer for sale in the US.

Are there surfaces in the machine you can't see, can't get to to clean? Those places build-up biofilm. There's a brewer on the market that has discs in it, and you can't see, and you can't reach, the bottom sides of the discs. It is not fun getting the discs out to clean their bottom sides. Think about the time involved in cleaning. Most LARGE brewers should have a way to rinse the tank down as you pump the tea out. Talk to Bruce Elliott on this one. He developed the solution for this.

The compost container has to allow free movement of the compost.

Solid baskets that don't allow compost movement, that allow the compost to compact in the bottom, are going to cause you fits. Compost should be in bags, so easy-flow is possible. The EPM baskets are there to keep the bag of compost from twisting in the water flow, so the compost isn't constricted in that bag-basket design. But any other brewer with a basket has to have an aerator inside the basket, or the compost compacts, and goes anaerobic (happens at about 10 hours into the brew, so beware of the brewer that only has data for hours 0, 8, and 24)

Bubble sizes should be medium to large, not micro-sized.

Tiny, tiny bubbles are a bad idea. They shatter the fungal hyphae. Ask for the data showing good FUNGAL results. And please make sure the lab they are testing with uses decent methods.

No data? Don't buy the machine.

Only plate count data? Don't buy the machine. Ask what plate count data mean. Typically, you'll get gobble-de-gook as a reply. There are no data documenting a consistent relationship between plant growth and plate counts.

C. 3b. Fermentative Compost Tea

Fermentative growth implies facultative anaerobic organisms in the medium.

Facultative organisms have the metabolic pathways for BOTH aerobic growth, and for anaerobic growth. They carry an “extra” genetic load, which makes them non-competitive with strict aerobes who carry the DNA for only aerobic metabolism, and non-competitive with strict anaerobes who also carry only one set of genes, for anaerobic metabolism. When conditions are fully aerobic, or fully anaerobic, the facultatives cannot compete well, but in the intermediate ranges of oxygen, where flucatuations in oxygen will shut down the true aerobes, or the true anaerobes, the facultatives "win".

When organisms growing in the tea use up oxygen at a rate faster than oxygen can diffuse into the tea, true aerobes go to sleep, and organisms that grow better in reduced oxygen conditions wake up and grow.

If fermentative facultative organisms are present, or are added, such as EM inocula, lactic acid fermenters such as in production of yogurt or kimchee, the facultative anaerobes will compete with and prevent the growth of the human pathogens. Typically the organic acids produced by fermentative facultative anaerobes and the competition for foods suppress human pathogens.

Inhibition of un-desirable organisms through production of antibiotics may occur, which means bio-pesticide abilities should be recognized.

But, the conditions that routinely encourages the growth of the inhibitory, competitive biology that removes the human pathogens and other disease-causing organisms, has not been documented. The problem with compost teas that become reduced in oxygen for a period of time is lack of knowledge of how long was the tea brew anaerobic? How reduced in oxygen did it become? What foods were present, to select for the growth of which organisms?

Once facultative, fermentative organisms growth conditions become as well understood as the conditions for actively aerated beneficial organisms to grow, then this kind of compost tea might be as accepted.

But until we understand how to make fermentative teas so they consistently and routinely produce the desired results, we should avoid the hype that says they can be used safely.

Please note that the Soil Soup machine, the Growing Solutions machine, most of the not-tested machines, and the drip-through the compost into a trough types of machines fall into this category of tea machine, where the tea drops down into anaerobic ranges. Sometimes these brewers get good results, because they either did not become fully anaerobic, or they managed to achieve conditions where the beneficial fermentative organisms grew. But consistency is lacking. The people who make these brewers do not know what product their tea makers are actually producing at any particular time. It seems that until they do proper documentation, buyers should avoid these machines.

C. 3c. Long-Brewing Compost Tea

Compost teas that start aerobic, move into the anaerobic ranges, and because they are brewed long enough, return to aerobic fall into this category. They contain aerobic bacteria, and put-to-sleep anaerobic bacteria. Beneficial fungi, protozoa and nematodes have been pretty much destroyed by the anaerobic phase, although if the brew didn't actually go anaerobic, then the beneficials may still be present.

These brews may contain some remnant anaerobic smells and materials. The diversity of food resources has clearly been increased, but the question remains what bacteria exactly were grown? Beneficials, or detrimentals? Disease-suppressors, or disease?

Disease-causing organisms often prefer, and grow better, in reduced oxygen condition. But if the brew went quite anaerobic, then the diseases were killed too. How low is low enough? When do the “bad guys” die, and when do the really bad guys, like Clostridium botulinum, start to grow? We don’t know.

