

THE COMPOST TEA BREWING MANUAL

Latest methods and research
5th edition



DR. ELAINE INGHAM

The Compost Tea Brewing Manual

Fifth Edition

by

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SOIL FOODWEB INCORPORATED

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The cover is a picture of 3 month old grass plants grown in well-aggregated, microbially active, healthy soil, showing that despite being cut to heights of a half inch during the summer, the grass did not lose roots. Certainly root depth was not limited to the same height belowground as the foliage was above ground.

Courtesy of Hendrikus Schraven Landscaping, Issaquah, WA

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Karl Rubenberger, the first to build a commercially viable compost tea-brewing machine, the guiding light behind the Micro-Brewer, and who continues to be a compatriot in the world of compost tea.
Merline Olson has been a true friend for many years. Currently is the President of SFI Australia. Remember taking samples every two hours from the Micro-Brewer for an entire week? Right-o mate!
Bruce Elliott, who currently manufactures the Earth Tea Brewer,
Leon Hussey, inventor and manufacturer of the Keep It Simple brewer, who is the first person to use aeration alone to extract the organisms from compost.
And for everyone who is making compost tea in any form, and has communicated with me about their results.

Keep sharing your ideas!

Elaine R. Ingham

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Contributed by Leon Hussey:

"This is a time when forces of a very different nature too often prevail - forces careless of life or deliberately destructive of it and the essential web of living relationships.

My particular concern, as you know, is with the reckless use of chemicals so unselective in their action that they should be more appropriately be called biocides rather than pesticides. Not even the most partisan defenders can claim that their toxic effect is limited to insects or rodents or weeds or whatever the target may be.

These are large problems and there is no easy solution. But the problem must be faced. As you listen to the present controversy about pesticides, I recommend that you ask yourself
- Who speaks?
- And Why?"

Rachael Carson, 1963 address to The Garden Club of America

"Her speeches during the last year of her life reflect her moral conviction that 'no civilization can wage relentless war on life without destroying itself, and without losing the rights to be called civilized.'"

LOST WOODS - Linda Lear

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Introduction to the Fifth Edition

We've come a long way since I started working on liquid extracts of compost in graduate school. At that time, variability was too great, so we went on to other projects. In the last 10 years, however, methods for making **aerated compost teas** have been determined, but the methods for producing **not-aerated teas** are lacking. We need to know exactly how to produce consistent and reproducible teas of each kind. Exactly what do the teas produced by **not-aerated, anaerobic or fermented methods** do to plants? How can we consistently produce each kind, so the effects are predictable?

Aerated compost teas contain all the species of organisms that were in the compost. Thus the compost has to be "tea-quality". Those organisms selected by the temperature, foods present, nutrient composition, oxygen content in the tea brew grow during the brewing process. When oxygen drops below a certain level, nutrients can be lost and disease-causing organisms may grow. Oxygen content is critical, but so is the diversity of aerobic organisms. The competitive set of organisms must be present to prevent pathogen growth. The amount of food added must be limited to enough to attain maximum growth of desired organisms but not so much that oxygen concentration drops below the aerobic level. Balance is critical - maximize growth, but maintain aerobic conditions. Machine cleanliness is important too. Anaerobic biofilms growing in the machine can result in poor quality tea. Documenting that a consistent, plant-beneficial product is always made is paramount.

Anaerobic teas require that low oxygen levels are reached, and this needs to be documented in order to make the claim that this kind of product was made. Certain organisms make specific toxins which combat disease- and pest-organisms. These toxins, like antibiotics, are only made in certain conditions. Machine, recipe, oxygen management and compost used must be documented and understood. The biology in an anaerobic tea is limited to basically anaerobic bacteria and yeasts. Since the set of organisms is so significantly altered from what occurs in aerobic compost, anaerobically brewed teas should not be called compost tea, but designated specifically as anaerobic tea.

Fermented, or plant, teas are typically produced by placing specific kinds or mixes of *un-decomposed* plant materials in water. Compost is typically *not* even a part of the recipe, and thus should not be confused with compost tea. Oxygen typically reaches low levels for several days to weeks, but not for the full two to three week production period. The full food web of organisms is not present in fermented tea, although typically some aerobic organisms return to activity as oxygen returns to the ferment.

Not-aerated compost teas typically do not have additional food resources added to the brews. The likelihood that the tea will reach low oxygen levels or be anaerobic is minimal. The full food web may be present if oxygen levels do not drop below aerobic levels. If the compost used was immature, enough soluble foods may be released, organisms will grow rapidly, and the tea will drop into anaerobic oxygen conditions. If the food web is lost, leaving only anaerobic bacteria, then the product should not be called a compost tea. The potential variance in this product is significant, and much more work is needed.

There are many aerobic tea machine companies in the market, and many people are having great success in improving plant production as a result. Soil Foodweb Inc has worked with most machine makers and helped them to be successful. Bruce Elliot, Leon Hussey, Carol Ann Rollins, George Hahn, Shepard Smith, Ray Gore, Steve Diver, Kirk Leonard and many others were important in improving our understanding of compost tea machines and how they work. But other advancements in the area of *not-aerated* and purposefully anaerobic teas have yet to be explained.

Aerated compost tea can have amazing benefits for plant production, regardless of any negativity some might have about this industry. To have consistently beneficial tea requires knowing what you are doing, and that means being able to test and determine exactly what biology is present in the tea.

Compost tea "works" only because of the biology in them. Management is not possible if you can't measure that biology.

What Is Compost Tea?

The simplest definition of compost tea is: **A brewed, water extract of compost.**

Properly made compost must be used, so that the compost tea needs no further pathogen reduction. Compost tea production is therefore, a "cold brewing" process, allowing growth of the organisms extracted from the compost.

Only if the process remains aerobic will the complex set of organisms extracted from the compost remain in the tea. The complex set of organisms is needed to establish all of the benefits of a healthy soil food web in soil, potting mix, or on the surfaces of plants. Plant growth is typically improved, although the correct mixes of beneficial organisms need to be matched to the type of plant (see Ingham et al. 1985, other papers by Ingham, and the Soil Biology Primer, 1999).

Compost is the main ingredient in compost tea, but in order to increase organism biomass and activity, other foods are added at the beginning of the brewing period. These ingredients and their effects are discussed later in this book. Many growers have special ingredients they add. New recipes are always being tested with the goal of achieving higher microbial biomass, better plant production, better soil structure, better nutrient cycling and less disease.

As the processes involved in producing compost tea are better defined, the important parameters that result in the growth of certain organisms will be better understood. Different kinds of aerated and non-aerated compost tea will provide the proper biology for different situations and will be ever-more integral parts of sustainable agriculture.

Sustainable farming is possible, if year after year, the soil is improved and productivity increases. While any one plant species is limited by its genetics, matching the plant to the biology in the soil solves production problems. Natural processes improve soil productivity, and in the natural world, plant species change with time. Plant communities shift from bare soil, to weeds, to grasses, shrubs, trees and then old growth forest. The mythology of modern agriculture is that soil productivity is set, and once a field is put into agriculture, productivity has no choice but to go downhill.

Fertilizer sales people have been heard to say that agriculture depletes soil health and results in loss of tilth. Nutrients are mined out of the soil, ultimately leaving a field devoid of life, plants and nutrients, unless fertilizers are added back into the soil, in plant-available forms. Instead of solving the problem, however, addition of high levels of strictly inorganic, soluble, plant-available nutrients has resulted in an enormous problem with water quality. The nutrients added are no longer held in the soil. As a result, excess amounts of inorganic nutrients have to be added. This is so different from a healthy soil, where the soil holds nutrients, thereby "cleaning up" the nutrients from the water moving through the soil.

Clean water comes out of healthy soil. Why is water coming from "conventional" agricultural fields laden with excess inorganic N, P, S and other minerals? Or if leaching is not occurring, why are the nutrients lost through gaseous emissions? This is not what happens in natural systems.

Change will occur when sustainable agriculture, not extractive, destructive agriculture, is practiced. Pesticides and inorganic fertilizers are not needed, if soil health is maintained. Tillage needs to be reduced to the minimum possible. Disease and pests are not significant in healthy, sustainable systems. Weeds are really just an indication that the system is not healthy. Nature gives growers clues with respect to what is wrong, if the information is read properly. We just need to learn how to read the information being given to us. We reserve the use of pesticides and other toxic materials to the rare situation when some unusual event occurs that harms the biology that should be present.

Only if soil lacks the biology required to convert nutrients from plant-not-available forms to plant available forms would addition of inorganic nutrients result in improved plant growth. If the proper biology is not present, then the soil is sick. Extractive agriculture uses tillage and addition of excessive inorganic nutrients which harm the proper biology. When there was plenty of land for "slash and burn" approaches to farming, and farming was done on small scale areas, the land and the biology could recover between extractive agricultural disturbance events.

But in today's world, land is not allowed to recover between farming events, and therefore the organisms and the foods to feed them have to be added back into the system without the luxury of "downtime" to recover. The lack of proper biology must be dealt with immediately, for without that set of organisms, soil structure, nutrient retention and nutrient cycling cannot happen or are severely restricted, and disease suppression and protection are practically non-existent. Returning the organisms needed to build soil health is required.

People who don't understand soil biology will say that bacteria are always present, at more or less the same numbers. But this is an error based on the methods that have been used. The classical medical way of looking at disease-causing organisms was applied to soil, and inappropriate conclusions made. "Plate count" methods assess mainly spores, which are dormant stages of some, but not all, organisms. Spores aren't affected as much as active organisms are by toxic chemicals or tillage. Plate media miss 99.99% or more of the actual species growing and being active in soil. As a result, people relying on plate methods have lead others to extremely mis-informed decisions.

Direct observation methods, especially of active biomass, show that soil biology activity is significantly harmed by pesticides, inorganic fertilizers, tillage and herbicides. The precise impact depends on conditions in the soil. For example, when soil is very dry, and most organisms are inactive, the impacts are limited. But if toxic chemicals are applied when the organisms are actively growing, impacts can be detected.

How rapidly can organisms colonize from another place? Something has to carry bacteria, fungi, protozoa or nematodes from one place to another, and if transportation agents, such as birds, snakes, and spiders, are also dead, how can microbes reach a distant place? Not that many organisms in soil survive a dry, wind-blown transfer. Where, in the chemically impacted agricultural valleys of modern technology, is there even a source of healthy soil for colonization to spread from? The necessary diversity of organisms was killed long ago. The wind can't carry what isn't there.

Therefore, we need to put back the full diversity of bacteria, fungi, protozoa, nematodes and if possible, microarthropods that were killed by toxic chemicals, tillage and lack of foods (organic matter) in the soil need to be put back. Until that happens, people will be forced to use toxic chemicals to attempt to grow plants. Proper nutrition for the plants will be lacking until the organisms that retain nutrients in their biomass are returned to the soil. How do we put back what has been harmed?

It's called compost. Or compost tea, if the source of compost is distant, and transportation costs are too high. Since compost tea extracts the full diversity, and then grows selected beneficials to high numbers, a small amount of good compost can be extended dramatically.

But we need to know how to make compost tea that will contain the full set of organisms needed, at high biomass and activity levels. Depending on what you want to do, choose the method of supplying the organisms your soil needs to become healthy (from the point of view of the plant you want to grow) once again.

Aerated Compost Tea (ACT)

ACT is a water extract of compost, brewed without use of heat, which allows beneficial organisms to grow to high numbers. Foods may or may not be added. If no additional foods are used, organisms are not typically active, and thus less likely to survive transfer to soil or to plant surfaces.

Not-Aerated Compost Tea

A water extract, brewed, with or without added foods, but aeration is not provided. If a highly mature compost with few active organisms is used, the organisms will not be highly active and thus not use up oxygen during the brewing. The tea will likely not become anaerobic, but neither will the organisms stick to leaf surfaces, since they are not highly active. More work on production conditions is needed.

Anaerobic Tea

A brewed water-extract but foods are added (or from the compost) to result in organisms multiplying rapidly, such that oxygen use is greater than oxygen diffusion into the water. The oxygen concentration will drop, and if it drops below the threshold of 6 ppm, aerobic fungi, protozoa and nematodes will be lost, replaced by strictly anaerobic bacteria and yeasts.

Manure Tea

Manure is added to water. If no mixing or stirring is used, only soluble nutrients will be extracted and the tea will typically be high in nitrates, salts, phosphorus, and/or potassium. Antibiotics used in the animal feed are soluble and so normally extracted into the water and can cause significant problems for microorganisms in the liquid extract. If the manure tea is mixed or stirred, high numbers of anaerobic bacteria will be extracted, since anaerobic bacteria are not as good at sticking to surfaces as aerobic organisms. Manure tea contains high numbers of ciliates, extremely low fungal biomass, and can have high numbers of nematodes. Human and animal pathogens can abound as well. At the very least, manure tea cannot provide all the benefits possible from compost tea. Once manure is composted, then it should be called compost.

Compost Extract

By running water at significant pressure through compost, the organisms and soluble nutrients can be extracted from the solids, depending on the extraction force applied.

Compost Leachate

Passive movement of water through good compost removes soluble nutrients and a few organisms. Leachate is not necessarily anaerobic, but can be if organisms in the compost are growing rapidly. Phytotoxic compounds can be present and nutrients can be lost if the leachate becomes anaerobic. Soluble nutrients, enzymes and hormones can benefit plant growth, of course, but care is also needed to make sure salts (e.g., nitrates) are not present in the compost, as high levels can "burn" plant surfaces.

Plant (or Fermented) Tea

Fresh plant materials (e.g., nettles, chamomile, marigolds, and horsetail) can be added to water to remove plant juices. Organisms on the surface of the plant material grow on the dead plant tissues and often go anaerobic for a period of time. As the plant material is used up, organisms stop growing, allowing oxygen to diffuse back into the tea. Usually high numbers of ciliates, extremely low fungal biomass, and many bacteria are observed. Plant teas usually do not contain all the organisms in compost tea, nor provide all the benefits possible from compost tea. Anti-microbial agents can be produced, and quite interesting effects have been produced. More work is needed to achieve consistent production.

Bacterial Soups

As with plant tea, mixes of bacterial species can have specific beneficial impacts. Single species of bacteria can produce bio-control effects, except the conditions in which a single species works is quite limited. Addition of these cultures to compost tea can add functions to the tea, however.

Organisms and Food Resources

Bacteria, fungi, protozoa, nematodes, soluble foods and other nutrients need to be extracted from compost during tea brewing. The higher the quality of the compost, the greater will be the number of beneficial species of each group of organisms. Diversity of food resources and nutrients will improve as more kinds of plant materials are used in the composting process.

Additional foods are typically added in compost tea, some to grow the organisms in the tea brew, but others are added to the finished tea, just before application, to enhance the activity of the organisms so they will glue and bind themselves to foliage, for example. Foliar applications require maximum coverage of the leaf surfaces, as well as maximum activity of the beneficial species.

Compost Quality

Compost quality is critical. Making certain that the compost has the organisms is extremely important. Aerobic compost means a habitat has been maintained that allows the beneficial organisms to out-compete the less or not-beneficial organisms that grow more rapidly in reduced oxygen conditions. The soluble nutrients and foods in aerobic compost help make certain the organisms will grow in the tea brewing process.

Additives of organisms, different kinds of foods, or nutrients can be used to improve conditions for beneficial bacterial and fungal growth in compost, or even in compost tea. These additives need to be checked for pathogens. Care needs to be taken to not add too much food resource. If excess is added, bacterial and fungal growth will result in oxygen consumption to a detrimental level.

Aerobic Conditions

Aerobic conditions maintain the presence and growth of beneficial organisms. If aerobic conditions are lost, and the tea becomes anaerobic or low oxygen concentrations, the aerobic organisms will be lost. If there are few aerobic organisms, then the resulting brew cannot actually be compost tea. The organisms in the compost have been lost, for the most part.

For that reason, anaerobic teas are not called compost teas, as the organisms which cause the beneficial effects desired in compost tea will not be present. Anaerobic teas may do some interesting things, but they cannot provide the benefits discussed below that are possible with aerobic compost teas.

Machine Testing

Tea-brewing machines must be tested to show that adequate biomass of all groups of necessary aerobic organisms were present in the final tea. The testing conditions should use:

1. either the food resources sold by the tea machine maker, or a standard set of foods, such as 0.01% fish hydrolysates and 0.01% humic acid (1 gal of fish, and 1 gal of humic acid in 100 gal of water),
 2. compost with documented initial biology,
 3. aerated conditions, such that oxygen remains in the aerobic ranges during the tea brew.
- The data from these tests (a minimum of three replicated tests) must be available to the buyer, in order that the buyer can assess whether this machine performs as advertised.

To obtain the full benefits possible from compost tea, the brewing process has to be aerobic. The balance of amount and type of foods added determines oxygen demand by the organisms growing on those foods. Testing of the machine must be displayed by the tea machine maker before anyone would consider buying a machine labeled as compost tea maker.

ASK FOR DATA so you don't have to do this testing yourself. You need to know what amount of food to put in the machine as temperatures change through the course of the year.

Anaerobic Conditions

Anaerobic teas are much less clearly defined than for aerobic tea. Sometimes compost tea may become anaerobic for only a few minutes, for a few hours, or sometimes for days or weeks. Brief anaerobic periods may increase diversity, if the aerobic organisms are not destroyed or put-to-sleep. Prolonged anaerobic conditions mean that many organisms will become inactive or die, and that nutrients will be lost.

Anaerobic tea will not replenish the full soil food web, nor can it be a nutrient supplier. Anaerobic teas add only anaerobic bacteria and yeasts. Leaf surfaces are aerobic environments, and anaerobic organisms do not stay active nor will they perform their functions in aerobic environments. An anaerobic tea applied to an aerobic environment may provide a physical barrier, for a short time, but that is the only function it provides from a food web point of view.

Filamentous fungi that build soil structure and hold nutrients are lost, or become dormant, when conditions become anaerobic. Aerobic bacteria that make micro-aggregates go into dormant stages in anaerobic conditions, and therefore soil structure will not be maintained. Protozoa, nematodes and microarthropods die in conditions that rapidly become anaerobic. Nutrient cycling will therefore no longer occur. In anaerobic conditions, nutrients are lost through volatilization, because major nutrients are converted to gaseous forms in reduced oxygen conditions. When you smell ammonia, rotten egg, vinegar, putrid, or sour smells, pH is dropping, alcohol is being produced, and N, S, and P are lost as gases.

The work Soil Foodweb Inc. has done was to define production requirements for beneficial, disease-suppressive, nutrient retaining, nutrient cycling, and soil-structure building compost tea. Anaerobic tea production parameters are still largely undefined, leaving us without a working knowledge of how to predict whether the tea will "work", or not.

Human Pathogens

A major concern is the potential for human pathogens to grow in compost tea. This can only be a concern if the compost is not properly made. Elements in the USDA take the view that even with non-manure materials, human beings could still contaminate compost starting materials. Therefore, all

compost must be properly treated (heat or worm contact). Even then, certain programs view compost as potentially containing human pathogens, but they lack a realistic understanding of the environment in which we live.

