How to Interpret Soil Foodweb™ Assays

Soil Foodweb assays assess the interaction of a large number of possible organism groups and their interactions in soil. The information obtained can be used to finely tune what is going on in soil, and what needs to be done to bring the soil back to a condition of health. There are many things to consider, however, so go through your report carefully, step by step.

On the Soil Foodweb report, note the bottom line of the table, which says "Desired Range". This indicates the MINIMUM desired range for each assay, based on previous testing done through the years by Soil Foodweb Inc. The only exception to this rule is ciliates (see section on protozoa, below)

The desired values can be different based on plant type, soil type, climate, season, etc. Of course, these values are based on plant growth when pesticides and other inorganic and toxic materials are not required to maintain healthy plant growth.

The values in the desired range row were determined based on years of collecting data about the biology in healthy conditions, when plant growth is optimal. The desired range therefore, changes based on plant, season, climate, soil, and on our ever-increasing knowledge base.

If the soil is not in healthy condition for a particular plant, then those plants will be stressed. It may not be incorrect biology, however, that is the sole reason for stress. If the soil is lacking in a nutrient, the biology cannot do anything to make available a real lack of a chemical. In this case, the nutrient will have to be added to the soil, but preferably in a biologically available form. Often soil organisms can solubilize not-plant-available nutrients and make them plant-available. To hold, and retain, nutrients, organisms may be required to act and turn nutrients into non-leachable forms. Such is the case with nitrogen – the inorganic forms are highly leachable, while the organic forms are not subject to significant leaching losses.

When the biology is lacking, after use of chemical pesticides, or high levels of N, for example, addition of inorganic nutrients be required until the numbers and balance of the different organisms can be improved.

Soil physics may have to be improved as well, and it is the organisms that build soil structure. Physics (soil aggregate structure), chemistry, and biology work together. It is silly to talk about any one of them being "most important": soil biology, soil chemistry and soil physics all have to be optimal for the chosen plants in order for the plants to grow well.

Use the following information to allow you to interpret what to do if the biomass of your food web organisms is too low, too high, or "just right".

How often should you check your food web? Certainly it should be checked whenever starting to work on a new field or project area. You can reduce the cost of resuscitating the system by focusing on what needs to be helped rather than crossing your fingers and hoping you are helping what isn't right. Once you determine what needs to be fixed, and take steps to fix the problem, a quick check of just the “out-of-whack” groups would be good idea in a month or two, to make sure the improvement is coming along. Then, annual “check-ups” would be a good idea.

There are basically 12 steps to repairing the Soil Foodweb:

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.

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).
4. 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 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:
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.
4. 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.
5. 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.
6. 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.

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 outcompete 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 mixed into the aeration cores gets the VAM spores into the root system without destroying the turf.
        ii. 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.
    i. 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.
    ii. 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.
    iii. 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 that wonderful nutrient tied up in the bacteria. Nutrients in 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

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.

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.

Ratios

Total Fungal Biomass to Total Bacterial Biomass

Different plants require different processes in the root system, different pH, different structural conditions, different rates of nutrient availability, and different forms of nutrients. By controlling the biology around their root systems, the plant can modify the soil environment, and their leaf surface environment to some extent. In this way, the organisms around the plant can be modified to select for different plant species.

Is the ratio of fungi to bacteria correct for the plant you desire? If the ratio is greater than one, the fungi are predominant, but if the ratio is less than one, the bacteria are winning.

In general, very early successional species such as most weedy species, brassicas, mustards, wetland annuals, require a strongly bacterial food web. Early successional grasses require slightly less bacterial dominance, only about 2 times more bacteria than fungi, for example, to make the soil most selective for Bermuda, Zoysia, most Bromus species. Vegetables, most cut flowers, and other annual plants need about 1 quarter to a third more bacteria than fungi, but most row crop plants need an equal ratio of bacteria and fungi.

Perennial plants typically do much better in fungal-dominated soils. Clover, some soybean, and strawberry plants do best in slightly fungal soils, while shrubs, bushes and early successional deciduous trees like alder, popular and small understory trees also can outcompete annual plants when the soil is 5 to 10 times more fungal than bacterial. Deciduous trees, like beech, maple, oak and elm need 10 to 100 time smore fungi than bacteria to be healthy. Conifers usually do better when the fungal biomass is in the 100 to 1000 times more fungal than bacterial.

Again, these are based on representative plants growing without disease or need for fertilizer additions. Not-healthy plants will eke out an existence in soils that aren't right for them, in stressed condition, with poor growth and poor yield. Balance the soil to help the plant, and these plants grow better.

Ratios of active to total bacteria, or active to total fungi -
How active is the bacterial or fungal populations? The more the population is growing, the more rapid the recovery of a community. Addition of foods for bacteria or fungi will increase activity,

but of course, the organisms have to be present to use that food and increase their populations. If you plan on bagging or bottling a material, activity has to be less than 10% of both populations, or the sealed container will implode or more often, explode through accumulation of respiratory gases.

Ratio active fungi to active bacteria -

Will the soil, compost or compost tea become more fungal, or more bacterial? This ratio lets you know. If the ratio is greater than one, fungi will be gaining ground over the bacteria, but if the ratio is less than one, the bacteria are winning.

Plant available N, in micrograms actual nitrogen, made available in the next three months per acre of soil – This is calculated from the number of protozoa and nematodes present and active. Research shows that these organisms consume and mineralize N from bacteria and fungal biomass. Given certain rates of consumption of their prey per day per unit biomass means a certain amount of nitrogen will be released.