What mix of foods results in the fermentative bacteria or fungi winning, versus the human pathogens? Is stirring vigorously at 12, or 16 hours going to select for the good guys enough to maintain the good guys? Or do you need to stir at 8, 12 and 24 hours? No one really knows. (If you do, please let me know, I’d like to see your data).

Most Biodynamic brews fit this LBCT definition, except Biodynamic preps do not always use compost. The preparations are plant teas, which means plant material is placed into water, stirred and the biology on the leaf surfaces grows using the sugars, proteins, carbohydrates, cellulose, and more recalcitrant (hard-to-decompose, quite complex and thus hard to attack) kinds of substrates.

Does that mean plant teas have no benefit? Of course NOT. If beneficial organisms are on the plant surfaces (and usually roots are included in the plant teas), the beneficial organisms will grow and increase in numbers or biomass during the brew cycle. Which good guys? It depends on the same factors as actively aerated compost depends – temperature, mixing, aeration, foods added, the age and stage of the plant (and therefore the actual foods added), etc.

But, in these LBCTs, no aeration other than occasional stirring is added. That means, if there are organisms present on the plant material, or in the compost if this is truly compost tea, the brew is very likely to go anaerobic for some period of time.

But for how long? And how low did oxygen go? And when did the growing organisms begin to run out of food, so that their oxygen use rate slowed? When did their metabolism slow down enough that oxygen began to diffuse back into the water faster than the organisms were using the oxygen?

By the end of a LBCT brew, the tea should no longer stink in any way, which means the tea has returned to the aerobic condition. The things that may kill your plant have been re-cycled back into bacteria biomass. Sorry, no fungi left in a brew that went anaerobic. The beneficial fungi are, for the most part, aerobic.

The time, or the conditions to allow conversion from aerobic to anaerobic and back again are not documented at all for these kinds of teas. That means that sometimes positive effects have been observed using these kinds of teas, but other times the teas have had no observable effect, and sometimes these teas kill plants. I’ve killed quite a number of plants using anaerobically produced tea, and while I have not published this data (it is hard to publish negative results), lack of publication does not mean it doesn’t happen.

That is why compost tea has been regarded as witchcraft, or voo-doo, or snake oil for all these years. The results have been too variable to make sense of what is going on. When sometimes great results occur, sometimes nothing, and sometimes really bad things happen, no one is inclined to put much trust in the results.

But, the Biodynamic approach controls many of the factors involved in tea making, IF THE PRACTIONER PAYS ATTENTION TO WHAT STEINER SAID. I've watched a number of biodynamic brews being made where part, or just about all of Steiner's advice was ignored. If people don't understand WHY something was required by science, they may ignore it. But then typically the results aren't what you would want, or they do not give you the benefit you should be able to get.

The bottom line is, we need to put more effort into understanding these types of tea. But for now, until the work is done, either do what Steiner said, exactly, or use AACT. We are really getting a handle on how to guarantee that AACT is consistent, and beneficial, each time. Without an oxygen probe, and the time to monitor properly, FCT and LBCT remain of questionable benefit.

C. 3d. Not-Aerobic Compost Tea

This is compost tea made with so much food resource in the tea, and so little aeration that it will become anaerobic (below 5.5 ppm or mg oxygen per L) quite rapidly. Typically this results in production of toxic materials that can be useful for preventing the growth of particular organisms. But there is no documentation of conditions that result in any particular end product. In addition, there are no consistent production parameters for any particular toxic material (presumably anti-biotics), or particular organisms.

A great deal more work is needed here before anyone would chose to use this approach on a commercial basis. Again, plant teas and manure teas have been made using this approach, but most likely the reason these teas did not catch on as useful practices is because the results are so variable.

C. 4. How to tell a "good" tea

Soil Foodweb Inc performed a study of how do you know if compost tea will "work"?

The results (given below in Table 1). clearly show that plate counts are inappropriate for determining whether a compost tea will protect plant surfaces from disease. Direct determinations were excellent means of showing that tea can protect leaf surfaces from disease causing organisms.

Methods

Plants were obtained from a greenhouse where blight was causing a severe problem. All plants used were just beginning to show "burn" on the leaves from the disease.

Five of the plants were sprayed with Tea One, five plants sprayed with Tea Two. Control plants (water alone) and fungicide treated plants died within a week, as did the plants to which tea one (tea lacking suppressiveness, see table below) was applied.