If there are no detectable pathogens in the compost, and conditions during compost tea production are managed to prevent pathogen growth, then the risk involved in pathogens in compost tea are minimal. There would be more probability of a bird infecting your sandwich while it was sitting on a picnic table than having pathogens grow in the aerobically maintained tea.

Therefore, understanding the conditions selecting against pathogen growth in compost tea is vital. These conditions that select AGAINST human pathogen growth are:

1. Maintain aerobic conditions in order to select against pathogens, which are mostly facultative anaerobes.
2. Make sure a huge diversity of aerobic bacteria and fungi are present, which compete-with facultative-anaerobe-growth in all conditions in the tea brewer,
3. Make sure no anaerobic bio-films are left in the tea brewer after a tea brew.

Cleaning is an extremely important factor that many do not consider before buying a machine. No one wants to spend hours cleaning a machine. The greater the number of "hidden-from-view" surfaces present, the longer it will take to clean the machine. Don't trust manufacturers to tell you the truth about cleaning issues. Talk to someone who owns the machine, and who tests their tea. They will relate how critical testing and cleaning actually are.

What Growers Need to Know

The point of applying compost tea is to return the biology that should be present, to grow the desired plants with as little effort as possible. There can be no question that presence of beneficial organisms improves plant growth (Ingham et al, 1985, USDA Soil Biology Primer, 1995 and numerous papers on the benefits of biology to plant growth since that time).

Growers need to know:

1. The biology that should be present in their soils and plant surfaces.
2. If they know what should be there, then they can determine what biology is missing from their soil.
3. What organisms are in the compost. Selection for bacterial or fungal growth can be managed during the compost tea brewing process by adding appropriate foods.
4. The tea sprayer does not kill the organisms in the tea
5. Delivery of the missing organisms, along with foods, has been successful.

Beneficial bacteria and fungi are needed to immobilize nutrients, to prevent erosion and run-off by gluing and binding soil particles together to form aggregates, to compete with disease organisms for food, to build soil structure and to allow roots of plants to grow deep into soil and find water and nutrients. Protozoa, nematodes and microarthropods consume bacteria and fungi, and thus release nutrients at the place, time and rates that plants require.

A maximum diversity of each of the sets of beneficial organisms is needed in soil and on plant surfaces. Each combination of environmental conditions selects for the activity of at least several hundred species of bacteria and fungi, several tens of species of protozoa, nematodes and microarthropods. There are always organisms performing their function, until the conditions become so extreme that all activity shuts down, such as when soil freezes, or moisture drops very low. Diversity is necessary, and the way to replenish that diversity is by using compost made with a wide range of plant materials, or compost tea, made from properly processed compost.

Even "pest" species should be present, in low numbers and low diversity, because they have a function in soil. Pests are designed to remove stressed plants, for example, and as such, are indicators that the soil food web is not healthy.

There might be a few disease organisms present in soil and compost. What is a disease in one system may be a beneficial organism in another system. Dormant stages of many organisms survive the composting process, but are not active and do not often cause disease.

The ratios of the different groups must be managed to promote the soil conditions that select for the

growth of the particular species of plant desired. For more information about the soil food web, check www.soilfoodweb.com for references, textbooks and publications.

Qualitative Assessment of Compost Tea

Perhaps one of the most exciting recent developments by Soil Foodweb Inc is a way that individuals can easily and cheaply assess every batch of tea of the organisms they want to know about. There is set-up required, and some training is needed to do this yourself, so an alternative is to send the samples into the lab or to an SFI advisor. These assays are typically a factor of 10 less than the quantitative assessments.

This method uses simple categories of assessment, from bad, to poor, to adequate, to good, very good and excellent. Enough people are starting to get "better" than excellent levels, so a new category of outstanding will likely be added. The categories are based on the presence and concentration of organisms observed in the sample, but they are not precisely quantified. They are placed in broad categories, but it allows a general assessment of tea quality.

Classes to train to do this work are typically held whenever enough people sign up, or at about one to two month intervals. Please see the SFI web site for dates and locations. And please remember that if you don't wish to do these assays yourself, contact your closest SFI lab (all labs on the SFI homepage, based on location world-wide).

The qualitative assay is \$77. The full-scale, quantitative assessment, necessary to do scientific study, varies depending on the number of organism groups being quantified.

The Habitat Must Select for Beneficials

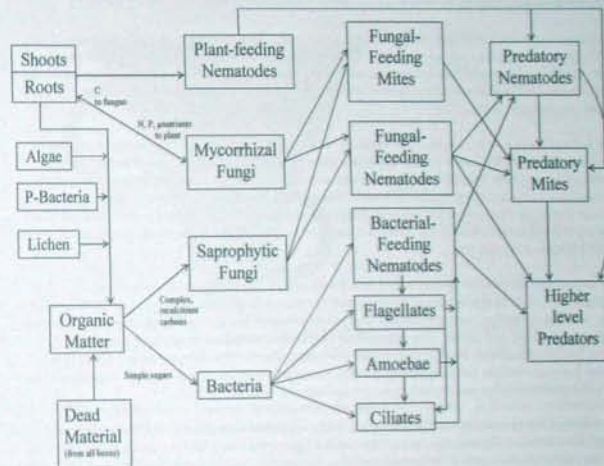
The habitat in compost and in compost tea needs to select for beneficial organisms and suppress disease organisms. Most plant and human pathogens require reduced oxygen conditions in order to be highly competitive. Since most beneficials require fully aerobic conditions to function, when oxygen becomes limiting, pathogens win in anaerobic, or reduced oxygen, conditions.

The factors that must be considered for making certain the habitat is correct for beneficial organisms are:

1. The foods used in the compost or the compost tea need to be selective for the beneficial organisms, not the disease organisms (see Recipe section).
2. The proper set of organisms needs to be present for the foods to be consumed, and for processes to occur.
3. Temperatures between 65 and 85 F in tea, salts within range, nitrates and sulfur less than 3 ppm and no toxic levels of any material.

With adequate extraction, compost tea will contain what was in the compost. If there are no human pathogens in the compost, then there will be no human pathogens in the compost tea made from that compost. Thus, compost quality is critical when making compost tea. This means we need to have standards for the biology in compost as well as in the compost tea.

Figure 1. A Soil Foodweb Diagram demonstrates the relationships between the sets of organisms (functional groups in boxes) needed in most crop, grassland, and vegetable soils to grow plants without requiring pesticides or inorganic fertilizers.



Is Compost Tea A Fertilizer?

Nutrients are removed when crops are harvested. These nutrients need to be replenished or "put back" into the soil. Even better, fertility should increase with time. Soils in natural systems increase in nutrient concentration as succession proceeds, but this doesn't occur in conventional agriculture, because erosion, run-off, leaching and compaction result in loss of nutrients from the soil.

Why does this happen? What changes? The organisms that should hold both soil and nutrients in place are destroyed in conventional agriculture:

1. by tillage, which slices, dices and crushes the organisms,
2. by use of pesticides which kill far more than just the target organism species,
3. by use of high levels of inorganic fertilizers (which are salts, all of them, killing organisms through osmotic removal of water), and
4. by compaction which changes oxygen content in the soil, resulting in conversion of organisms metabolism from aerobic to anaerobic species. The problem is, those nutrients will not be held in a biology-poor soil, resulting in nutrient pollution of surface and ground waters, and atmosphere.

Because of all these losses, conventional chemical systems require 150 to 200 pounds - or more! - of N, to be "added back" to the soil each cropping cycle. In sustainable systems, where the biology is managed properly, and holds nutrients, only the nutrients removed through harvest must be replaced. Based on nitrogen (N) content in plant material, for example, only 15 grams of N per ton of plant material is removed. Therefore, in an orchard where perhaps 4 tons of fruit per acre is removed per acre, only 4 times 15, or 60 grams of N per acre is needed to replace that removed by harvest. Why are some conventional orchardists putting 1000 pounds of fertilizer per acre on their orchards each year?

The "worst case scenario" with respect to harvest removal of nutrients is production of silage, where 200 tons of plant material may be removed per acre. At these high rates, 200 times 15, or 3,000 grams of N (3 kg of N) would need to be added back per acre.

Can compost tea supply these needs? The surprising answer to this question is yes. Not in the standard "fertilizer" form (nitrate), however, but as organic N, held by the biology in organic matter and microbial, biological forms.

Most people have been told that compost is not a fertilizer. That statement can only be made if only soluble, inorganic nutrient values are used. The fertilizer industry has pushed to define N as only nitrate, possibly nitrite, and maybe ammonium, the inorganic forms of N. While this is based on the soluble forms of N that most vegetable and row crop plants take up through their roots, it is far from the only source of N in soil.

If the full soil food web is present, then forms of N that are not nitrate, nitrite or ammonium will be cycled into these soluble forms by the organism. And not just N, but any not-soluble form of any nutrient will eventually be converted from its non-soluble form to the plant-available, soluble form by the organisms cycling system in a healthy soil. Phosphorus, for example, is converted from not plant available forms (in rocks, in sand, silt, and clay, in humic materials, in organic matter, in dead plant material) into organism biomass and then be consumed by predators which results in release of plant-available forms of the nutrient.

If the organisms that perform these cycling processes have been destroyed by agricultural "management", then nutrients cannot be processed from not-plant-available forms into plant available forms. Leaching, erosion, and compaction then result in loss of the remaining nutrients from the soil, and plant production will suffer. The engineering and chemical answer is to load more and more soluble, inorganic nutrients into the soil, while bemoaning the fact that water quality suffers. These sciences have ignored the fact that natural systems manage to hold nutrients, manage to produce clean water, and produce higher plant yields than any agricultural system.

Plans for cleaning up nutrients using mechanical filtration systems (requiring engineers to design, build and maintain them), using soil-less mixes have been suggested as solutions to the water quality problem, all the while ignoring that nature has been successfully feeding everyone since life began on this planet. We have all the food we need, it is social systems that prevent people from having food. The human system needs to be fixed, not the plant production system. We need to learn the lessons nature puts in front of us everyday.

Nutrient Pools in Compost

Why is it that when you send a sample into a soil chemistry lab, compost will always be reported as being low in nitrogen? First, soil chemistry labs may remove the obvious organic matter as soon as the sample arrives, because their methods cannot extract minerals from large chunks of organic matter. They typically dry the sample and then use extracting agents to remove the soluble forms of the nutrients from the soil solution (soluble pool), or remove the "exchangeable" forms of nutrients from the surfaces of the clays, silts, sands and organic matter.

Does either approach to extracting nutrients assess bacteria? Fungi? Protozoa, nematodes or microarthropods? No. Nutrients in humus are not extracted either. Nor nutrients in parent material. Only the nutrients that are soluble (dissolved in water) or that can be extracted from the SURFACES of sand, silt and clay particles and organic matter are pulled from the soil. The exact value obtained for any nutrient also depends on the extracting agent used. Some extractants pull more nutrients than others, so in order to compare one lab's results with another's, the extractants used must be known.

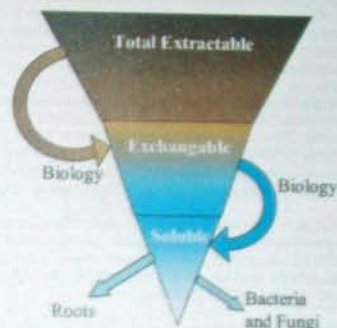
What test tells you what the plant will take up? Neither soluble nutrient pool concentration nor exchangeable nutrient pool concentrations will tell you what the plant will take up. Water soluble nutrients concentrations (N or P, or N, for examples) just indicate what is dissolved in water, right now. The plant may not be able to take up any of that if osmotic concentration is too high. If salt content is too high, water is held by the salts, and the plant cannot access either nutrients or water.

Figure 2. The three pools of nutrients in soil. The total extractable pool is assessed using very strong extracting agents, while the exchangeable pool uses less and less strong extractants, until the soluble where weak extracting agents are used. In natural soils, it is the bacteria and fungi that make enzymes and organic acids to solubilize nutrients from rocks, organic matter, clay, sand and silt particles, and tie-up those nutrients in their living biomass, as well as organic matter waste products. Nitrogen is not

held in rocks, but N-fixing bacteria perform the same function. These bacteria immobilize that fixed N in their biomass. In both cases, predators are required to mineralize these nutrients into inorganic forms the plants require.

Components of Soil Nutrient Pools

Tests used for each pool



Grind; Conc. Nitric acid, combustion
10% HCl, H₂NO₃

Melich III
Bray 2
Amm. Cl / BaCl

Colwell
Olsen, Bray I
Melich I
Morgan (Reams)
1 M KCl, Universal

Soluble nutrient concentration does not predict what the plant will take up. It does not predict what nutrients will be solubilized in the next instant. To predict what will be made available to plants requires knowledge of what plant material is present as food for the microbes (how active will the bacteria and fungi be?), what population of bacteria and fungi are present that can solubilize nutrients from parent material, from humus and dead plant material, what population of predators of bacteria and fungi are present and how active they are consuming bacteria and fungi, and releasing soluble nutrients.

Consider the following information based on extractions of nutrients from soil. The original soil contained on average only 1.8 ug of phosphate per gram (ppm) of soil. Rock phosphate and compost were added to achieve a value of 75 ppm phosphate, on average. Two weeks later, soil from the same field was sampled using the same methods and phosphate was 200 ppm. Bacteria has decreased slightly, and fungi had increased by nearly 2-fold. Nothing was added to the field in the intervening 2 weeks. No fertilizer, no pesticides, no tillage, no seed, just grass growing in the field.

Where did the "extra" phosphate come from? Did the lab have a problem? "Mess'd up" in their assessment? Which time?

Think it through. Plants were growing, making exudates, feeding bacteria and fungi in the root system. Phosphate was solubilized from a plant-not-available pool. Organisms solubilize many nutrients. If the organisms are present, and have foods, they will perform nutrient cycling processes.

What then is the chemistry information that we need in order to predict what will become available to plants through the course of a growing season? If we know the extractant methods used (see right hand side of Figure 3), we can properly interpret what part of the nutrient pool is being assessed by any soil chemistry test. If we then know the biology in that soil or compost, the activity of the bacteria and fungi, the activity of the predators, then we can begin to predict the rate at which N, or P, or other nutrients will become available for plant use. Examination of any of the journals in the area of soil ecology, e.g., Applied Soil Ecology, or Soil Biology and Biochemistry, or Biology and Fertility of Soil, will reveal that this area of investigation is beginning to be understood.

The problem in agriculture has not been a lack of nutrients, but a lack of the proper biology to make those nutrients available to plants. The total extractable nutrient level is in excess in most soils examined so far. But the biology has been destroyed.

Similarly, compost contains plant-available (soluble) nutrients, exchangeable nutrients but an even greater pool of plant-not-available nutrients that will only be made available as the bacteria and fungi in the compost solubilize those nutrients, and then protozoa, nematodes and microarthropods release those nutrients from the bacteria and fungi.

Compost contains both excellent biomass of organisms (bacterial and fungal biomass both in excess of 300 micrograms per gram, protozoa in excess of 50,000 individuals per gram, and nematodes in excess of 60 per gram) and high levels of total extractable nutrients (16,000 micrograms of N per gram of compost, 9,000 micrograms of P, and similar levels for most other nutrients).

Compost tea contains soluble nutrients extracted from the compost. Nearly all of the soluble and exchangeable pools will be extracted, plus perhaps 50% of the total pool in compost, based on an assessment of the compost after tea production. For example, an assessment performed by the Environmental Analysis Lab at Southern Cross University showed that the three pools (as shown in Fig 2 above) in a good compost contained about 286 micrograms of soluble N per gram dry weight of compost, about 340 ug of exchangeable N, and 17,000 ug of total extractable N per gram of compost.

That means, in a compost tea (2000 L or 500 gal of water using 15 pounds or about 7 kg of compost), approximately 45,500 micrograms of N were released into the 2000 L of water. One application of compost tea would supply a small but significant amount of N. And even more, when soil organic matter is present, and humic materials were added in the compost tea, a continuing supply of N would be provided to the plants through the nutrient cycling processes the biology provides.

Several compost tea applications could supply all the N a crop needed. But even more, a single application of one ton of compost plus compost tea could supply everything a crop needed, from nutrients to disease protection to weed prevention.

Compost contains many years worth of any nutrient. As long as the biology remains un-compromised by toxic chemical additions, the organisms will cycle those nutrients into plant-available forms. This strongly suggests that compost is a fertilizer, an organic fertilizer. Compost tea will contain many, but not all, of the nutrients that were in the compost. Compost quality is critical to understand, in order that we can maximize nutrient concentrations in the tea. Understanding the role of the organisms is all important, therefore.

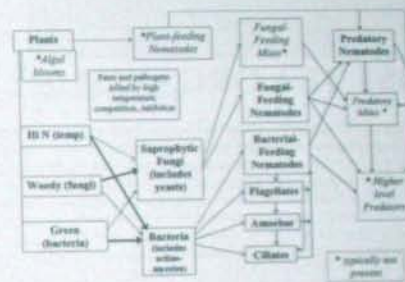
Natural systems don't require additions of inorganic, soluble (and thus very leachable) forms of nutrients to maintain productivity. The most productive systems on this planet are systems which do not have, and have not ever had, inorganic fertilizer applied.

If we want clean water, we have to get the biology back in our soils. If we want to grow and harvest crops, we have to build soil and fertility with time, not destroy it. The only way to reach these endpoints is to improve the life in the soil.

COMPOST QUALITY IS CRITICAL

Of all the organism groups in soil (Figure 1), how many are in compost? Compost typically contains all the important groups that are in soil, but typically lacks pathogens, if made properly (Fig 3).

Figure 3. The Compost Foodweb. The organisms in compost tea come from the compost. All of the species and many individuals of each species are extracted from the compost, but individuals reproduce based on the habitat present in the tea. If conditions are appropriate for beneficial species to grow, they will out-compete disease organisms. If the habitat in the tea is more conducive to the growth of disease organisms, disease organisms grow. Care in providing the proper conditions are critical.



Organisms

Well-made compost will contain, for the most part, only beneficial bacteria or fungi. Think of the bacteria or fungal boxes in the soil food web picture above as having a dotted line down the middle: Half of the species are "good guys" and help your plants grow, while the other half are "bad guys" that decompose plant tissues if growing on plant surface. These "bad guys" bacteria and fungi are selected against in the composting process, whether by high temperature, competition, inhibition or consumption by predators, or by passage through earthworm digestive systems, the result is the same. Pathogens should be inactive and not detectable in well-made compost.

Organism biomass, diversity and growth or activity can be enhanced by adding organisms, different kinds of foods, or nutrients to improve conditions for beneficial bacterial and fungal growth. Check to make sure they are without pathogens, which means documentation of the biology must be given by the seller of the product. Care needs to be taken to not add so much food resource that the growth of bacteria and fungi will consume oxygen to a detrimental level and allow the compost to become anaerobic.