Root-feeding nematodes – Are there any "bad guy" nematodes present? At economic damage levels? If there are, you can treat the soil to exit these problem nematodes. By improving mycorrhizal fungi, the root-feeders can be masked from finding the root. Beneficial nematodes also interfere with the root-feeders from being able to find the roots. And of course, nematode-trapping fungi, or nematode parasitic fungi can be effective bio-control agents. Root-feeding nematodes can be removed by getting these beneficial organisms back into the soil in a short period of time, if they are added in high enough number.

Amount of compost typically needed

In the fall, compost should be applied between 5 ton per acre (just a minimal inoculum) to 30 ton per acre to add organic matter as well as the inoculum of the organisms.

Again, in the spring, compost should be applied at rates required to bring the organism numbers back to desired ranges. If just an inoculum is needed, i.e., activity is adequate, but total biomass is low, then the lower rate is chosen. If long-term organic matter is needed to deal with high salt, pesticide residues or high nitrate, pH, or heavy metals, then addition of high rates of compost is indicated.

In turf, fairways can be treated as above, but the compost should be screened to prevent large chunks interfering with play. On greens, the lower rate is always chosen, and the compost should be finely screened, followed by tea use.

Given a source of good compost, minimal compost applications are possible to bring the foodweb back to health. BUT monitoring is necessary, to make sure the conversion to healthy actually is proceeding apace.

Amounts of compost tea typically needed

Compost applications can be replaced with fall and spring applications of 15 to 20 gal of tea per acre. Enough water is used, as a carrier, to allow easy application of the tea to the area desired.

Then, tea should be applied based on disease, weed and nutrient limitations in soil. Weekly applications of tea, made to offset the problems present (fungi maximized if lacking fungi, high concentration of humic acids if salt problems exist, calcium additions if composite weeds are a problem, or iron if moss is significant) should be made until disease problems are alleviated. Weed problems should be dealt with by altering the nutrient limitations that allow the weeds to out-compete the desired plants. Once the diseases are dealt with, and weed problems are minimized, reduction in tea applications should be possible. Typically, back off to twice a month applications, then to once a month applications, or less, depending on the plant response. If disease begins to rear it's ugly head again, increase tea applications.

If the Extension Service announces a disease alert for your plant, you should increase applications to protect the plants ASAP. Even if you don't see disease at this time, increased disease load needs to be off-set immediately.

Amendments

Kelp – can be set the stage to remedy plant health, and improve the plant's ability to resist attack by Fusarium, Xanthomonas, black spot, and other bacterial diseases.

Molasses – contains some humic acid, so improves fungal biomass more than many other simple sugars. There are many types of sugar in molasses, so helps improve diversity of species that will grow in the tea.

Lime – calcium addition

Rock Dust – mineral nutrient addition. Make sure your plant needs to have these mineral elements increased before applying.

Please e-mail any questions to info@soilfoodweb.com and let us know if you have any problems interpreting the Foodweb, or need help with observation that you don't understand.

Example: How to Interpret Soil Foodweb Information

Be sure to take samples from that place that will answer the question you want answered. Typically, that is from the place that most affects the plant. Keep this in mind when looking at drip wells versus drive lanes, etc.

Where is the food web that most affects the plant roots?

There is a best soil 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.

State the question you are trying to answer very clearly. The tests you need then should be come clear.

- For example, you want to know if your soil is healthy. That means a full foodweb analysis is needed, since you don't know what part of the food web may or may not be "out of whack".
- 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 probably total fungal biomass. Perhaps mycorrhizal colonization as well, since this assay includes disease encountered on the root system, as well as insect feeding damage.

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^{TM}:
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.

Let's take a look at SFI results from some soil samples:

Vocabulary:

Hyphae (plural), Hypha (singular): The threadlike strands of fungi; see pictures on the SFI website: www.soilfoodweb.com

Inoculum – means a set of individuals of a designated group to be added in order to re-establish these organisms in the material.

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 of 1 gram Fresh Material	Active Bacterial Biomass (µg/g)	Total Bacterial Biomass (µg/g)	Active Fungal Biomass (µg/g)	Total Fungal Biomass (µg/g)	Hyphal Diameter (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 Range		0.45 - 0.80	See A 15 - 30	See B 150 - 300+	See A 15 – 30	See B 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.

Dry Weight: All three composts have moisture 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 indicates 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.

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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 Bio1	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.

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Sample #	Treatment	Total Fungal To Total Bacterial Biomass	Active to Total Fungal Biomass	Active to Total Bacterial Biomass	Active Fungal to Active Bacterial Biomass	Plant Available N Supply from Predators (lbs/ac)	Root-Feeding Nematode Presence
91046	Control	0.65	0.04	0.09	0.29	< 10	None detected
91047	Plus-HH	1.61	0.10	0.13	1.35	100 - 110	None detected
91048	Plus Bio1	0.75	0.02	0.003	4.85	40 - 50	None detected
Desired Ranges		(1)	(2)	(2)	(3)	(4)	(5)

(1) Based on 25 year's of data, Grass:0.5-1.5; Berries, Shrubs, grape: 2-5; Deciduous Trees: 5-10; Conifer: 10-100.

(2) Warm spring, early summer: 0.25 to 0.95; Early spring, late winter & mid-summer: 0.10 to 0.15; Fall rain: 0.15 to 0.20; Drought/frozen soil/heavy metal/many pesticides: 0.05 or lower. Values greater mean the organisms are recovering from a negative impact. Values lower mean organisms are not recovering and help is needed, typically addition of their food resource is required.

(3) Generally 1:1 results in good soil aggregate structure in crop soil; 2 to 5 for deciduous trees; 5 for conifers.

(4) Based on release of N from protozoan and nematode consumption of bacteria and fungi (see Ingham et al 1985, and recent papers in Ecology supporting this work).

(5) Identification to genus.

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 food webs 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 has 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. (info@soilfoodweb.com)