Does the fact that plants sprayed with Compost Tea One died mean that compost tea does not work? No, because the plants sprayed with compost Tea Two (tea capable of suppressing disease in the table below) survived and grew well.

What was the difference in the teas? Tea Two, designated tea capable of suppressing disease in the tbale below, had high levels of active and total fungi, active and total bacteria, and good protozoan numbers. Application of these organisms to the plant foliage resulted in excellent coverage of the leaf surfaces. All of these plants lived.

Tea Two, designated tea lacking suppressiveness, did not contain adequate fungi, or fungal activity, and lacked the protozoa needed. While exactly the same amount of tea (or water, or fungicide on the control and fungicide-treated plants) was sprayed on all plants, Tea One did not have an adequate microbial population to protect the plant surface.

Plate methods could not differentiate between the two teas.

TSA incubated at room temperature, in aerobic conditions, measures “aerobic heterotrophs”. There was no detectable difference between the two teas using plate methods, despite the fact that Tea Two was capable of suppressing blight, while Tea One, sprayed at the same concentration, in the same conditions, did not suppress disease.

King’s B medium selects for pseudomonads, but not all these bacterial species are beneficial to plants. Enumeration indicated that there were more pseudomonads in the not-suppressive tea. Plate methods cannot distinguish whether the bacteria growing on this plate, and thus presumably pseudomonads, will be beneficial to the plant. If these values were used to measure “species richness-diversity”, the not-suppressive tea would get a higher “index” score than the tea that resulted in the plants remaining alive and producing a bumper crop of tomato later in the year.

Please note that “species richness-diversity” is not a valid name for any ecologically accepted measure of diversity. The lab that developed and uses this index will NOT explain how this index is calculated, and will not show any data that documents what relationship the index has with plant health. They claim the index is in any introductory textbook, but in fact, no textbook anywhere has a measure called species richness-diversity. Until such time as the lab using this index documents the claim that a higher index value actually means a benefit to the plant, the use of this index must remain highly questionable.

Spore-formers are determined by boiling the material in question to kill vegetative cells, followed by plating the material on TSA. Only spores or highly dormant stages of organisms survive boiling. Those spores capable of growing on TSA, at room temperature, in the particular oxygen conditions present in the plate (please recognize that oxygen exchange is reduced by the fact that the plates are covered), are then enumerated. Again, the not-suppressive tea had higher plate enumeration values. What is the relationship between what will grow on a plate, and physiological functions occurring in the soil, or on plant surfaces? These data show that there is no relationship.

Direct determinations separate bacteria from fungi. Plate media do not separate even bacteria from fungi, much less not giving an indication of what is going on with approximately 99.9% of the species present in the material plated.

Direct determinations also let you know whether protozoa or nematodes are present and performing their functions. A much clearer picture of what biology is present and performing their functions is possible when using direct determinations. Direct methods let you know if coverage on leaf surfaces is adequate. These types of assessments need to have a clear relation back to benefit to the plant.

Please note that there is no consistent relationship between plate count enumerations of "species richness-diversity" and improvement in plant growth. Plate counts do not assess diversity or activity of the organisms in the test material. An insignificant number of the actual total individuals or total species present in a sample grow on any single plate medium or set of lab conditions that it is difficult to see why anyone would continue to pretend that there is a relationship between plant growth and plate count assessments of diversity.

	Tea lacking Suppressiveness	Tea Capable of Suppressing Disease
Plate Methods (MPN)		
TSA	1.6 (0.5) X 10^8	1.6 (0.7) X 10^8
King's B	5.0 (1.4) X 10^3	1.2 (0.2) X 10^3
Cellulose	35 (12)	210 (43)
Spore-formers	7.9 (0.4) X 10^2	0.3 (0.1) X 10^2
Direct Microscopy (ug per ml)		
Active Bacteria	8.0 (2.6)	12.7
Total Bacteria	25.1 (1.0)	245
Active Fungi	0.00	3.76 (1.00)
Total Fungi	0.35 (0.12)	11.1 (2.33)
Direct Microscopy (numbers per ml)		
Flagellates	17 (10)	110 (34)
Amoebae	124 (59)	1,801 (1,112)
Ciliates	0	7.5 (5.9)
Nematodes	0	0.35 (0.05)
Leaf Coverage (%)		
Bacterial	27 (4.7)	86.9 (9.7)
Fungal	0	5.1 (0.6)
Disease Incidence		
(5 plants)	All plants diseased, all dies	15% showed blight symptoms; None died