Disturbance

The less disturbed the compost, especially in the maturation phase of composting, the greater the likelihood that compost will contain higher biomass of fungi, and numbers of predators, such as beneficial nematodes, protozoa, and microarthropods. Good aerobic compost should NOT contain root-feeding nematodes, weed seeds, or human pathogens. Good aerobic compost should contain very few plant pathogens.

Of course the need to not disturb compost during the composting process must be balanced with the need for air in the compost. If the bacteria and fungi have gone through their burst of growth early in the composting process, and are truly maturing the pile, then heat will no longer be generated and the pile will cool. If the microbes are still growing and using food resources, the temperature of the pile will not cool. Often when anaerobic conditions occur, the pile "never cools". If the pile remains at 140 to 150 for months and months, this is a clear indication that the pile is not compost, and should be

considered putrefying organic matter (POM).

Do not use putrefied organic matter to make compost tea, and do not expect any of the benefits discussed relative to good compost to occur if POM is used.

Compost should contain a maximum diversity of many types of bacteria, fungi, protozoa, and nematodes. If water movement through the compost is adequate to pull the organisms from the surfaces of the compost, but not crush the organisms, the microbes in the compost will be extracted into the tea solution. Higher quality compost will have a more diverse microbial population, resulting in greater diversity in the compost tea.

Clearly, compost and compost tea become even more critical, as sources of the indigenous beneficials disappear from the landscape.

COMPOST TEA ORGANISMS

The "Good Guys" or beneficial organisms – including bacteria, fungi, protozoa and nematodes – are present in good compost and therefore will be present in compost tea. Species diversity may be as high as 25,000 species to as many as half a million species in a gram of compost or tea. DNA methods for assessing species diversity of bacteria, fungi, protozoa and nematodes will be the way to determine the actual number. Fingerprinting methods sound promising for assessing diversity. Plate count methods are not useful for assessing diversity. Currently, a combination of selective media, enzymes and fingerprinting can serve to determine whether 20 specific beneficial species are present or not. In this way, you can determine whether your tea includes the beneficial organisms that you need. If they are lacking, then you would know to add them back to your compost or compost tea. More advances are forthcoming in this area, however.

Bacteria

Good compost teas have on the order of a billion bacteria per ml (10^8 to 10^9 bacteria per ml), most of which are beneficial to plant growth. Highly aerobic teas can contain even greater numbers, on the order of 10^{10} to 10^{11} bacteria per ml. Beneficial bacteria compete with disease organisms for food, for space, and for infection sites on plant surfaces.

Since coverage of leaf or root surfaces by the tea organisms is what is important, these numbers mean that 100 times more tea from a bucket method might be needed to achieve the same results as from one of the commercial units that make good compost tea.

Bacteria make glues that hold them strongly on leaf, root or soil surfaces. This is why nutrients held in their biomass don't leach and will not be lost from soil or leaf surfaces. Given this fact, it is thus necessary to apply enough energy to compost to physically pull these organisms from compost particles into the tea. Some of the initial testing with the Micro-Brewer was conducted to determine the strength of the vortex in the liquid that would remove by not destroy organisms. If too much force is applied, the organisms will be killed by impact on the surfaces of the brewer. This type of testing must be performed with other machines, to make certain the physical blending performed does not macerate or disintegrate some of the organisms, but is enough to pull the organisms from the compost.

Once pulled from the compost, the organisms must be able to pass through the mesh of the compost container, and must survive in the tea. If conditions drop below aerobic levels, many of the beneficial bacteria will not be able to grow, and some will be killed or put into dormant condition. If there are no foods to feed the beneficials, they will become dormant in the tea, and not increase in numbers in the tea. The desired conditions in the tea are aerobic, with good levels of foods to grow beneficial organisms.

Figure 4. Fungi (strands), bacteria (tiny dots and rafts of dots), ciliate cysts (large circles) in a compost tea.



How to Measure Bacteria and Fungi

Direct Methods are the best way to assess both active and total bacterial and fungal biomass in any material. The organisms are viewed and counted and there is no question that what is being counted is the organism of interest. There is no requirement to know what food resource is needed to grow the bacteria or fungi, what temperature the organisms grow at, what humidity is required by the different species, etc. as there is with plate count methods.

It is impossible for a single set of incubation conditions to meet the growth requirements for all the different species of bacteria or fungi. For example, a plate count assessment cannot enumerate both heat-loving and cold-loving bacteria species, wet-loving and dry-loving bacterial species, species requiring high N and those requiring low N. Direct methods can assess total and active biomass of bacteria or fungi in any kind of material.

No incubation step is required using direct methods. There is no "guess" required with respect to dilution. Samples are finished within several hours of arrival in the lab so if a different dilution is needed, the original sample can be used. The actual sizes of the bacteria and fungi in the sample are measured, so no guesswork about bacterial and fungal biomass occurs with this method.

Plate Methods are best for identifying SPECIFIC species, using selective growth media. When technological methods for performing direct count methods were not particularly reliable, perhaps 20 to 30 years ago, plate counts were used to estimate total or active bacterial or fungal numbers in soil. However, no one particular type of medium can grow all the different bacteria or fungi that occur in any environmental sample, including compost or compost tea. Consider that the microorganisms in soil, or tea, or compost, grow at many, many different temperatures, use many different foods, and a whole range of moistures and humidity's. These variations are not mimicked in any way by the growth conditions used in a laboratory. In order to understand true diversity in any sample, plate methods would have to use several thousand kinds of food resources, incubated at each temperature, each moisture, each humidity and each oxygen concentration of interest.

In plate counts, ten-fold dilutions are typically prepared and the quantifier has to "guess" which dilutions to plate on the medium chosen. Plates are then incubated at one temperature, one moisture, one humidity, one set of limited carbon, nitrogen, P, K, Fe, Ca, etc. concentration. The plate that has a "countable" number of colonies, between 30 and 300 per plate, is counted at 1 and 2 weeks, but how many of the total bacteria present were missed? How can you possibly know which ones were active in the conditions of your soil? Microbiology texts discuss problems with plate count methods (i.e., Sylvia et al., 1999). Plate counts always underestimate the number of actual bacteria present, but what is not known is by how much numbers are under-estimated - 2-fold, 10-fold, 1000-fold, or more?

Plate count methods are therefore NOT useful for assessing species diversity, or species richness.

Why Are Bacteria Needed in Tea?

Bacteria occupy most of the leaf or root surface and thus are most effective at consuming the food resources that the disease-causing organisms would otherwise consume. Bacteria occupy most of the infection sites, which would otherwise be occupied by the disease-causing organisms. In soil, bacteria have additional functions beyond consuming foods and occupying infection sites, they also retain nutrients (N, P, S, Ca, Fe, etc) in their biomass (given the C:N ratio of bacteria, they cannot mineralize N, they have to be immobilizing N in their biomass - the exception is nitrifying or ammonifying bacteria which use N as electron acceptors or donors, but these are unusual and very special processes which occur in particular conditions in soil). Bacteria also decompose plant-toxic materials and plant residues (especially the simple, easy to use substrates), and build soil aggregate structure. The smallest "building-blocks" of soil structure are built by beneficial bacteria. Without these bacteria, the bricks to make the "soil house" will not occur and further development of soil structure will not happen. Water-holding capacity can never be improved and soil will remain compacted, if the organisms are not present and functioning in soil, or in compost. Bacteria build the bricks that allow passageways for diffusion of oxygen into, and carbon dioxide out of, the soil.

Thus, it is critical to have bacteria in high enough numbers, and with as great a diversity of species as possible, so that some portion of these bacteria can function within existing environmental conditions and suppress various cultivars or races of disease-causing organisms. Most of the bacteria added in the tea will not be the right ones at the moment you add the tea, so they go to sleep in the soil, and wait for the right conditions that will allow them to wake up, suppress their competitors, retain nutrients, decompose residues, and build soil aggregate structure. But of the tens of thousands of species of bacteria added in tea, several hundred will match the growth conditions present at this moment, and suppress disease, retain nutrients, decompose residues and build soil aggregates. What are the names of these bacteria? We don't know. We can't grow them on ANY culture medium; plate count methods cannot be used to assess these organisms.

Do we have to know the names of each of these bacterial species in order to have them work for us? No. Until science develops ways to inexpensively identify them, just get the critters in tea working without worrying about their names. Let plants select the organisms needed. The plant feeds those organisms that prevent diseases around its roots, leaves, stems, etc. The plant feeds bacteria and fungi, so that protozoa and nematodes will have something to eat, and result in nutrients being made available in the form plants require. The plant feeds bacteria and fungi so they will build soil structure, keeping oxygen diffusion flowing smoothly, as well as making the water-holding pores in soil.

Wise agriculturalists will learn to stop killing beneficial organisms with toxic chemicals and let the organisms in soil do the work nature designed them to do.

Fungi

There should be 2 - 10 micrograms of active fungal biomass per ml, and 5 - 20 µg total fungal biomass per ml in good compost tea. Decent compost, which should contain 150 to 200 µg of total fungal biomass per gram, contains both simple extractable carbon sources (sugars, proteins, amino acids, simple organic acids) as well as more complex fungal foods (complex amino-sugars, complex proteins, hormones, siderophores, complex carbohydrates, phenols, tannins, and humic acids). Simple carbon sources are easier to extract than more complex molecules, but fungi require complex molecules as their food resource.

Energy must be provided during tea-brewing to extract complex molecules. Complex molecules are needed so fungi have something to grow on in the tea. Fungi also have to be extracted from the compost, which means the aggregate structures that fungi form must be broken, and the fungal strands teased free into the tea solution. This is tricky, to provide enough energy to disintegrate aggregates and to break fungal strands, but not destroy them.

Why Are Fungi Needed in Tea?

Just as with bacteria, certain fungi compete extremely well with disease-causing organisms. The foods added to tea should help these fungi. Materials high in inorganic nitrogen are not wise additions to tea, since high nitrogen levels help disease-causing organisms grow rapidly. Fungi and bacteria often compete with each other for food, space, oxygen, water, etc, so a bacterial tea tends to reduce fungal growth and vice versa. Plants generally require either bacterial-dominated, or fungal-dominated soils because the microbes control nutrient cycling and the FORM of the available nutrients. For example,

most trees do NOT do well with nitrate. Nitrate/nitrite tends to select for disease conditions along the roots. Thus ammonium, requiring pH levels lower than 7, and supported by the metabolites produced by fungi, is a better choice for trees.

Fungi tend to occupy only 5 - 20% of the leaf surfaces, but appear to be very important for competition with disease-causing organisms. One reason why applying a single bacterial species to control blossom rot doesn't work is because the environmental conditions may not favor the growth or survival of that single species. Or fungal interactions may be more important under those specific conditions. Beneficial fungi may be needed to consume the exudates that plant leaf surfaces, stems, blossoms, etc., produce, so there is no food to allow the disease-causing organisms to germinate and/or grow on the leaf surface. Infection sites on the leaves may need to be occupied by beneficial fungi so that disease-causing organisms cannot infect the plant.

In soil, fungi have additional functions beyond protecting plant surfaces from non-beneficial organism growth, by competing for nutrients, space and occupying infection sites. These additional functions include:

1. retention of nutrients (N, P, S, Ca, Fe, etc) in fungal biomass (the C:N ratio of fungi means that fungi cannot possibly be mineralizing N, they have to be immobilizing N in their biomass).
2. retention of micronutrients in fungal biomass - fungi are the major holders of Ca, at least in soils we have tested,
3. decomposition of plant-toxic materials and plant residues (especially more recalcitrant, less easy to use substrates), and
4. building soil aggregate structure. The visible aggregates that are seen in soil are built by fungi by binding together the "bricks" made by bacteria, organic matter, root hairs, fecal pellets provided by soil arthropods, etc. Without fungi, visible aggregate formation would not occur as often, and further development of soil structure would not occur. Soil would remain compacted, because fungi build the hallways and passageways between aggregates that allow oxygen to diffuse into the soil, and carbon dioxide to diffuse out of the soil.
5. improvement of water-holding capacity by building structure in soil.

Thus, it is critical to have fungi in high enough biomass and with as great diversity of beneficial species for the plant as possible to be present, so that at least some species of beneficial fungi will be functioning within the existing environmental conditions. It is the fungal biomass that is most rapidly destroyed by continuous plowing. Fungal biomass is typically lacking in any field that has been plowed more than 10 to 15 times. Thus, beneficial fungi are critical components to return to the soil.

Of the thousands of species of fungi added in tea, the conditions in the soil will match the conditions that are best for only a limited set of fungal species to grow and perform their functions. Which set of fungi will this be? What are their names? We don't know. Typically, we can't grow them on ANY culture medium; there is no plate count method that can enumerate them. We can detect their presence using DNA analysis and molecular approaches, but we then cannot match their function to their DNA sequence.

Do we have to know the names of each of these fungal species in order to get them to work for us? Until methods are available to identify them and give them names, that isn't possible. So, just get the full diversity of fungi back and let the exudates plants produce select for desired species. Don't kill beneficial fungi with toxic chemicals, especially fungicides, or too high levels of inorganic fertilizers.

Figure 5. Basidiomycete fungi (dark brown) with clamp connections growing in brown amorphous soil organism matter. Small dots in the picture are bacteria. Magnification is 250 times actual.



Protozoa

Three factors are important for protozoan extraction:

1. Breaking apart aggregates so protozoa can be extracted from these previously protected places.
2. Supplying energy to pull the protozoa off surfaces, but not kill them.
3. Minimizing brewing time during which protozoa are subject to changes in pressure that results in cytolysis, or breakage, of individuals.

Protozoa eat bacteria, releasing nutrients that stimulate the growth of bacteria, fungi, and plants, if plants are present. So, when scientists say "bacteria mineralize N in soil", what is REALLY happening is that protozoa mineralize N as they consume bacteria.

With time, protozoa will increase in number in the tea, but when brewing times are short, there is no time for reproduction to occur. For example, a 24-hour brew time is not enough time for an increase in numbers, and only the protozoa extracted directly from the compost will be present in the tea. For short-term tea makers, this means use of good compost is critical in order to extract the protozoa from the compost, since growth will not be possible during the extraction time. Teas that are brewed longer can have protozoa grow in the tea. For example, in a three days tea brew cycle, protozoa could multiply, giving a 3 to 6 times increase in numbers.

Flagellates and amoebae do not tolerate reduced oxygen conditions well. If the tea becomes anaerobic at any time, these groups of protozoa will be killed. Thus flagellates and amoebae are good indicators of aerobic conditions – if their numbers are low, anaerobic conditions or extreme mixing pressures are indicated.

Ciliates, on the other hand, tolerate anaerobic conditions, and indeed, apparently prefer to feed on anaerobic bacteria. High ciliate numbers in tea, or soil, or compost are indicative that anaerobic conditions occurred sometime during the production cycle, although conditions may not be anaerobic at the time of sampling. Anaerobic conditions could have occurred in the PAST, and no longer be a problem.

Immature compost most likely will not have a decent set of protozoa, which therefore cannot be extracted into the tea. Compost needs to cool to at least 125° F (50° C) before most protozoa will start to reproduce normally. Thus, a pile should cool at least 1 week, without turning, after falling below 125° F (50° C) to allow the protozoa to grow and reach minimum numbers (20,000 per gram dry weight of compost) throughout the compost pile.

Nematodes

Like protozoa, nearly all the nematodes in the compost will be extracted in good tea making machines because enough energy is applied to the compost to pull these organisms out of the compost. Dripping water through compost is not adequate for extraction, however. Good compost normally contains fifty to several hundred beneficial nematodes per gram, which can be extracted into the tea. All these nematodes should be beneficial; only poor compost would contain root-feeding nematodes.

Nematodes play a number of different roles in soil, and it is important to recognize that while one group of nematodes is detrimental to plant growth, most nematodes in soil are beneficial for plant growth. There are four major functional groups of nematodes in soil:

- Plant-feeders are the "bad guys", and consume root material, reducing plant growth and yield,
- Bacterial-feeders consume bacteria, releasing N, P, S, etc which are then available for plant uptake,
- Fungal-feeders consume fungi, releasing N, P, S, etc which are available for plant uptake, and
- Predatory nematodes consume other nematodes and keep the population numbers of the bad guys, and the good guys, under control. Too many bacterial-feeders could reduce bacterial populations below the level needed to suppress disease, retain nutrients, decompose residues, or build soil aggregates. Thus predators are important controls on the foodweb system.

Compost that has reached high enough temperatures for long enough (131F or 55C for three full days in all parts of the pile), or been processed completely by earthworms (surface contact, or passage through the nematode digestive system) will not contain root-feeding nematodes. Care is needed to choose compost that is mature in order to have a good set of beneficial nematodes in the compost. Awareness of post-production contamination is also required.

Beneficial nematodes do not start to grow in a compost pile until after temperature drops back to less than approximately 115° F (45° C). Both predatory and most fungal-feeding nematodes are killed if the pile is turned too often. Thus, the pile has to mature, unturned, at least two to three weeks AFTER temperature has dropped below 115° F (45° C) in order for there to even be a hope that it will contain adequate nematode numbers.

Mycorrhizal fungi

These fungi do not grow in tea solutions, although spores and hyphae will be extracted into the solution from the compost. The heating process during composting often kills the spores, so although present, they will not be viable. It is usually of some benefit to add an inoculum of mycorrhizal spores to the final tea solution when the tea is to be used for soil drench or root applications. The food resources present in tea may cause mycorrhizal spores to germinate after a few days, but if the germinated spores do not find active roots within 24 to 48 hours of germination, they will die. Therefore, spores should be added to the tea just before application to the crop, not at the beginning of a tea brew.

Species Composition of Bacteria, Fungi, Protozoa and Nematodes

Species diversity in tea is dependent on diversity in the compost. If there is poor diversity in the compost, the tea will not give the benefits that would result with a healthy diversity of species. Healthy compost has between 15,000 to 25,000 species of bacteria per gram (based on DNA sequence more different than the sequence difference between human beings and chimpanzees, for example), but the DNA analysis required to establish the set of species in highly diverse compost versus the number of species in not-highly diverse compost – or compost tea – awaits further work.

In a study using plate methods, performed by the Soil Microbial Biomass Service (SMBS), every morphological type and every species that occurred in compost was found in the compost tea. Some of the bacterial species extracted will grow in the tea solution, provided the correct food resources are added or present. It is unlikely, though, that all the food resources for all bacterial species will be present in even the best compost tea solution. Therefore, this is a selective step. It is important that the food resources in the tea are selected for beneficial species, and not pathogens.

Diverse sets of bacterial species will control pathogen growth. Most pathogens cannot compete well with beneficial species. Therefore, by maximizing bacterial and fungal species diversity, selection will

be against the growth of pathogenic and pest species.

In the study performed by SMBS, fungal species and biomass were found in much smaller quantities in the tea than in the compost. Extraction efficiency for fungi was not great using tea-making methods. In addition, the fungi extracted did not grow well in tea because they were shattered and killed by mixing and agitation. All protozoan and nematode species found in the compost were found in the tea (SMBS study, 1993).

Pathogens in Tea

E. coli is just an indicator of fecal contamination. Over the last century, total coliforms, fecal coliforms, fecal *E. coli*, and *E. coli* O157 have been used to indicate human health problems with water and soil. Of these groups, which ones are truly of no concern (you have them on your hands, skin surface, any door handle recently opened, in the roots of plants, etc), of some concern, of significant concern and which can kill people?

Total coliforms are found in a wide range of habitats, and are not of concern, except to say that a fecal *E. coli* test should be performed. Wash your hands and your food to remove this bacterial load.

Fecal coliforms exist in animal digestive systems (birds, snakes, rabbits, humans, cows, etc), and are important for proper digestion. Fecal coliforms occur wherever people are present, or where animals are housed. For example, benches and door handles can be good reservoirs, since people touch these objects all the time, and sooner or later someone who has not washed their hands after visiting the restroom will leave a load of fecal coliforms on these objects. Instead of vowing never to touch these things again, vow to wash your hands before you eat. These bacteria are secondary invaders, and only people already sick or stressed by something else will succumb to fecal coliforms. Typically, if you have been getting a normal set of coliforms in soil into your food, there is little risk from these organisms. BUT if fecal coliforms are present in food, or a food preparation area, it means some source of contamination is occurring, and should be tracked down and removed.

Fecal *E. coli* presence indicates, however, that a problem exists. *E. coli* doesn't survive all that well or for that long in aerobic, non-fecal conditions. That's why it is a good indicator of a problem. If fecal *E. coli* is surviving, then it is possible that the true human pathogens such as *Shigella*, *Salmonella*, *Pasteurella*, etc are also surviving. If *E. coli* can survive, then so too might the true human pathogens.

But listen carefully to what was just written. If *E. coli* can be detected, then the true bad guys MIGHT also be present. Fecal *E. coli* presence is an indicator that the possibility exists, and that sooner or later, there will be a problem. So, when fecal *E. coli* shows up on the selective medium, it is time to start investigating where the contamination is coming from. What is going wrong? Why are cleanliness procedures not taking care of the problem?

Ask for the results of *E. coli* testing when you buy compost to put on your vegetables or food crops. If you apply a source of questionable material anytime 120 days before you are going to eat those vegetables without washing them, there's a possibility that *E. coli* could still be present, especially if your crop production system does not have adequate aerobic organisms to out-compete the coliforms. But, a good washing will likely take care of the problem, both on your hands and on the surface of the vegetable.

Fresh vegetables sold in containers are the place where problems are likely to occur, because if the vegetables have a high load of contamination, the bacteria have a chance to grow while they are on the shelf in the package. There is therefore, a much more stringent set of rules for those processes. A less stringent set of rules is required for back-yard gardeners. This then means we need to make sure that local gardening education programs such as Master Gardeners teach this information and keep up with new information over the years.

If contamination in compost is found, an investigation should then occur, to determine where breakdowns in processing are occurring. The questions would be:

1. Are proper temperatures developing during the composting process? Ten to 14 days at 131 degree F or higher.
2. Is re-contamination of the pile occurring? If material rolls off the pile, and doesn't heat properly, but is then added back to the pile, contamination can occur, especially if the set of organisms in the

compost was not fully active and functioning.

3. Where is the contamination coming from? Quite often composting operations forget that machinery that contacts fresh manure will carry the disease organisms into the finished material, if the machinery isn't cleaned before it is used with finished product. There should be a separate truck or loader used at the beginning of the process with the raw materials and a different loader or truck for the finished product, or re-contamination will occur.

The problem needs to be found, fixed and then the piles re-tested for indicator organisms. When buying compost from a commercial source, you should ask for their *E. coli* data, to document that they are at least monitoring the pathogen problem. You should probably also ask for a report on the active bacteria and active fungi, because that's part of the protection system as well.

Only one sub-species of *E. coli* are truly human pathogens. The people in danger from this sub-species are those with immature or stressed immune systems. If *E. coli* O157 is on or in their food, death can be a result. Only fecal material from people or animals sick with this pathogen contains this pathogen, but there can be animals with sub-lethal illness that can spread the pathogen if care is not taken in the processing of the compost. Thus, compost used to make compost tea should be processed correctly and tested to make certain no contamination of the tea is occurring. While most *E. coli* contamination will be removed by proper tea aeration, high loads of *E. coli* will not be removed. Thus, making sure that the compost is not contaminated is a must.

E. coli and aerobic conditions. There is some confusion about the habitat that allows *E. coli* to grow. No single condition selects against or for *E. coli*, or any other human pathogen. Each pathogen has a particular set of conditions within which it does best. Those conditions must be met in order for the disease organism to grow to high enough numbers to cause a problem if ingested by a person.

What are the conditions that select for human pathogen growth in general, and then in particular? All human pathogens grow much better when oxygen is limiting. Just consider the habitat in which *E. coli*, *Salmonella* and *Shigella* generally grow - inside warm bodies, where oxygen is limiting and there are sufficient food resources, of the right kind. How limiting? In general, below 5.5 to 6 mg oxygen per liter of liquid. But some don't grow until oxygen reaches even lower levels, 4.5 mg, or maybe 5.2 mg.

The "indicator" organism, *E. coli*, makes enzymes that are more capable of taking nutrients away from other bacteria when the habitat is oxygen limiting. If *E. coli* can grab food away from other organisms, then the other bacteria can't grow, both because of limited oxygen and because they can't get food. Competition is limited and *E. coli* flourishes.

Perhaps not adding any of the sugars that *E. coli* can use could be one approach, but then the growth of the competing organisms would be limited in aerobic conditions. Not adding sugar is the incorrect choice. Maintain aerobic conditions, allow lots of aerobic organisms to grow. In aerobic conditions, enzymes work better than those of the human pathogens or indicators of potential pathogen growth.

Compost and compost tea need to have BOTH aerobic conditions AND high diversity of active organisms in order to be a habitat that does not allow disease organisms to grow. If the growth of other organisms is suppressed, then *E. coli* can grow aerobically. This is why in lab cultures, when we test for *E. coli*, the medium contains foods selective for just *E. coli*. The medium often contains antibiotics which kill competing bacteria and fungi. The temperature best for *E. coli* growth is also maintained in lab culture conditions. A stain is used to select against other organisms, as well as to detect the pH change that occurs when *E. coli* grows. But these lab conditions are a far cry from the real world. In healthy soil, compost or compost tea, there are many other organisms, which in aerobic conditions, grab food away from *E. coli*, take up the space *E. coli* needs to grow, and consume *E. coli*.

Table 1. Can Brewing Tea Remove *E. coli*? Composted manure high in *E. coli* but also high in beneficial bacteria and fungi was used as the compost to brew a tea. The aeration and growth of both the beneficial bacteria and the beneficial fungi out-competed *E. coli*. The protozoa in the brew also consumed *E. coli* (along with other bacteria) to drop *E. coli* numbers to less than what is allowed in irrigation water. *E. coli* was assessed using Coli-Blue medium, a standard EPA approved method. Results are the mean of three samples.

Material Tested	Active Bacterial Biomass (µg)	Total Bacterial Biomass (µg)	Active Fungal Biomass (µg)	Total Fungal Biomass (µg)	<i>E. coli</i> (# CFU)
Composted Manure (per gram dry material)	10.5	13,455	0.35	0.56	44,000
SD	1.5	2,446	0.29	0.44	0
Comments on manure	Low activity using FDA staining, most of the bacteria were growing anaerobically	Lots of bacteria present, most of which were anaerobic	Highly variable, because such low levels in the anaerobic manure	High variation, it's hard to find fungi where there are so few.	Really high numbers of <i>E. coli</i> , anaerobic conditions
Compost Tea (per ml of tea)	18.9	722	1.33	5.28	2.7
SD	1.9	53.5	0.38	2.45	0
Comments on tea	Mostly aerobic bacteria	Bacterial biomass much reduced	Activity within desired range; aerobic	Good totals only possible if aerobic	Below irrigation water levels for <i>E. coli</i>

SD means standard deviation of the sample values, a measure of variation in the results. The variation should be less than 10% of the mean.

In aerobic habitats, with high numbers of beneficial organisms out-competing and consuming the pathogens originally present, *E. coli* will not survive, much less grow. Presumably, if these conditions are encouraged, reduction in *E. coli* and other human pathogens can be expected. *E. coli* does not long survive in aerobic habitats with lots of competitors and consumers present. That fact should be used more extensively in organic production.

Does the above table GUARANTEE that *E. coli* has been killed? No. Clearly there are fecal *E. coli* left in the tea, but from a regulatory point-of-view, concentration was brought to below the risk level for vegetable production. Growers of fresh vegetables for market need to understand these interactions, to assure safety for their clients. Monitoring and checking the compost is necessary.

Consider these points when trying to determine if compost or tea should be checked:

1. If *E. coli* is not present in the compost, there will be no *E. coli* in the tea, no matter how much molasses or sugar is added. (May 2003 BioCycle).
2. If there are low *E. coli* numbers in the compost, and if adequate aeration is maintained, *E. coli* will not survive in the tea.
3. If *E. coli* is present in the "compost" but too much food was added in the tea and the tea drops into reduced oxygen concentration zones, then *E. coli* MAY be detected, depending on the growth of competing organisms.
4. If there are high numbers of *E. coli* in the compost, it may take more than 24 hours of aeration to reduce *E. coli* numbers to below detectable levels.
5. If the tea maker is not cleaned properly, the biofilm will form a habitat for *E. coli* to out-compete other bacteria and *E. coli* will be detected until the machine is cleaned properly.

In another experiment, *E. coli*-free compost (documented with "Coli-blue" MPN medium, standard EPA methods) was used to make tea in 5 gal KIS brewers. No matter how much molasses was used (from 0.1% to 5%), along with kelp, *E. coli* was not detected in the tea.

If *E. coli* were not present in any starting material, and were not present in the tea brewer, then there can be no *E. coli* in the compost tea, regardless of whether sugar of any kind was added. This clearly refutes statements that have been made suggesting that if sugar is used, then *E. coli* will grow in compost tea.

If the compost used was actually putrefying organic matter, which is a habitat for the growth of human pathogens, and molasses was used in the compost tea, then it cannot be surprising that *E. coli* would be detected in the compost tea. But when the tea brew was well-aerated, and conditions were not correct for *E. coli* growth, no or very low levels of *E. coli* were detected in the compost tea.

Fungal Pathogens.

Normally, aerobic conditions in the compost tea maker, the fact that humic acids and complex food resources select against fungal pathogens, and competition from beneficial organisms prevent the growth of disease-causing organisms, particularly fungi, in well-made compost tea.

Ascari or eggs of helminth worms can be present in compost, but they are rarely small enough to escape the compost bag. Mesh sizes of greater than 30 mesh retains these eggs. They do not survive or grow in water, so if they are extracted into the tea, they do not increase in number. Properly made compost should prevent these from being a concern. If the compost was treated properly to kill *E. coli*, then these parasites should be killed as well. Weed seed will not be extracted into compost tea either.

However, if the compost was not properly composted, and if the tea lacks proper aeration, then fungal pathogens can be present and grow in the compost tea. Pathogens may find a perfect home in felt or fabric bags, if they are not washed and cleaned properly from brew to brew. Tea machine makers should test their equipment for these problems and warn customers of these possible situations. In the best of all worlds, the tea machine maker would change the compost bag so their customers would not have to even consider this problem.

Worm compost

Worm compost contains worm castings plus material that did not pass through the worm digestive system, but contacted the outside of the worms. Typically the organisms inside worms add plant growth hormones, enzymes and diversity that are not in as high concentration in thermal compost. If the worms have been mis-treated, these beneficial materials will be lacking from the worm compost. Therefore, worms have to be considered to be very small livestock, and must be managed correctly to obtain maximum benefit.

Maintaining Aerobic Conditions in Teas

How can aerobic conditions be maintained in compost tea, to assure that the beneficial aspects of compost tea will remain intact and not be lost to anaerobic conditions developing?

The following are some ways you can assess anaerobic conditions:

1. Aerate compost tea sufficiently. This information should be determined by the machine manufacturer.
2. Measure oxygen, or use a tea maker where the amount of compost, food resource and growth of the organisms at different temperatures and air pressure (elevation) have been studied and the information on how to alter the food resources or aeration rate is given with the tea brewer.
3. Use your nose to detect bad smells. But production of these gases may not reach a level your nose can detect unless you accumulate the smells. Fill half a clean plastic bottle with tea, seal, and incubate overnight at ambient temperature. Open the bottle (carefully!) and smell. If it smells bad, you aren't aerating enough. If the tea smells ok, then there is most likely enough aeration and not too much food in the tea recipe.

If the tea smells bad, then it probably is bad. Put this tea on something that will not be harmed by the toxins potentially present, for example, an area of weeds, an area with known plant diseases, bare soil that needs organic matter. Let the area recover before growing any plant in the area. This typically requires 120 days if the soil is quite poor and does not have an adequate Foodweb. If the food web is in good shape, recovery (*E. coli* or other pathogens no longer detectable) can occur within 3 days.

HOW TO USE COMPOST TEA

Every chemical-based pesticide, fumigant, herbicide and fertilizer tested harms or outright kills some part of the beneficial life that exists in soil, even when applied at rates recommended by their manufacturers. Reviews of these effects are in the scientific literature (e.g., see Ingham, 1985). However, less than half of the existing active ingredients used in pesticides have been tested for their effects on soil organisms. This is an oversight that should perhaps be dealt with by a comprehensive government testing program.

Compost teas, correctly made and applied, improve the life in the soil and on plant surfaces. With time and continued use, compost and compost tea of a quality designed to improve the set of organisms relative to the plant species desired, will increase the number of individuals and the species diversity of the communities of leaf, stem, flower, seed-surface and soil microorganisms, and will select against disease-causing or pest organisms. Thus use of compost tea is indicated when the set of organisms in soil or on plant surfaces is below optimal levels for the plant life desired.

Compost and compost tea add a huge diversity of bacteria, fungi, protozoa, and nematodes. Typically, if the compost is well-made, beneficial organisms are present in the compost, not diseases or pests. Thus, making or obtaining good compost is critical.

Standards for compost production and for the biological components of compost relative to the requirements of the plant are given on the SFI website (www.soilfoodweb.com). The beneficial organisms and the soluble foods to feed them must be extracted from the compost and survive in the tea in order to obtain the full benefit of a healthy compost tea.

Potential Benefits of Compost Tea

The whole set of beneficial organisms must be extracted and survive in tea. Soluble foods must be extracted or added to tea so the beneficial organisms can grow. If all these things occur, then the benefits of using compost tea for foliar or root applications can include the following:

1. pathogens cannot infect the plant tissues because the specific infection sites on the plant surface are already occupied by beneficial organisms;
2. disease-causing organisms have no food and cannot grow because the exudates produced by the plant are used by the beneficial species present on the plant tissues before the disease-causing organisms arrive;
3. spaces on the surfaces of plant are physically occupied by beneficial organisms. The pests and pathogens cannot reach the plant surface, and disease cannot occur;
4. plants take up nutrients in the tea needed to allow them to resist infection more rapidly because the beneficial biology influences leaf surface gas concentrations, causing stomates to open sooner and for a longer time;
5. food resources in the tea allow beneficial microorganisms to grow, protecting plant surfaces;
6. nutrients are retained on the leaf surface and become available to the plant with time, improving plant nutrition and health;
7. soil structure is improved and more oxygen reaches the root system, preventing toxins from being produced in the soil, increasing plant health;
8. water-retention in soil is improved, reducing water use by up to 50% in two years in some cases;
9. rooting depth of the plants is increased, increasing the nutrients the plant can access;
10. decomposition of plant materials and toxins is increased;
11. the nutritional quality of plant produce is enhanced;
12. worker exposure to potentially harmful chemicals is reduced;
13. chemical-based pesticides, herbicides and fertilizers are no longer used, and beneficial microorganisms in the ecosystem are no longer killed or harmed;
14. chemical input and labor costs are reduced;
15. on-farm recycling of waste is enhanced;
16. landfill space requirements can be reduced;
17. plant growth can be improved.

Not all of these benefits will be observed in every case of tea application, perhaps because the compost did not contain the necessary organisms. The necessary organisms may not have been extracted from the compost, or did not grow in the tea or may have been killed during removal from the compost or during the growth process. Other reasons for lack of the necessary organisms in the tea may be that toxic materials were leached from poor compost, or the compost became anaerobic and killed the aerobes during the brewing cycle, or some other factor was not optimal.

Application of Compost Tea

There are two different, but not mutually exclusive, ways of applying compost tea: as a soil drench, or as a foliar spray.

- 1) **Foliar applications:**
 - a) Apply beneficial organisms to plant aboveground surfaces, so disease-causing organisms cannot find infection sites or food resources (i.e., pro-biotic approach).
 - b) Provide nutrients as a foliar feed.
- 2) **Soil applications:**
 - a) Help develop the biological barrier around roots (i.e., pro-biotic approach),
 - b) Provide nutrients for roots to improve plant growth,
 - c) Improve life in the soil in general, with effects on soil structure, water holding, root depth,
 - d) Improve nutrient cycling, nutrient retention and disease-suppressiveness.

Foliar applications

These are applied typically with no dilution, although water is often used as a "carrier". Concentration of organisms in the tea is critical, so careful attention to maintaining that concentration is important. If the tea is diluted, inadequate coverage on leaf surfaces may occur.

If tea is within the desired range indicated on the Soil Foodweb report (see following sections on beneficial organisms in tea), then it can be used at 5 gal/ac (50L/HA). If organism numbers are greater than this, then the tea can be used at a lower rate, relative to how much it can be diluted based on getting adequate coverage on the leaf surfaces.

If disease is visible on leaf or blossoms surfaces, then tea should be sprayed directly, with no dilution, on the affected area, without regard to a per acre amount. Drenching the affected plant tissue and immediate surroundings, where the foliar disease organism may have spread, should be performed as rapidly as possible, typically within 24 hours of observing the first evidence of a problem.

Generally on seedlings and small plants, such as tomato seedlings, peppers, basil, etc, five gallons of tea to the acre (50 liters/HA) every one to two weeks through a disease infection period give excellent protection of plant surfaces.

For larger plants, more tea is required because of the greater foliar area to cover. For example, a single 25-foot (8 meter) tall oak tree may require 25 gallons (250 liters) of tea to adequately cover the leaf surfaces. Generally, apply 5 gallons of tea per acre for each 6 feet in height of the plants. Thus, an acre of 25 foot tall trees would require 25 gallons of tea (5 gallons for the 0 to 6 feet height, another 5 for the 6 to 12 foot height, another 5 gal for the 12 to 18 foot height, another 5 gallons for the 18 to 24 foot height, and another 5 gallons for the top foot, or 25 gallons per acre). Most people err on the side of too generous, because as far as we are aware, you do not have to worry about over-application. Under-application can lead to problems if the organisms in the tea are inadequate.