SD = Standard deviation of the mean

C. 5. Compost Tea Standards

Desired levels of organisms (direct microscopy) in compost tea

- 10 to 150 or more µg active bacteria /ml compost tea
- 150 µg to 300 or more µg total bacteria /ml compost tea
  15,000 - 25,000 or more bacterial species (using molecular methods)
- 2 to 10 µg or more active fungi /ml compost tea
- 5 to 20 or more µg total fungal biomass/ml compost tea
  5,000 to 8,000 or more fungal species (using molecular methods)
- 2,000 or more protozoa
  1,000 or more flagellates
  1,000 or more amoebae
  10 – 30 ciliates. Higher numbers indicate anaerobic conditions resulting from organism in tea growing so fast that oxygen is consumed
- 2 to 10 BENEFICIAL nematodes/ ml (desired; typically lacking in tea)
  1 - 5 bacterial-feeders
  up to 5 fungal-feeders
  1 - 5 predatory nematodes (typically lacking in tea)
  No root-feeding nematodes
- Minimum of 10% active bacteria and fungi

With biology at or above these minimal ranges (more is better), this tea should result in improving foliar or soil life significantly, as long as pesticides, pollutants and dust are not a problem.

Application of a tea containing this set of organisms should result in a minimum of 65% of the leaf surfaces covered with bacterial biomass, and 5% with fungal biomass. In trial after trial, we have shown that with this minimum level of coverage, the leaf surface is protected, through a variety of mechanisms, from colonization by pathogenic organisms.

Compost Tea Standard Conditions

ome rumors flying out there suggest that someone is saying that there are no standard conditions for tea production, but in fact standard conditions are necessary in tea production.

In order to make consistent compost tea, the starting conditions must be t he same, and the same conditions must be maintained during the brewing.

We manage to routinely make teas with the same bacteria, fungal, protozoa and nematodes biomass and numbers present, time after time. But if you want something with a different set of organisms, or different levels of organisms, change the foods, the temperature of brewing, aeration, or water conditions. Maintaining the same conditions allow the same brew to be made over and over. Changing conditions allows a different tea to be made. Like making cake, or beer, biology responds to what you put into the starting mix and how you treat the material during the brewing, or cooking, process.

Standard conditions are:

1. room temperature water to begin,
2. no chlorine (aerate to de-gas)
3. neutral water (pH 6.5 to 7.5),
4. oxygen maintained above 6 ppm through the entire brewing cycle, and
5. good aerobic compost (per gram dry weight of compost) containing at least:

The list of papers specific to compost tea and compost have been summarized by Steve Diver, and are listed on the ATTRA website, www.ATTRA.org

Habitat requirements for beneficial bacteria and fungi required to prevent pests and pathogens

- Maintain 5.5 ppm O2 or higher during brewing cycle
- Pleasant Smell
- Increase in temperature of 1 to 10 F is normal
- Foam is typically sign of good bacterial metabolite development
- Maintain tea fully aerated as long as held before use

Testing Requirements

For new (untested) tea making machine:

- Compost quality (outlined above)
- Starting recipe of the tea
- Temperature, oxygen concentrations through the tea cycle
- Color of tea, foam, smell
- Chemistry and Pathogen testing must meet local standards (city, county, state, Federal).
- Organism assessments must be performed on three batches of tea
- Duration of the tests are 32 hours or until the growth of organisms in the tea is completed. This establishes the brewing cycle; extraction, growth, expected increase in organisms, duration of the tea cycle, when tea is ready to be used and whether the machine can hold tea for any length of time.

For existing machines with the above data available from the manufacturer:

- Type of tea maker used,

- Compost quality
- Starting recipe of the tea
- Temperature, oxygen concentration, and CO2 or O2 data through the cycle must be submitted for each of the first three batches of compost tea
- Chemistry and Pathogen testing must meet local standards (city, county, state, Federal).
- Initial three batches of tea must show three consistent sets of organisms produced at or above levels given above
- Once initial testing passed, each batch test each 3 months, or each set of different starting materials.

Sampling requirements for healthy foodweb assessment

- At end of desired brew cycle (depends on machine), measure temperature and CO2 or O2
- With the tea maker still circulating the tea, take at least 5 different 1 to 2 ounce or 30 to 60 ml samples and place them in a clean plastic 8 to 12 oz (100 to 500 ml) plastic bottle with sealable lid.
- Put the lid on the bottle, mix by shaking. If after mixing, the sample bottle is more than _ full, drain to halfway mark to allow airspace. The bottle should contain at least 125 ml (4 oz) of tea.
- Send overnight to SFI lab. Send with completely filled out sample submission form