The critical factor with respect to foliar applications is coverage of the leaf surface by the organisms in the tea. One reason coverage is important is that beneficial organisms must consume the leaf surface exudates, leaving no food for the disease-causing organisms so these organisms are unable to germinate or grow. Another reason is that all the infection sites on the leaf need to be occupied by beneficial organisms, so no site allowing infection is left unprotected.

Without assessment of leaf coverage at some time during the season, there may be serious problems preventing adequate organisms in the tea (tea quality) or adequate coverage on the leaves (leaf coverage). Testing is necessary. If the leaf is covered adequately by beneficial organisms, there can be

no colonization of the plant surface by disease-causing organisms. Does this always work? Given adequate coverage of the plant's surface, the answer is yes.

The plant surface must be assessed for adequate coverage in order to make certain the tea contained the required set of organisms and that these organisms cover the plant surface adequately.

In Recent Experimental Results section, a minimum of 60 - 70% coverage of the leaf surface was required. A minimum of 5% of that coverage had to be beneficial fungal biomass in order to prevent disease from establishing on leaf surfaces.

Pesticide residues in tanks, chlorine in water, too cold water either in the tea brewing or for dilution in the spray tank, application when UV may destroy the organisms, temperatures too hot in the brewing process or too high when spraying, and poor extraction energy are all factors that must be recognized as resulting in poor coverage of organisms on leaf surfaces. Testing is needed.

Tea organisms on the leaf surface can be removed by rain or wind, killed by UV, or pesticide drift, especially if the plant is not supplying adequate food resources.

Figure 6. Compost tea application to vineyard in Monroe, Oregon, as part of the USDA-SARE study on Compost Tea Effects on Mildew and Botrytis awarded to the Sustainable Studies Institute, Eugene, Oregon



Use of a biological spreader-sticker, such as yucca, pine sap, or simply molasses, can help, but choose a material that does not cause osmotic shock or destroy organisms. As long as the leaf material is adequately covered with beneficial organisms, then the plant surface will remain healthy and disease cannot win in the competition for the leaf surface. How would you know if the organisms are still there? Have a leaf organism assay performed.

If disease appears after tea is used, consider then that something prevented adequate coverage of the leaf surface or killed the organisms before or after they were applied. The disease may have been misdiagnosed, and what was called a foliar leaf disease was in fact stem rot. The soil needs to have a healthy food web to prevent stem rot and the tea should then be applied to the stem and soil around the plant, not to the leaves. Alternatively, if pesticide residue in the sprayer killed the organisms in the tea, then disease may occur through no fault of the conceptual approach! If a leak in the machine's pump let oil into the tea, organisms will be killed, or if pump pressure was too high or too low.

Leaf samples should be sent for analysis after the first tea spray of each season, so the quality of the tea and coverage of the leaf is assured. As long as the leaf stays adequately covered, no problems have been observed. If tea is applied and plant surface coverage has been shown to be adequate, and still disease takes over, then this is a situation that requires attention because it is unusual (i.e., has not been seen before). The author of this manual would request further interaction on this situation, because it presents a situation that needs to be understood. What allowed diseases to be able to "win" in the

competition for the leaf surface and how can we prevent this from occurring again? This situation would present a challenge to our understanding of why compost tea works, and figuring out how to overcome this challenge keeps us on the cutting edge.

Soil applications

The soil needs to be inoculated with the right set of organisms, and the foods for the organisms to consume, in order to keep beneficial organisms functioning through the year.

On a per plant basis, typically 1 liter (0.25 gallons) of tea (water can be used as a carrier if required) is applied per 100-mm (3 inch) tall seedling when planting into the field. The foliage and soil around the plant should be drenched by this application. A one-time application has proven adequate to prevent soil root disease if the soil contained a reasonable food web before tea application.

If the soil does not contain an adequate food web set of organisms, then multiple applications may be needed. For example, in strawberry fields where methyl bromide was injected before planting, 20 liters of tea per acre (5 gallons/acre) were applied at each two week to 1-month interval to maintain soil health. This 5 gal of tea can be added in any amount of non-chlorinated water, as long as the full 5 gal of tea is applied to the 1 acre of area.

An alternative is to apply good compost around the root systems of the plants, so soil drenches of tea may not be necessary. **As always, if disease is observed, then a tea application is immediately indicated.**

How far does the tea move into the soil? It depends on the soil texture, compaction and the amount of organic matter in the soil. The sandier the soil, the further down the tea, and the organisms in it, will move. The heavier the clay, the more the tea stays at the surface. Organic matter can open up structure in heavy clay, and then the tea, and the organisms, will move deeper. Organic matter usually allows the organisms added in the tea to continue growing, so added benefit is obtained from a single application of tea with greater organic matter in the soil. Compaction of course reduces the ability of water to move through soil, and increases the likelihood that inadequate oxygen is present.

In the greenhouse or nursery or a field where disease has been a problem, the soil should be drenched before planting. In pots, a drench means water should just barely begin to drip from the bottom of the pots. Be careful that the tea does not just run along the inner surface of the pot and out the bottom of the container. In the field, soil should be wetted to the depth of the plant's root system. Once plants are planted, apply tea to the foliage as well as using a soil drench. In situations where disease has been serious, saturate the soil surface, and maintain stem and leaf coverage by tea organisms every week to two weeks to keep the soil and plant healthy. If problems are encountered, feedback is requested, so unusual situations can be explored and solutions found.

Generalized Approaches for Using Compost Tea

How and when do you apply compost tea? It depends on the plant, the soil, the seasonal cycle, and exactly what it is you want to do. A few examples are given below.

Application of compost in conjunction with compost tea needs to be considered. Properly made, aerobic compost contains an amazing amount of nitrogen (16,000 ug N per gram of compost), phosphorus (23,000 ug/g), sulfur, calcium, and micronutrients.

When assessing the need for compost, determine the amount of compost by considering the amount of N needed to replace the nutrients removed in the crop. The previous crop removed between 50 and 100 pounds of N per acre (residues left in the field). That means 50 to 100 pounds of N must be replaced in the soil. Aerobic compost has a C:N of 20:1 and thus 2 tons up to 4 tons of compost should be adequate to replace the N, P, K, etc. removed in the crop. Paying attention to just nitrate or ammonium is not going to tell you what N will become available from the organic matter and the organisms also added in the compost. These count as sources of N, if you have adequate biology present. Compost tea will also contribute N, P, K, etc. but not usually enough to do more than give a foliar "shot-in-the-arm".

Figure 7. Asparagus grown with an autumn application of compost (1 ton/HA) and three monthly applications compost tea through the spring growing period. No weeds to speak of were present in the organic area while asparagus could barely be seen for the weeds in the conventional field. The

asparagus was on average 5.5 to 6 foot tall in the organic field, and only 4 to 4.5 feet high in the conventional field. The yield in the organic treatment was double as compared to the conventional asparagus. Richard Prew, Cambridge, New Zealand.



Potato

In the fall, after harvest, just before fall rains or snow occur, apply enough compost to improve the soil food web to desired ranges (1 to 5 tons/ac, or 2.5 to 12 tons/HA), but no more than 10 tons to the acre (too much compost in one application will compact and possibly become anaerobic).

Soil chemistry should be assessed, and any nutrient deficiencies should be dealt with by adding fish, kelp or other micronutrients into the compost or compost tea. Making sure the compost or tea brings in the proper biology is also necessary.

Generally 10 tons of compost is much, much more than needed, but in the first year of resuscitating soil after years of methyl bromide applications, it may be necessary to apply as much as 30 tons to the acre. Typically, in soils not destroyed by severe chemical usage, 1 to 5 tones to the acre is reasonable.

If that many tons of good compost are not available, apply compost tea instead. It might be a good idea to apply mulch or ground "compost" material, followed by an application of compost to inoculate the proper biology. Typically 15 to 20 gal of compost tea per acre (150 to 200L/HA) is applied as a soil drench.

If the tea is top quality and contains more than an adequate amount of fungi, then less compost tea might be used. But, if the compost tea lacks fungal biomass, then the amount of tea must be increased to assure adequate fungal application. Without adequate fungi, plant residues may not decompose rapidly. Without adequate fungi, pesticide and inorganic fertilizer applied during the summer may not properly decompose. A good rule-of-thumb is that the residues should be half-gone within a month of harvest, if temperature and moisture have been in reasonable ranges. If the plant residues from harvest are not half-gone within a month, then a second application of compost tea as a soil drench is indicated.

In the first spring following conversion to sustainable growing, a second application of compost should be applied, again at 15 to 20 gal/ac (150 to 200 L/HA) compost tea as a soil drench.

If the conversion to sustainable is started in the spring, no guarantees can be given with respect to success in the first crop cycle. It is just too soon to expect, with 100% confidence that all the improvements that biology can supply will actually occur in the first growing season, when the biology has not had the entire winter, or non-growing season, to establish and start the process of building soil structure.

In the spring, seed pieces should be treated with a surface spray of compost tea. If VAM colonization is not adequate on the root surfaces, add VAM spores to the tea. VAM colonization should be monitored each year in the fall in order to know if VAM spores will be needed.

If potato seed pieces have been treated with fungicide, then the compost tea with VAM spores should be sprayed or dribbled onto the soil below where the seed pieces will be placed. This allows the roots to become colonized with beneficial organisms and VAM as the roots grow out of the seed piece and through the compost tea inoculum.

Figure 8. Applying compost tea with a jet nozzle at Jolly Farmer in New Brunswick, Canada. Almost any nozzle will do for applying tea, as long as the nozzle opening size is larger than 400 micrometers in diameter.



At the first true leaf stage, and then again just before blossom and again just after blossom, the plants should be treated with 5 gal/ac (50L/HA) of good, as-fungal-as-possible tea as a foliar application. If the fungal component is too low, then increase the gallons of tea applied to make sure adequate coverage results. Brewing and applying another tea should be considered if fungi are inadequate.

Add foliar nutrients if the plants show any signs of nutritional limitations. Organisms in the tea increase uptake of foliar nutrients. This means the concentration of nutrients applied as inorganic fertilizers can be sharply reduced even in the first year of conversion to biological.

After harvest, begin the cycle again.

Since diseases, root-feeding pests and foliar insects are excluded from these systems through the addition of a healthy food web, rotation of crops will quite quickly no longer be necessary. Nutrient cycling will begin to occur again. Diseases that were enhanced each year in the conventional management system because of developing resistance-to-the-chemicals no longer develop. But consider that diversity is critical to maintain a healthy food web, so variation in the foods going into the compost will continue to be extremely important.

Monitor the soil food web annually in the fall to know what kind of compost is needed to replace the organisms that may have been lost during the crop cycle.

Weather patterns can be strange, and surprises will always be part of the growing system. Monitoring the soil food web is necessary. If plants looked diseased, then additional applications of tea may be needed, either as soil drenches or foliar sprays. In the worst cases, fungicides or insecticides may be required to deal with a plague situation. If used, just remember that some beneficial organisms have been harmed, and need to be replaced or helped to be resuscitated. Use compost or compost tea to do the job of putting back in the biology as well as some foods.

Table 2. Data from Jolly Farmer 2003 Compost Tea Potato Trial, using Russet Burbank cultivar, Ernest Culbertson field agent.

	Check	With Compost tea	Differences
Total Yield (cwt/ac)	304	335	+ 31 in tea
Market Yield (cwt/ac)	233	272	+ 39 in tea
Large size (%)	10.3	16.2	+ 5.9 in tea
Small size (%)	23.4	19.0	- 4.4% in tea

Row Crops / Broadacre Crops

Corn, wheat, tomato, lettuce, etc all are treated the same as potato:

1. Fall application of compost (1 to 5 tons/ac) or compost tea (20 gal/ac as soil drench) need to be made.
2. Monitor VAM colonization in plants needing mycorrhizal colonization (many brassicas are not mycorrhizal).
3. Monitor residue decomposition.
4. Apply compost or tea (20 gal/ac soil drench) in the spring to replace anything missing in the soil.
5. Apply compost tea to the seed or to the soil in the planting row, with VAM spores and/or humic acids if needed, to improve VAM colonization.
6. Applications of foliar compost teas (5 gal/ac for each 6 foot height of canopy) should occur at first true leaf stage, before blossom, and after blossom.
7. If any diseases are scouted, apply the teas ASAP to re-occupy the leaf surfaces so the diseases cannot win. Along roads, boundaries with neighbors that spray chemicals, and where drift from toxic areas occurs, extra teas may be required.
8. Monitor leaf surfaces.
9. Check the tea for the beneficial organisms (SFI assays).

As with any system, variation in application times and methods will occur. No matter what sprayer, tea maker or weather condition, checking leaf surfaces, or checking the soil to determine if the biology is present, or checking leaf surfaces to determine coverage, checking to determine if the organisms are growing, or active, can always be done, and give peace-of-mind.

A new approach in field crop or row crop systems is to put a perennial cover crop in the system as has been tried at Washington State University. Green "manure" cover crops have often been used, except that herbicides or tillage are then needed to bring down the cover crop in the spring, both of which are detrimental to building good soil life and maintaining soil structure. Instead of using a tall grass or row crop species, use a short canopy (1/2 inch tall) plant species that goes dormant when water becomes limiting, or when it is shaded by the over-story plant. Direct drill or strip till the row crop plant into the system, and maintain the under-story cover year-round. This reduces erosion. The reduction in evaporation from the bare soil surface is more than enough to make up for water use by the cover crop in the summer. It is a bit of mythology that ground covers always take moisture away from the over-story plant. Studies showing ground covers take away water from the crop may have been biased by the funding source. Those studies need to be repeated by researchers with no connection to herbicide companies.

Figure 9. Melons in Australia. Shane Gishford, an SFI advisor in Brisbane, Australia, used compost in the soil and three applications of foliar tea applications in the growing season. Weeds, insect pests and fungal pathogens were significantly reduced, while yield was increased, water use was decreased, and rooting depth improved.



Figure 10. Radish grown in potting soils, with either a compost tea (Nature's Solutions product), or a common inorganic fertilizer addition. Plants with the compost tea clearly were far ahead of the inorganic fertilizer, and remained more productive through their whole growth cycle.



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Turf

Perennial grass systems are a bit different than annual systems and turf is unique in many ways. Turf will be walked on, whether by grazing animals, golfers, football or soccer players, or by people walking on a lawn. Compaction is a never-ending issue with grass systems of any kind. The food web has to be healthy enough to maintain soil structure and not succumb to compaction.

Application of pesticides or high amounts (over 100 pounds/ac) of inorganic fertilizers will kill organisms in the soil, and disease will be the likely result. Instead of toxic chemicals, try the following:

1. Apply 1 to 2 ton per acre of finely sieved worm castings or worm compost in the fall (the sieved compost should be able to shift between the blades of the grass to lie on the soil surface), or
2. apply 15 to 20 gal/ac (150 – 200 L/HA) foliar compost tea application.
3. Apply 5 gal/ac compost tea (50L/HA) each week until frost occurs, and then hold off on any more applications until spring.
4. Again in the spring, apply 1 to 2 tons finely sieved worm compost/castings to highly compacted areas (the greens), and where needed in to fairways, tees and putting surfaces.
5. Apply 5 gal/ac compost tea through the summer until diseases are gone, or poorly covered or thatch problem areas are grown in.

If aeration is needed, a practice that should rapidly end as turf health improves, apply a good compost tea (match the needs of the soil with the biology in the tea) immediately and then fill the aeration holes with a mix of 15 to 30% medium sieve compost high in woody or fungal foods, and 70% to 85% sand. Add VAM inoculum in the tea and compost material if the roots of the grasses are not mycorrhizal enough. Add humic acids if colonization is present but inadequate.

Figure 10. Rugby Club in southern England used the typical Soil Foodweb approach, with the following results. For details contact Mike Harrington, Laverstoke Park, England.



Orchards and Vineyards

In these perennial systems, an under-story cover crop is required in the tree, vine or berry bush row in order to prevent herbicide sprays in the area that needs to be fully fungal dominated. The under-story plants need to be fungal dominated, need to be good weed mats to prevent weeds from growing in the tree rows, should be colonized by the same kinds of mycorrhizal fungi as the over-story tree requires, should be short canopy so mice cannot girdle the trees without the predatory birds seeing them, and should easily go senescent or dormant in a dry summer period, but otherwise maintain a good layer on the surface so the soil does not dry out. During the summer, the grass in the inter-row areas should be mowed and blown onto the row area under the trees. This allows composting to continue all summer long. The under-story plant should be able to let grass clippings blown on top of the plants shift between the stems and reach the soil surface.

In the fall, compost should be applied at 5 to 10 tons per acre under the rows and again, the compost should be able to sift between the plant stems to reach the soil surface. Apply compost tea at 15 gal per ac after all leaf fall has occurred, in order to cover all leaf litter surface. This prevents diseases from

being able to grow on the leaf material and overwinter. Leaf litter should be 50% reduced in weight within one month. If the leaf residues are not 50% gone within one month following leaf fall, apply tea again to speed the decomposition process. Leaf litter should reduce by well over 50% the amount of disease that occurs in a conventional orchard.

In the spring, if needed, apply another 1 to 5 tons of compost followed by a soil drench of compost tea. Then, 2 weeks before bud break, apply foliar compost tea to establish the beneficial organisms on all the leaf surfaces. For as long as no foliar disease is found, only apply tea in a foliar fashion once a month. Avoid applying foliar teas when pollination is at its peak. If a disease outbreak occurs, it may be necessary to apply the tea each day until the disease is out-competed.

Landscape Trees

In these systems, the challenge is to maintain the soil biology appropriate for the plant desired, even though a bacterial-dominated plant is within inches of a plant requiring fungal-dominance. This spatial heterogeneity is maintained by use of bacterial and fungal foods applied correctly to the root system and drip line of each plant. Management of the proper biology is maintained in this fashion.

Trees may need to have root trenches dug several feet deep, fungal-dominated compost added to the trench and then filled in with the soil, after applying a strongly fungal-dominated compost tea. While no guarantees can be made about effectiveness, in many cases effects of root rots, wilts, blights and other fungal diseases have been reversed by application of compost tea. The proper biology will compete with, and possibly prevent the disease from establishing on roots of trees. Work by a number of Soil Foodweb Advisors has shown that the use of tea has suppressed disease, and possibly prevented disease. However, a great deal more work is needed before we can say for certain that compost tea can consistently and with complete assurance work to remove disease from perennial root systems.

Greenhouse

Apply aerobic woody compost at about 30 to 50% in potting mix to replace peat moss and/or coconut fiber. Drench flats with compost tea to make certain the beneficial organisms are established. For vegetables to be planted in the field, place seeds rolled in compost tea and VAM spores in 100% good compost, or dilute the compost by half or three-quarters. Teas should be applied as soon as first true leaf stage is reached. All watering events should include some compost tea to maintain healthy root systems and maximize rooting depth. Drench the soil with compost tea just before sales.

Hydroponics should have 1 gal of compost tea added per each 50 gals of water. Beds or "soil-less" potting mixes should be drenched with compost tea to establish the beneficial organisms that will protect plants. Roots systems in aeroponics should be misted with compost tea instead of Hoaglund's solution. In water systems, again, 1 gal of compost tea should be added to 50 gal of water to prevent disease. In the case of water lettuce, for example, the entire plant should be dipped into compost tea made without humic acid (the humic acids can cause spotting of the leaf surfaces). Aquatic bulbs should be immersed in compost tea for 10 to 15 minutes before planting in order to establish the beneficial organisms around the bulb and on the roots. Compost tea should be added periodically to the water.

Nurseries

Potting soils should contain 30 to 50% aerobic compost, as a replacement for peat moss or coconut fiber. Beds should be made with 30% to 100% aerobic compost and drenched with 15 gal per acre (150L/HA) as-fungal-as-possible compost tea immediately before planting. Bare root plants should be dipped in compost tea with VAM spores (see spore package for density of spores) and then planted into the beds. Foliar surfaces should be treated with compost tea (5 gal per acre) each month or more often if disease requires. Soil drenches should be performed before planting and when litter or residue need to be decomposed. If possible, addition of compost tea to the watering system will reduce disease outbreaks.

Ponds and Lagoons

Aeration is the most important factor in maintaining pond or lagoon health. Plants can contribute to aeration, but if a layer of algae begins to grow, or if food resources (like manure) going into the pond or lagoon increase organism growth beyond the rate at which oxygen diffusion or photosynthesis adds oxygen to the pond, the pond will go anaerobic. Stink begins. Either reduce input of foods (manure, sugars, and dead plant material) or increase rate of aeration. Algal blooms may be adding oxygen into

the water on the surface, but as the lower layers of algae die, and the dead bodies are decomposed, oxygen uptake increases, often beyond the level where the photosynthesizing algae can offset the oxygen demand.

At this point, aeration of the lower levels of the water in the pond must occur. Thus, any aerator needs to pull water from the bottom of the pond, not just stirring the surface waters. Addition of the beneficial organisms that were lost when the water went anaerobic is a must. Thus, compost tea needs to be added to the water, at 1 gallon per acre foot of water. Just an inoculum is needed; the foods are present, and aeration is occurring. Recovery can be rapid. As long as the pond or lagoon does not become anaerobic again, that single application of compost tea should be adequate to re-establish the needed biology.

The basic approach to using compost tea in conjunction with compost and soil should be apparent by this point. There are additional factors to be considered in making certain compost tea is disease-free and capable of giving the best benefit.

Factors Affecting Compost Tea Quality

Compost tea can be inconsistent from batch to batch, but this variability is actually relatively easy to control. When making tea, test the tea periodically to make sure the set of organisms in the tea is maintained and no unexpected problems occur to harm extraction and growth of the organisms.

Added Materials. Many ingredients can be added to compost tea to enhance the growth of specific microorganisms and provide micronutrients for plants. This manual gives a basis for choosing some of these materials (see The Recipes later in this manual), but a great deal more work is needed to understand why some additives work in certain conditions but not in others. It is important to recognize that only certain microorganisms will be encouraged, or selected by different foods. Combine food resource with aeration, pH, temperature and interactions with soluble compost material, and very different organisms can grow at different times. Make certain that the kind of compost, the temperature, etc are maintained the same, and each tea brew can be very similar.

Aeration. Oxygen is required by all aerobic organisms. A large problem in making highly beneficial teas is when microbial growth rapidly uses up a significant portion of the oxygen such that anaerobic conditions ensue, and materials that are toxic to plant growth are produced in the tea. Properly controlling oxygen input into the water is critical. It is a wise idea to buy an oxygen probe in order to make certain the tea remains in the aerobic range (above 6 ppm or 70 to 80% dissolved oxygen - versus carbon dioxide - in solution, or 20 to 22% oxygen as total atmospheric gases; see Table 3 below).

Table 3. Relationship between Oxygen, Carbon Dioxide, and Aerobic, Facultative Anaerobic and Anaerobic Organisms

Type of Organism	Total Atmospheric Gases	Percent Dissolved Gases	Dissolved Gases (mg/L)
Aerobic	20 - 21% oxygen 1 to 6% carbon dioxide	95 to 98% oxygen 1 to 5% carbon dioxide	> 6 mg/L oxygen
Facultative Anaerobe	15 - 16% oxygen 6 to 12% carbon dioxide	75 to 95% oxygen 5% to 25% carbon dioxide	4 to 6 mg/L oxygen
Anaerobe	2 to 15% oxygen > 12% carbon dioxide	< 75% oxygen > 25% carbon dioxide	< 4 mg/L oxygen
Temperature and air pressure (elevation)	Percent oxygen declines and other gases increase as elevation increases	Oxygen and carbon dioxide will always sum to 100% regardless of elevation, pressure or temperature	Maximum concentration of oxygen at sea level, freezing is 16 mg/L, decreases as temperature increases or air pressure decreases

Oxygen has to diffuse into water at the interface between air and water. By bubbling air into water that interface is increased, resulting in more diffusion of oxygen into water. The smaller the bubble size, then the greater the exchange surface and the more efficient the transfer of oxygen into the water. Bubblers that decrease the size of individual bubbles improve the oxygen content of water more rapidly than aerators with larger size openings to produce bubbles. Of course, if the bubble size is extremely small, then airflow may be restricted because it is harder to push air through a small opening. Aquarium bubblers typically produce rather large size bubbles and are not very efficient oxygenators of water, but they are very inexpensive and can run all the time. Depth of the water is important too, since in order to produce a bubble, the air pressure must be greater than water pressure, and water pressure increases with increasing depth. Thus an air pump adequate for a 5-gallon machine may not be adequate for a 500-gallon machine, depending on the water depth.

If bacteria and fungi are not growing, tea solutions will remain well oxygenated. Bacteria consume the majority of the oxygen during aerobic metabolism. If the oxygen is replenished at a rate greater than what is consumed by the bacteria, the tea will remain aerobic. Conversely, when oxygen is consumed at a rate greater than the rate at which it is replenished, the tea will become anaerobic.

When dealing with tea, and the need for a short brew cycle, the growth of bacteria and fungi can be so rapid that air can be drawn below aerobic levels extremely rapidly, within an hour or less of adding molasses, humic acids or other food resources. Therefore, air needs to be provided at a relatively high rate to offset the use of oxygen by the aerobic, beneficial organisms.

Teas can become anaerobic if molasses or sugar is added to the solution. The offensive odor produced (rotten egg smell, vinegar or sour smell, sour milk or vomit smells) is an indication of anaerobic conditions. However, if the tea is allowed to continue "fermenting," microorganism growth slows as food resources are used up. Oxygen will begin to diffuse into the tea more rapidly than it is consumed by bacterial and fungal growth, and aerobic organisms will begin to grow using the organic acids produced during anaerobic metabolism. The tea will become aerobic again.

Strict aerobes require oxygen concentrations around normal atmospheric levels (18 to 22% total atmospheric gases or 8 ppm, or 8 µg per liter; see Table 3) in order to perform the functions of life. Examples of some of these genera of bacteria are *Pseudomonas*, *Bacillus*, and *Aerobacter*. As oxygen concentration is reduced, dropping below 5 ppm, strictly aerobic organisms will become dormant, and eventually die. Lack of oxygen allows the growth of facultative anaerobes (which switch from aerobic to anaerobic metabolism when oxygen levels fall below 15 to 16% O₂ or 5 to 6 ppm oxygen). Examples of bacteria that are facultative anaerobes are *E. coli*, *Klebsiella*, and *Acinetobacter*. True anaerobic bacteria cannot tolerate O₂ above 7 to 8%, or 4 to 5 ppm oxygen while strict anaerobes require low oxygen concentrations (less than 2% oxygen) to grow.

Anaerobic organisms are not detrimental in themselves, but their metabolic products can be extremely detrimental to plants as well as many beneficial microorganisms. Anaerobic metabolites produced are volatile organic acids (valeric acid, butyric acid, phenols, see Brinton, 1997) that are very detrimental to the growth of plants and beneficial bacteria, fungi, protozoa and nematodes. Anaerobic products may kill some disease-causing microorganisms, but usually the death of a few disease-causing microorganisms is not positive enough to offset the reduction in plant growth.

When aeration is too great, the tea can become over-charged with oxygen, which can be detrimental to beneficial microorganisms. However, there is no compost tea maker on the market that over-charges tea. Only if someone decided to add hydrogen peroxide, or ozone to the water would it be likely that the water could have too great an amount of oxygen.

Aerobes, facultative anaerobes and strict anaerobes are everywhere. They live in soil, on plant surfaces, on the surfaces of stones, on and in pavement and clothing. Facultative anaerobes include some species that are highly beneficial to plants as well as some disease-causing species. These microorganisms are needed so that the cycling processes within nature can occur. Thus, sterilization of tea is not the answer. Many highly beneficial microorganisms would be lost if the tea were sterile. The goal is to keep the tea fully oxygenated and maintain aerobic conditions, so that the benefits from a widely diverse set of microorganisms can be realized.

Organism growth in a batch of compost tea follows a typical pattern (Fig. 11). The organisms first adjust to the liquid environment as the organisms and the soluble nutrients are ripped off the compost by mixing and aeration. Adjustment to changes in temperature occur as well, although it may take a few hours for that adjustment to occur, called lag time, before growth commences again. The temperature of the water should match the temperature of the soil, or leaf surfaces, depending on the purpose of the tea application.

As the organisms grew faster and activity increased rapidly, both foods and oxygen were depleted. At a certain point, which is dependent on the food resources added, the aeration rate and the rate of movement of water through the compost and tea brewer, the organisms used up oxygen at a rate faster than the machine was adding air into the water. As a result, oxygen levels in the water dropped. The point at which organism activity peaked (green triangle line), the organisms had used up the simple, easy-to-use foods in the tea and growth begins to wane.

At that point, the organisms are no longer using up oxygen faster than it can be replaced, and oxygen concentration in the water begins to increase. As the organisms stabilize, their activity reaches an equilibrium for the next few days.

The critical part of the curve is the relationship between organism growth causing oxygen to dip into anaerobic ranges, and aeration rate. In these teas (Fig 11), filamentous fungi, protozoa and beneficial nematodes were lost as oxygen was depleted and fell below 6 micrograms oxygen per ml (or 6 mg oxygen per L). These teas could not suppress foliar disease on the plants they were applied to, because the beneficial fungal were lost.

Compost Tea Oxygen Levels

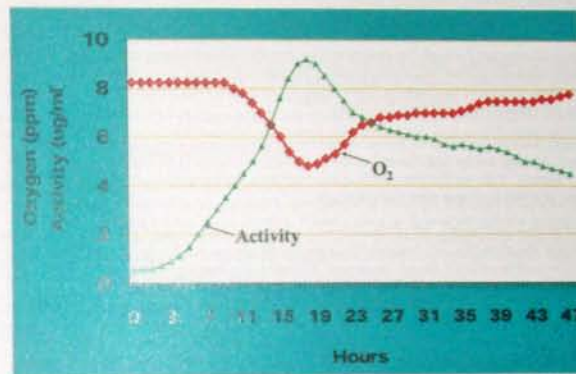


Figure 11. This curve was generated based on eight tea brews using the same recipe with 1 gal. molasses and 1 gal dry kelp product. Note the lag time associated with addition to cold water which must be overcome by the organisms early in the tea brew.

Brewing time. Up to the point that most of the soluble nutrients are all extracted from the compost, and most of the organisms capable of being pulled from the compost are off the compost, the longer the time the compost remains suspended in the water or tea solution, the greater the amount of soluble material extracted from the compost and the greater the number of organisms extracted. More soluble material in the tea means more food resources to grow beneficial bacteria and fungi, and more nutrients that will potentially be made available for plants.

The easiest way to know how long a machine takes to make tea with adequate organism numbers in it is to measure them over time.

Organisms growing in tea consume the extracted nutrients, immobilize them in their biomass and keep the nutrients from washing through soil or off the leaf surfaces. If the tea is well mixed and well aerated (see Compost Tea Production Methods), all these processes will be maximized.

If oxygen supply is not adequate, bacteria and fungi growing in the tea can use oxygen faster than oxygen diffuses into the tea, and then anaerobic organisms grow in the tea with the production of potentially phytotoxic materials in the tea. Any corner of less than 120 degrees angle tends to be a place where bio-films form rapidly, a well-known phenomenon in the world of biofouling. Despite any amount of mixing in the container, the "dead-air" effect of a corner results in no replenishment of well-oxygenated water, so that oxygen is rapidly depleted as microbes grow. Thus corners can result in the production of rank-smelling materials, and have quite negative impacts on plant growth if these anaerobic decomposition products are not used by aerobic organism growth before the tea is placed on or around the plant.

The shorter the brew time, the less likely it is that anaerobic bio-films can develop. Thus there is a balance between extraction of nutrients and growth of organisms, giving an optimal time for tea

production, depending on the exact conditions of brewing.

The longer the brewing time, the more likely weather will change and application will have to be put off. With longer brewing times, the organisms in the tea will use up all their food and go to sleep, or if brewing times are very long, some of the organisms colonize the surfaces of the containers and begin to develop anaerobic layers on the container walls. Thus, there needs to be a balance between the time organisms immobilize nutrients extracted from the compost and the time they will begin to colonize the container walls and produce anaerobic layers.

Each tea brewer has an optimal time for extraction unique to the design of the machine. For example, the Micro-Brewer and the Earth Tea Brewer can produce the optimal number of organisms within 20 to 24 hours when run at room temperatures (colder temperatures require longer brew times). The bucket method of brewing (see Ingham, 2000) requires 3 days, and some trough methods of production, and most not-aerated brews require 2 to 3 weeks.

Not-aerated, no-nutrients added tea brews may have such low numbers of organisms in a tea that biofilms never develop and the liquid never becomes anaerobic, no matter if the liquid is never stirred or mixed or aerated. If the tea does not contain many organisms, the tea cannot have the benefits that organisms give that have been discussed previously.

Compost Source and Quality. All of the soluble compounds in compost can be extracted into the tea. It is essential, therefore, that only beneficial food sources be present in the material being extracted. Only by composting correctly can this be assured. Whether using thermal, or static compost, temperature must have reached AT LEAST 131 to 135° F (57° C) continuously for 3 entire days throughout the entire pile (the surface of the pile is not at 135° F (57° C), so the outside material must be turned to inside and temperature maintained). The material cannot have been anaerobic for any length of time or phytotoxic compounds may be present, and nutrients will volatilize if the compost becomes anaerobic. If worm-compost (vermicompost) is used, the material does not have to reach temperature, but must be adequately processed by the worms. Passage through the earthworm digestive system kills human pathogens and most plant pathogens, although more work needs to be performed to document this in a fully scientific manner. Adequate time in the worm bin must be allowed for full processing of all materials by the worms to occur.

All of the species of organisms that can be detected in the compost will be extracted into the tea. This does not mean all individuals of all species will be extracted however. Many individuals will be left in the compost, so the compost can be re-added to the compost pile. If pathogenic or pest microorganisms are present in the compost, then they too will be extracted into the tea. Therefore, **GOOD COMPOST, which does not contain significant numbers of active disease-organisms, is essential.**

If compost is properly made, disease-causing microorganisms will be killed, out-competed, inhibited or consumed by beneficial organisms in the compost, or in the tea. A huge range of beneficial food resources is made during the composting process (see Cornell's Handbook on On-Farm Composting, Rodale's books on composting, and the Soil Foodweb Web Site for more information on making good compost).

How do you know compost you buy is good? Data are REQUIRED. Ask your compost supplier to show the temperature information on the batch you are buying. Ask them to show you the data on oxygen concentration (or the reverse measurement, carbon dioxide concentration) during composting. Because the heat during composting is generated by bacterial and fungal growth, that increase in temperature also reveals whether bacteria and fungi used up oxygen and if the compost became anaerobic during peak temperature times.

Temperature should, however, not exceed 155° to 160° F (68° to 71° C) and the oxygen level should not drop below 12 to 15%. When temperature reaches these high ranges, oxygen is being consumed rapidly, and anaerobic conditions, with production of phytotoxic materials, is quite likely. If compost gets too hot, does not heat enough, or becomes anaerobic, the set of organisms in the compost is not desirable. If you use poor compost, the tea will not contain the desired set of organisms.

A good test of compost that you can do yourself is determining smell. It should smell like soil, or mushrooms that you buy in the store. If compost went anaerobic for a significant period of time, it will

smell sour, like vinegar, or sour milk, or vomit, rotten eggs (hydrogen sulfide) or urine (ammonia). Not only will the material have lost nitrogen and sulfur (and why would you pay good money for something lacking fertility?), but it also contains phytotoxic materials that can kill your plant if they encounter any plant surface.

In order to maximize populations of beneficial organisms, it is important that an adequate range of food resources be extracted from compost into the tea. This can only occur if organism numbers are adequate in the compost. It is the organisms that make humic and fulvic acids. Minerals will be extracted from the compost as well, making it critical that the salt level not be too high, and that no toxic chemicals, or at least no high concentrations of toxins, be present.

Extraction and Mixing. Mixing needs to be not too much and not too little. **Too rapid** mixing will physically destroy beneficial microorganisms in the tea. Think about yourself impacting the wall of the container going 320 km (200 miles) an hour. If the speed of the impact would kill you, it will kill the organisms in the tea. **Too slow** mixing means a lack of organisms pulled from the compost, allows bio-film development to be rapid, and the surface of everything will develop an anaerobic slime with resulting phytotoxic materials present in the liquid.

There are two things to understand about mixing.

1. Enough energy has to be imparted to the compost to physically remove the bacteria and fungi from the surface of the compost. Bacteria can glue themselves onto the surface of any particle in compost, and it takes significant energy to remove bacteria from these surfaces. Fungi wrap around particles and the hyphae have to be broken enough to let the strands be pulled out of the compost, but not broken so much that they are shredded into tiny pieces. Thus, most extraction methods that involve blades, whirling mixing bars, or blender action can break up the hyphae, or the bacterial cells, too much and result in poor fungal and/or bacterial biomass in the tea.
2. Uniformity of the end product, the tea, is necessary. Good mixing – enough but not too much – produces both effects. Most of the commercially available machines were developed around the principles of enough aeration and enough mixing to get organisms into the tea, but not shred them to death.

If brown color comes from the compost, then fungal extraction is probably good. Add fungal food resources and surfaces that will allow fungi to grow in liquids. So, BEFORE placing any dark-colored materials in to the tea water at the beginning of the cycle, add the compost into the tea maker, in whatever container you have, and make certain the compost tea-maker is mixing the water well enough to pull the humic acids (brown color) from the compost. No brown color out of the compost in the holder should instantly indicate that adequate extraction is not occurring. Additional mixing of the compost in the container will be necessary.

Foam. The presence of foam on the surface of tea is considered a positive sign, but just means there are free proteins, amino acids or carbohydrates present. This can occur as the result of adding fish hydrolysate, certain organic acids or carbohydrates. If worm compost was used, excessive foam suggests a few earthworms were in the compost and their dead bodies are providing this source of protein/carbohydrate. Excess protein or amino acids should not occur if bacteria are growing well, although dead worms may continue to release proteinaceous materials throughout the brewing cycle. Foam can be suppressed by using organic surfactants, such as yucca or vegetable oil (not olive or canola oil!). Don't use commercial de-foamers – every single one we have tested kills the organisms in the tea.

Maintaining Compost Activity. If a large amount of compost is bought to make tea during the rest of the year, be aware that the organisms in the compost go to sleep, become dormant, and don't extract from the compost easily the older compost gets. Maintain compost organism activity by adding compost tea to the compost. Even then, we have seen a compost get so "mature" that you can't wake them up to grow at all in a 24 hour brewing cycle.

Compost for foliar compost tea applications should be SLIGHTLY IMMATURE! That means, a little bit of temperature is a good thing – about 5° - 10° above ambient is the desired range.

Mesh size of the tea bag or final filtration material. The opening size in the compost container or any filters through which the tea must pass, can affect the kind of particulate material and organisms that will be present in the tea. Mesh is a measurement of the number of holes in an inch surface area. The smaller the mesh number, the larger the size of the holes. For example, an 80-mesh screen has holes with diameters of 170 micrometers (a micrometer is a millionth of a meter). A 20-mesh screen has holes with diameters of 800 micrometers.

The finer the size of the openings, the more likely only soluble components will be extracted. If the openings are too large, particulate matter in the tea may clog sprayers and irrigation systems.

A variety of materials can be used, as long as they are inert to microbial decomposition. For example, polycarbonates, plastic, nylon, silk and fine-weave cotton work well, but window screening, wire mesh, and burlap may also be used. Fresh burlap should be used with caution, though, as it is soaked in preservative materials which can be extracted into the tea and kill the organisms.

Consider the size of the organisms desired in the tea. The largest beneficial nematodes are around 150 to 200 micrometers (10^{-6} meters) in length, but only 30 to 50 micrometers in diameter. Thus, a mesh that allows organisms of this size to pass, but restricts passage of larger materials, is desirable. The openings should not be smaller than this size since then a number of the beneficial organisms would not be present in the final product.

Microbes in tea. A wide diversity of bacteria, fungi, protozoa and nematodes need to be present in the compost and be extracted into the tea (see previous discussion of the organisms in tea). The greater the diversity of beneficial microorganisms, the greater the likelihood that disease-causing organisms will be out-competed on leaves, stems, roots or in the soil.

Nutrient retention will be higher, because all the food resources will be used and the nutrients retained and not leached from the leaf, stem, root or soil. Plant-available nutrients will be cycled at a more beneficial-to-the-plant rate, and soil aggregation will improve, along with water-holding capacity, breakdown of toxic materials and decomposition rates.

When the diversity of microorganisms in the compost is low, the health of plant surfaces will be limited, and one particular set of metabolic products can accumulate to the detriment of plants and other microorganisms. Thus good compost is critical to the production of good tea (see Wagner, 2000, Rodale books on composting, the Soil Foodweb website, www.soilfoodweb.com for information about the set of organisms in good compost and how to tell if they are present).

Ratio of Compost to Water. The dilution of soluble materials and microorganisms extracted into the tea is important. Too little compost will result in too dilute a tea with too few nutrients or organisms. Too much compost means not everything is extracted that could be extracted. If the "spent" compost is placed back into an active compost pile, then "wastage" isn't a worry. But it may be possible to overload some tea makers with too much compost, such that water cannot flow through the compost and extraction efficiency will be low. Because the optimal ratio of compost to water tends to be variable, experiment with the amount of compost put in your compost tea brewing machine to find the best ratio. If your machine calls for 7 pounds or kilos of compost, try 6 or maybe 8 pounds or kilos and see if the amount makes a difference.

Temperature. Temperature, humidity, evaporation and other abiotic conditions influence the growth rate of microorganisms. For example, high temperatures volatilize nutrients. Evaporation concentrates salts, while low temperatures slow microorganism growth. Obviously, these conditions can have a significant influence on the quality of the tea. Again, experiment a bit to find the optimal temperatures for your particular situation.

Place the tea making equipment inside a greenhouse or shed. In hot weather, cover or shade tea-making units prevent evaporation and concentration of salt.

In machines where the tea goes through a pump, the growth of microorganisms elevates the water temperature, but as long as the tea is well mixed, temperatures will not exceed 100° - 110° F (38° - 43° C). If temperature in the machine exceeds 100° F (38° C), something is wrong with the pump, or too much biofilm has developed in the pipes or tubes, suggesting that the machine should be cleaned to

remove restriction of the passageways in the machine.

Machines mixed using aeration, where the tea does not go through the pump, are cooled by the temperature of the ambient air and rarely have an increased temperature. In these machines, it is wise to use a tank heater to raise temperature and increase microbial reproduction.

Water Source. Water high in salts, heavy metals, nitrate, chlorine, sulfur, tannic acid, carbonates, or contaminated with pathogens (human, animal or plant disease-causing microorganisms) should not be used. Where present, removal of contaminants becomes a priority before using the water. Both chlorine and sulfur can be removed by aeration. Carbonates can be removed by precipitating them with additives, and then de-gassing those additives. Contact your water treatment department or send a water sample to a testing lab for analysis. Or, try some of these simple assessments: Drink a glass of bottled water (make sure it is less than 1 ppm ($\mu\text{g/ml}$) nitrate. Drink a glass of your own water.

- Bitter? May be high in nitrate.
- Rotten egg taste or smell? High sulfur.
- Chlorine smell? High chlorine. Keep aerating, or remove chlorine with reverse osmosis or a chlorine filter.
- Slippery feel to the water? High in carbonates. Use some acid to remove the carbonate and balance the pH
- Earthy taste? Algae or actinomycetes (actinobacteria) present. Find a better source of water.

Compost Tea Standards

The desired MINIMAL ranges for active as well as total bacteria, active and total fungi, protozoa and nematodes in a good tea, i.e., one that will begin to move the soil in the direction of improving the communities of beneficial organisms and provide the benefits discussed previously (page 7). In order to see these benefits, the following points must occur:

1. Adequate amounts of tea, with adequate concentrations of organisms must be applied to the plant surfaces.
2. Cover plant surfaces at least 70%.
3. At least 5 gallons of tea should be applied per acre (50L/HA) for leaf coverage, and 15 gallons per acre (150 L/HA) for a soil drench.
4. The organisms have to survive the application.
5. The organisms require foods to begin to grow.
6. If disease is already present, it may be necessary to displace the disease through the mechanisms of competition for space, food, or infection sites. There is little evidence that antibiotic or toxic-compound production is a major, or even important, mechanism. Therefore use of the term "bio-pesticide" or "pesticide" is NOT appropriate for the mechanisms by which compost or compost tea has its major, or most important, impacts on disease.

The following table lists the minimum levels of each organism group required in compost (per gram dry weight of compost), or in the tea (per mL of tea before spraying).

Table 4. The desired minimal ranges for different organisms in compost or compost tea.

	Active Bacteria (μ g)	Total Bacteria (μ g)	Active Fungi (μ g)	Total Fungi (μ g)	Protozoa (#)			Beneficial Nematodes (#)
					F	A	C	
Compost (per gram dry weight)	15 - 30	150 - 300	2 - 10	150 - 200	10,000	10,000	20 to 50	50 - 100
Compost tea (per ml)	10 - 150	150 - 300	2 - 10	2 - 20	1,000	1,000	20 to 50	2 - 10

μ g means microgram, or one millionth of a gram. A gram is about one teaspoon

Active Bacteria - The biomass of bacteria performing measurable aerobic metabolism

Total Bacteria - All of the bacterial biomass present, including the sleeping, dormant, inactive and not-very-active portions of the community. Gives a relative idea of whether adequate bacterial diversity is present.

Active Fungi - The biomass of fungi performing their functions right now.

Total Fungi - All of the fungal biomass present, including active, inactive and dormant. Gives an idea of the diversity must be adequate in order to be able to prevent diseases under all conditions.

Protozoa - All three groups cycle nutrients from bacteria into plant available forms. Flagellates and amoebae are strict aerobes. Ciliates prefer to feed on anaerobic bacteria and thus indicate that the conditions are conducive to anaerobic bacteria growing. Higher than the desired range of ciliate numbers indicates lack of oxygen somewhere in the material. If flagellates and amoebae numbers are above the desired range, then even greater than minimal nutrient cycling will occur.

Beneficial nematodes - These are the bacterial-feeding, fungal-feeding and predatory nematodes. They consume their prey group, and release nutrients from the prey group into plant available forms. The greater the diversity of these groups, the more likely nutrient cycling will occur in all conditions.

There will be variability from tea-to-tea, even if compost, mixing, amendments used, etc. are the same. But that variability is not excessive, and typically is no more than 10% for bacterial and fungi biomass, and up to 20% for protozoa. Note that for ciliates, numbers should not exceed greater than 100 individuals per ml of tea, as this would indicate limited oxygen conditions (anaerobic) in the tea. Tea can be diluted if the biomass of all categories will still be within desired ranges AFTER dilution is complete. If the biomass/numbers are lower than the desired range, the amount of tea sprayed will have to be increased from the 5 gallons per acre typical to achieve the desired coverage.

In all the studies performed the organisms must occupy AT LEAST 70% of any plant surface. The

desired ranges are 60 to 70% for bacterial coverage, and 2 to 5% fungal coverage, for a total of at least 70% coverage.

Comparison of a Not-Suppressive Tea with a Suppressive Tea

How do you know compost tea is doing the job? Well, which job are you interested in? If it is protection of a plant from disease, then to document protection, you need to have plants that you know are being attacked by the disease, and you need to show that the plant does not come down with the disease.

Do this experiment yourself, and demonstrate whether your tea is doing the job.

Protocol:

1. Plants were from a nursery where the greenhouse was infested with blight. All plants were infested, and the greenhouse was being fumigated to get rid of the problem. Plants from the greenhouse were donated to SFI. Presumably all plants remaining at the nursery succumbed to the disease.
2. Two compost teas were made. The suppressive tea was made in an EPM 100 gallon tea maker. The not-suppressive tea was made in a home-modified version of a commercially available tea machine. The EPM machine used 10 pounds of compost (mixed 50-50 thermal and worm compost), while the modified machine used 5 pounds of compost in a fabric bag. The recipe used was the same in both machines: molasses and kelp, aerated water, at ambient temperature (about 65 F air temperature at the start; water temperatures slightly lower).
3. The teas were brewed for 24 hours, and applied to the tomato plants using a hand-held spritzer.
4. All leaves were well-covered with the straight tea.
5. Tea samples were removed for SFI methods and for plate count analysis (dilution series was begun). The process of clean-up took about an hour.
6. Leaf samples were removed from the plants (leaves were dry), stained and examined using SFI methods.
7. Tea was assessed using SFI methods (1:10 and 1:100 dilutions used), and plates were spread for plate count assessment (1:10, 1:100, 1:1000, 1:10,000 and 1:1,000,000 dilutions spread plated as needed).

Results: The following table shows the results from this study. It is clear which tea was able to protect the plant and which tea was not able to protect the plant, based on the fact that all plants died in the non-suppressive tea trial, and all the plants lived in the suppressive tea trial. There were five plants in each treatment, and several hundred plants in the control (the plants in the greenhouse succumbing to disease when the tomato plants were given to SFI for this trial).

The plate count data are shown as they would be reported from a standard plate count lab. These are the Colony Forming Units, or Most Probable Number of individual bacterial cells that can grow on these specific media, under the specific incubation conditions in the lab. The problem with *Pseudomonas* counts is that you cannot tell whether these are disease-causing *Pseudomonas* species, or beneficial species. The not-suppressive tea had higher counts of bacteria that can grow on King's B medium, but does that mean more or less suppressive species? You cannot tell from this assay.

The Cellulase-producing bacteria and fungi were higher in the suppressive tea, but not by a significant amount. In the BBC "Species Richness Diversity" Index, this difference in CFU would not result in a different index reading. So, is it significant? There is no way to tell.

The number of spore-forming bacteria and fungi were higher in the not-suppressive tea, but again, were these beneficial species, or were these the disease-causing species? Just because a number is higher, and would perhaps get a higher "index value" from a BBC Lab assessment does not mean anything beneficial. A higher number of disease organisms is not a beneficial thing.

The comparison of aerobic to "anaerobic" bacteria was not performed, because this is a truly meaningless test. Many, if not most, of the bacteria that grow on the aerobic plate are in fact facultative anaerobes. That means, they will grow on the "anaerobic" plate as well as the aerobic. So, what does it mean that some grow on both plates? Which are the strictly aerobic species, and which are the disease-causing switchers? The "aerobic/anaerobic ratio" calculated from these plate methods cannot give that information. It is a meaningless ratio unless there are data showing that plants die when the ratio is at some level, and what plants are benefited at some other ratio. Once that

information is made available, then perhaps that ratio could be useful. The aerobic/anaerobic ratio has no data to back up what it means.

Table 5. How to tell that tea will be suppressive. Comparison of results from plate assessments and direct assessments when tea was not able to suppress disease, compared to when tea was able to suppress disease.

	Tea Lacking Suppressiveness	Tea Capable of Suppressing Disease
Plate Methods (MPN or CFU per ml)		
TSA (Aerobic Bacteria)	1.6 (0.5) X 10 ⁶	1.6 (0.7) X 10 ⁶
King's B (Pseudomonads)	5.0 (1.4) X 10 ³	1.2 (0.2) X 10 ³
Cellulose (Cellulose producers)	35 (12)	210 (43)
Spore-Formers (Bacillus sp)	7.9 (0.4) X 10 ²	0.3 (0.1) X 10 ²
Direct Microscopy (µg biomass per ml of tea)		
Active Bacteria	8.0 (2.6)	12.7 (5.0)
Total Bacteria	25.1 (1.0)	245 (34)
Active Fungi	0.00 (None detected)	3.76 (1.00)
Total Fungi	0.35 (0.12)	11.1 (2.33)
Leaf Coverage (%)		
Bacterial Coverage	27 (4.7)	86.9 (9.7)
Fungal Coverage	None detected	5.1 (0.6)
Disease (5 tomato plants)	All plants died within a few days	All plants lived and produced tomatoes

Numbers in parentheses are Standard Deviations of three readings taken for all the lab methods. These values indicate variation levels in the measurements taken.

It is clear from the direct microscopic methods which tea will be able to perform the job. Adequate fungi must be present to deal with blight. Without adequate fungi and bacteria covering the leaf surface, there will be no disease suppression. Both the assessment of the tea itself, and the leaf surface once the tea was sprayed out were predictive of whether the tea was going to be able to deal with the disease beginning to grow on the leaf surfaces. It is easiest at this time to use the direct assessment of the tea solution. Once we have the equipment to assess the leaf surface IN THE FIELD, this will become the more useful measure, most likely.

Will all fungi adequately suppress disease? There is probably some specificity of fungal species which are better at occupying the spaces on leaf surfaces, or using up the foods that the disease fungi need. Do we know if those fungi were present in this tea? No, we don't. That we had adequate fungi and bacteria present are clear. But, in the next tea made, will adequate species diversity, the right species of suppressive organisms be present? Most likely they will. But until we have methods that can measure that information, we are left to try to maximize the beneficial species in compost, and in tea, and let the plant do some of the work by putting out the foods that will feed the right fungi and bacteria to take care of the problems on the leaf surfaces.

Brewing Methods and Machines

Each kind of compost tea machine extracts, aerates and mixes tea differently than other machines. Yet, when the machines do a good job, the results can be quite similar. As long as the factors involved in making good tea are paid attention to, extraction, survival and growth of the organisms will be maximized.

Evaluation Criteria

Therefore, each machine needs to be evaluated based on the following factors:

- Aerobic?** Ability to maintain aerobic conditions (above 6 mg oxygen per L). This level is based on effects on plants and leaf material. Burning, browning, lack of foliar pathogen control, lack of nutrient color improvement all indicate anaerobic toxins produced. Quite often this is also related to compaction of the compost in the container, and too many nutrients added as amendments.
- Extraction of organisms from the compost?** Did the machine extract the ALL the different kinds of organisms? Some machines do not extract the fungi, protozoa and nematodes. Only by obtaining data about these other organisms can their presence be determined.
- Extraction of soluble nutrients from the compost?** Did the machine extract soluble nutrients from the compost? Or are the nutrients only from added materials? Then why make compost tea?
- Compost compaction?** If mixing and aeration are not adequate, the compost will compact, most likely go anaerobic if there are organisms growing in the tea. The tea will lose the beneficial fungi, because these beneficials require aerobic conditions in order to survive. Teas can go anaerobic because oxygen is used up by bacteria and fungi growing in the tea and in the compost. Especially if the compost does not have aerated water moving through it, the compost will go anaerobic and anaerobic products from anaerobic bacterial growth will disperse into the tea, killing beneficial aerobic organisms.
- Amendments?** Were adequate amounts of food added to grow beneficial organisms? Or too much food, causing the bacteria and fungi to grow rapidly, and outstrip the capacity of the aerating unit to keep up with their oxygen demand? Or food supply too low, resulting in extracted organisms, but no growing organisms? The machine manufacturer should test their machine, and tell their clients the correct nutrient concentrations to balance the growth of the organisms with the aeration rate. Please be aware that higher temperatures mean less nutrient amendments can be added because the organism grow faster. In addition, water that is higher in temperature can hold less oxygen. As elevation increases, less oxygen is present in the atmosphere, and so less rapid growth can be allowed before the water goes anaerobic. Please see the USGS website for a table of these values.
- Ease of Cleaning? Cleaning is serious business.** In all production systems, a biological film of microorganisms, called a biofilm and sometimes much thicker than a film (up to an inch or more in thickness in some systems), develops on surfaces. With time, the deepest layer of the film becomes anaerobic, resulting in production of strong organic acids that can kill organisms in the tea, kill plant tissue if applied to them, and can etch the tea-maker's surfaces. If the surface is metal, the metal will be solubilized and end up in the tea solution. For this reason, a metal container is not recommended. If brew time is short, and the unit is cleaned to remove the biofilm between brews, there will be little problem. Wood or plastic containers are preferable because they can be easily cleaned.

Cleaning the tea maker is SERIOUS. If biofilms aren't cleaned off, tea may contain pathogens and other toxic materials that can harm plants. A bio-film doesn't necessarily mean things are terrible, but they always occur when a problem has been seen.

Early Methods of Compost Tea Production.

Bucket Method. Bucket methods date back to early Roman, Greek and Egyptian times (Brehaut, 1933, Cato's De Agricultura, Varro's Rerum Rusticarum Libri Tres). Many versions of "compost in a bucket" are still used today. Typically, the compost is either free in the water (which means that the non-soluble chunks have to be strained out of the tea if you want to put it through a delivery system) or suspended in a sack or bag, along with other non-soluble ingredients.

Fill the bucket half-full with water and stir vigorously for 10 to 20 minutes to de-gas any chlorine. Add the compost until the container is full, within an inch of the top for stirring to occur. Stir periodically with a stick, which mixes the solution as well as adding a small amount of air. Brew times need to be several weeks long, in order to get any of the organisms extracted from the compost. A few organisms will grow, but biofilm formation on surfaces is not usually that great, because there isn't much food for the organisms in mature compost and the bacteria won't grow rapidly enough to use up oxygen more rapidly than it can diffuse into the water. Molasses or sugar can be added, but in tea that is not aerated, this typically causes the tea to become anaerobic. Immature compost can be a problem, however, and can result in highly anaerobic teas. After brewing, the solution is strained and applied to the crop (see Application Methods on page 18). These are typically the production methods from which we hear reports about "the tea killed our plants", because poor compost, anaerobic conditions develop or toxic materials are extracted into the tea.

Bucket-Bubbler Method (based on work by Pat Battle at Highland Inn, Asheville, NC, and summarized by E. Ingham in Kitchen Gardner, Oct/Nov 2000). A more modern version of "compost in a bucket" is one used by many homeowners and backyard gardeners because small quantities can be made inexpensively. This is not useful at a commercial level however.

On the bottom of a 3 to 5 gallon (15 to 20 L) bucket, tape (waterproof tape, please!) air stones or bubblers attached to an aquarium-type pump. Fill the bucket half-full with water and bubble air through the water for 10 to 20 minutes before adding the compost. Add compost to fill bucket to nearly the top, with enough space for bubbling (DO NOT compact the compost or extraction will be poor and the tea may also go anaerobic). Add molasses or another food source for bacteria or fungi, as desired, but realize that the amount needs to be kept minimal, or growth of bacteria and fungi will use oxygen in the air faster than the aquarium pump can replace it. The aerator provides a continuous flow of air and creates enough turbulence to provide mixing. Still, in most cases, an occasional brisk stir helps the quality of the tea, by removing the organisms from the surface of the organic matter.

Brew for 2 to 3 days, minimum. Longer is ok. Then turn the aerator off and let the brew settle for a half-hour until most of the solids are on the bottom of the bucket. The soluble portion of the tea can be decanted from the top, leaving the insoluble solids to be returned to the compost pile. If the tea is used in a backpack sprayer, it may be necessary to strain the tea through cheesecloth, or a fine mesh tea sieve to prevent plugging the sprayer nozzles.

Trough Method. In this version, compost is suspended on a wire tray over a large tank of water, for example an old horse trough - thus the name of the method. Water is pumped from the tank, sprayed over the compost, and allowed to drip through the compost, like water through coffee grounds, into the tank. The trough can range in size from 5 to 500-gallons (20 to 2000 L). The brewing period generally has to be quite lengthy, as in several weeks, because not enough energy is applied to the compost to physically remove the organisms from the compost. Because the water is sprayed onto the compost, UV light kills many of the organisms in the water droplets if the unit is outside. Evaporation can be a serious problem, concentrating salts in the tea. As the water drops fly through the air before impacting the compost, oxygen diffuses into the drops, but typically not enough to maintain enough oxygen in the tea if molasses, sugars, humic acids, or some other food resource for the bacteria or fungi is added. Aerators are often used to supplement air diffusion into the water. Nutrients are of course extracted from the compost, and that benefit to plant growth can be significant.

Bio-films typically form on trough surfaces, especially in the corners of the tank and can result in amazing smells for a portion of the brew cycle while the few bacteria that are extracted grow rapidly in the tea. It would be better to use round-bottom containers. However, diversity of bacteria and fungi is typically quite limited in these teas. But these teas are not likely still anaerobic when applied on plant material, if the brewing has gone on long enough.

The following table shows results from replicated trials with the Bubbler and the Trough methods. The teas produced were not within the desired ranges, and quite often, plants were not protected from disease organisms, did not jump-start nutrient retention, or nutrient cycling, or build soil structure or consume toxic compounds.

Table 6. Comparison of Microbial Numbers Using Bucket Bubblers and Trough Brewing Methods. Microbial populations in tea produced by different methods. Same quality compost, starting materials (1% molasses, 1% kelp), brew time as indicated.

Production Method	Brew Time	Temperature above ambient	Active Bacteria	Total Bacteria	Active Fungi	Total Fungi	Protozoa (see below) F, A, C	Nematodes (see below)
Bubbler	3 days	1 - 2° F	None detected	1 µg	None detected	10 µg	100, 25, 0	1 B
Trough	3 weeks	No increase	None detected	1 µg	None detected	None detected	0, 0, 2000	5 B
Desired Range	NA	NA	10 - 150 µg	150 - 300 µg	1 - 10 µg	2 - 20 µg	1000, 1000, 50	2 - 10 B, F, P

Protozoa = F stands for flagellate numbers, A for amoebae numbers, C for ciliate numbers
Nematodes = B stands for bacterial-feeder numbers, F for fungal-feeders, R for root-feeders, and P for predatory nematodes (beneficials).

Micro-Brewer Results, 1998 to 2000.

As an example of an unforeseen problem, compare the result from the Micro-Brewer year 2000 test with the Micro-Brewer year 1999 test. In the year 2000 test, this machine had significant bio-film formation in the pipes, resulting in poorer organism numbers in the tea because of anaerobic conditions that develop, and toxic materials produced by those anaerobic organisms. The Micro-Brewer 1999 tea, without any bio-film formation in the pipes, was clearly outstanding. For this reason, the pipes that used to occur on the bottom of the Micro-Brewer were replaced with clear plastic tubing, so users can see when a bio-film is forming. The solution is easy: Use a long-handled brush to clean the bio-film out of the pipes at the end of the run. Cleaning ANY tea-making machine, not just the Microbrewers, is a VERY important step in equipment maintenance.

Table 7. Micro-Brewer Tea Results, 1999 versus 2000. Similar quality compost, starting materials (1% molasses, 1% kelp), 20 hour brew time in both years.

	Active Bacteria (µg/ml)	Total Bacteria (µg/ml)	Active Fungi (µg/ml)	Total Fungi (µg/ml)	Protozoa (#/ml)			Nematodes (#/ml)
					F	A	C	
1999	138	1235	32.5	1524	2,546	3,398	45	11 B 3 F 1P
2000	96	536	12.5	21	2,250	1,679	145	43 B 2 F 3P
Desired Range	10 - 150	150 - 300	2 - 10	2 - 20	1,000	1,000	50	2 - 10 B, F, P

Nematodes = B stands for bacterial-feeder numbers, F for fungal-feeders, R for root-feeders, and P for predatory nematodes (beneficials). Protozoa = F stands for flagellate numbers, A for amoebae numbers, C for ciliate numbers

Comparison of Different Commercial Brewers

The Sustainable Studies Institute Tea Grant, 2002

In the tea grant sponsored by the Sustainable Studies Institute, growers made tea using the machines they bought, with nutrient starters sold by the companies or prepared by the grower, using their own choice of composts. Composts chosen for use were widely variable, temperature, water source, and cleaning conditions were widely variable, and yet the teas produced were quite similar. Of course, assessing total and active bacteria and total and active fungi does not take into account species diversity per se, so the level of resolution assessed means only one kind of variation was assessed. But good tea machines resulted in good organism numbers, regardless of conditions, while poor tea machines rarely produced decent organism numbers.

This is opposite claims by some tea machine makers that because compost, water, food resources and so forth are so different from tea brew to tea brew that the teas are so variable that consistent data cannot be obtained. Clearly, tea contains reasonably the same bacterial and fungal biomass and same levels of activity if decent compost and recipes are used. Only tea machine makers trying to hide the fact that their machine cannot make consistent brews would use arguments that testing is not possible.

In the following study, teas were made according to the manufacturer's directions. In some instances, the teas were made at SFI by SFI technicians (maintained at 72 F, using de-gassed Corvallis city water), but in most cases, the teas were made by growers, using the instructions received from the tea machine manufacturer, and sent overnight mail to SFI Coryallis, or New York. Growers were requested to make their composts from 50% thermal compost and 50% vermicompost. The compost was mixed well before use, the amounts needed for each machine measured, placed in the unit, with the same amount of molasses and soluble kelp per volume of water added to each machine. Each machine was run for the specified time.

One to three sub-samples of tea were removed from the machine, typically via whatever method was available to move tea from the tea-making machine into the spray tank of a sprayer. If there was no discharge pump, this is noted. Samples were sent to the lab by overnight mail in plastic water containers filled a third to a half full. Each sample was assessed for total and active bacteria, total and active fungi, protozoa, and nematodes at SFI.

Results. The most notable finding is that despite widely different sources of compost, and different machine designs, the resulting teas were reasonably uniform with respect to achieving minimal levels of bacterial and fungal activity and biomass. Some manufacturers have suggested that there is so much variation from tea to tea that testing is meaningless, but generally what that means is the tea maker is trying to disguise an inferior machine. If the machine does not achieve the same minimum levels of organisms from tea brew to tea brew when using similar compost, ingredients, and climate conditions, then there is quite likely something wrong with the machine.

Growers need to recognize that brew-to-brew differences based on different composts, different food additives, and different weather conditions are possible, but if the compost has decent organism levels, similar food resources are added, and temperatures are reasonably warm, the tea will always have organism numbers above the minimum levels on the desired range of the SFI test.

Some machines routinely have much higher fungal or bacterial biomass than others and there are machines that ALWAYS give higher than the minimal range on the SFI test. This is excellent, and quite likely a true difference in the ability of the machine to extract organisms from the compost.

In several instances we have documented that the reasons some machines cannot extract organisms from the compost are:

1. Compost compacts in the basket, making water movement impossible through the compost. Without water movement through the compost, organisms cannot be extracted from the compost and organisms will be lacking in the tea.
2. When water cannot move through the compost, it is quite likely that the compost will become anaerobic during the brew cycle. Visit trade shows where the machines are running. Put your hand in the compost in a machine to see if water is actively moving through the compost. But be careful - some manufacturers have been known to use compost with a higher-than-normal amount of chunky material to make it seem like the machine has good water flow, when in fact, using non-woody compost, the material compacts. Check in-use machines to determine flow-through in the compost.
3. Bio-film build-up occurs. Usually build-up within one brew cycle is not a problem, except where water flow does not occur. Cleaning then becomes an important factor. Some machines are difficult to clean, and when considering different machines, consider cleaning ease.

The number of samples in each assessment below are given in the table. Some growers sent in one tea, some sent in three, a few sent in more teas. Results are listed by machine type and volume. In some cases, new machines have come on the market, but the only testing has been with the manufacturer. The tea grant will be repeated in 2003, and the results should be available next year.

Note the differentiation into compost tea and bacterial tea. If only bacteria grow well in the tea, and fungi, protozoa and nematodes do not appear in at least minimal amounts in the tea, then the tea cannot be called a compost tea.

Table 8. Tea Quality Assessed by the SFI Tea Grant Study. Growers sent in compost teas from different machines, using their own or manufacturer supplied compost, the manufacturer's nutrient starting mix, or molasses and kelp, in conditions in the field through the summer of 2002. Data from SFI research is included as well. While some range of response is present, in general the data by machine are not widely different. In general, when variability is greater than the mean, the compost tea machine has trouble making consistent tea.

Desired Ranges for suppressive teas*	Active Bacteria (µg/ml)		Total Bacteria (µg/ml)		Active Fungi (µg/ml)		Total Fungi (µg/ml)	
	10 - 150		150 - 300		2 - 10		2 - 20	
Compost Tea Brewers ^a	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Earth Tea Brewer								
500 gal (8 teas)	527	468	13224	3841	57.6	38.5	109	57.0
500 gal (2001-1 tea)	35	ND	6700	ND	23	ND	30	ND
100 gal (6 teas)	168	118	4518	1054	2.24	1.36	8.46	3.33
Simplified-Tea KIS								
5 gal (10 teas)	141	93	3730	2755	6.88	2.63	11.8	3.12
EarthWorks								
85 gal (9 teas)	326	219	10210	5084	1.70	1.52	2.62	3.45
Clarke								
60 gal (12 teas)	70.3	66.6	2519	2231	1.88	1.13	3.62	2.26
100 gal (3 teas)	52.4	22.9	1306	363	3.55	1.49	7.63	0.83
Alaska Giant								
1 gal (3 teas)	35.8	22.8	5254	4022	1.03	0.57	5.79	4.43
5 gal (2 teas)	52.4	53.3	2528	1312	0.34	0.46	2.47	1.07
Compara								
50 gal (200 L) (3 teas)	89.1	19.7	2115	715	2.79	1.37	5.72	1.73
Bacterial Tea Brewers^a								
SoilSoup								
30 gal (6 teas)	40.2	23.1	1769	947	0.03	0.03	0.25	0.19
^N Nylon Bag (3 teas)	101	13.3	1500	210	1.23	1.26	3.01	1.88
Growing Solutions								
25 gal (4 teas)	346	545	4156	4246	0.53	0.85	0.89	1.41
100 gal (12 teas)	184	268	2644	1861	0.88	1.08	2.30	2.80
500 gal (12 teas)	60.6	34.7	4106	5579	1.02	1.01	5.36	7.75
^S Schraven (1 tea)	70.4		209		1.57		2.21	

*Based on work comparing teas that are not suppressive with teas that are suppressive

^aBased on results that show that bacteria, fungi, protozoa and nematodes in the compost are successfully and routinely extracted into the tea. On rare instances bacterial tea can put enough bacteria on leaf surfaces to use up food and prevent disease growth.

^NNylon Bag - set of brews done at SFI using a nylon bag instead of the fabric bag sold by SoilSoup.

^SThe Schraven method of running the GSI System involves different foods, changing the aerator in the basket and altering the basket arrangement when used in the larger machines. Clearly, things can be done to improve this bacterial tea machine so it COULD make decent compost tea.

A great deal of assessment goes into determining whether a tea machine in fact can extract decent levels of bacteria, fungi, protozoa and nematodes from the compost and grow the organisms in the tea during the 24 hour aerobic brewing process. For example, Bruce Elliott who makes the Earth Tea Brewer machines has worked with SFI since he started building tea makers in 1999. He has invested a great deal of effort in determining the best recipe of foods to grow fungi in his tea maker. In addition, EPM has just developed a 22 gal tea machine, and so far, is getting as good organism numbers in the tea as their other tea brewers.

In the cases where we have data, it is interesting to compare the tea data with the compost from which

the tea was made. If nematode, protozoa or fungal biomass were low in the compost, that often explains low biomass or numbers in the tea. Remember, however, that bacteria may increase by 100 to 500 times the original number during a brewing cycle, while fungi may only increase by 5 to 10 times. Protozoa and nematodes DO NOT increase in numbers in a tea cycle. Their life cycles are longer than the duration of a compost tea brew cycle.

If the organisms are present in the compost, but not present, or low, in the tea, then the reason for the lack of those organisms needs to be determined:

1. Were the organisms extracted? If neither active nor total fungi or active or total bacteria are present, there's a good indication that extraction is the problem. Is the mesh on the basket, bag or compost container a problem? Neither active nor total fungi can be a result.
2. Were they killed by too much pressure going through a pump? No organisms at all present.
3. Did something in the tea kill them? Minimal amounts of total bacteria and total fungi (extraction occurred), but no active biomass.
4. Did they lack food? Did they lack a surface to grow on? No active fungi, minimal biomass of total fungi.
5. Did the tea drop into limited oxygen or anaerobic conditions? Low active and low total fungi, but what is seen is covered with bacteria that do not stain with the activity stain.

Fig 13. Ciliates look like kidney beans and swim rapidly through the soil solution looking for bacteria, the smaller dots. Organic matter (out of focus) in the lower left. Ciliates need to eat at least 10,000 bacteria per day to stay alive. On a daily basis then, that is nearly a μg of N released in a plant available form, per ciliate.



Application Methods

Compost tea, with the right set of organisms present, can be applied with water in any of the many ways water is applied. For example, through pivots, irrigation systems of any kind, back-pack sprayers, boom sprayers, hoses, drip, helicopters or airplanes. An important point is that the tea cannot contain particles which will clog the water delivery system, and therefore must be properly screened to pass through the spray nozzles, sprinkler heads, drip irrigation lines, emitters, etc. A good mist is desirable, but the drop sizes should not be so small that UV light harms the organisms. Most pivot sprayers make drop sizes large enough that tea can be applied at any time of the day (study done in the summer of 2002). Fine mists result in drop sizes so small that the organisms should not be applied mid-day, because UV will not be blocked.

Sprayers are ideal for applications of tea onto leaf surfaces. Sprayers range from tractor mounted models for large acreage to simple backpack versions. When applying compost tea to leaf surfaces, the key is getting at least 70% of the leaf covered with the tea organisms - on both sides of the leaves.

Tea can be applied to foliage as a foliar spray - typically at 5 gallons to the acre (50 L/Ha) per 1 to 6 feet of plant canopy, once per growing season, every two weeks, or when needed to occupy leaf surfaces and compete with disease organisms. Coverage of leaf surface is the critical measure. It should be clear that if organisms are delivered to leaf surfaces at too high a velocity, the organisms will smash into the leaf or stem surface and disintegrate. This means they will not be present to protect the leaf surfaces or occupy infection sites instead of the disease-organisms.

Tea can be applied to soil as a drench, typically at a pint to a quart per plant of undiluted tea. Additional water can be used, but the point is to apply enough organisms to inoculate the soil around the root with a good set of organisms. Tea can also be applied to drench the soil surface, typically 15 gallons to the acre (150 L/Ha) in whatever amount of water is desired.

Other methods of root zone feeding vary from simple hose-end sprayers to elaborate drenching systems that dose each plant with a pre-measured amount of solution to injection systems. It should be clear that with injection systems, the pressure applied cannot smash the organisms into the soil particles, or all that results is cytoplasm seep as the organism's impact on soil particles and disintegrate. No more than 60 to 100 psi should be used to spray out organisms; they should not hit surfaces at more than 20 to 80 psi.

Do not apply tea when it is raining hard, but a light mist often helps the organisms establish a foothold on the leaf. Tea should be applied during weather when plants are active. This means starting at two weeks before bud break, through to senescence of all plants in late fall in temperate zones, and in tropical areas, when the plants need protection.

Tea should be applied so the liquid will remain on the leaf, stem and flowers of the plant, and not drip off. The larger the drop size, the more likely the tea will run off the plant. Low volume sprayers with moderate pressure are the best suited for tea application.

How Long Can Tea Be Held? This is an area currently being researched. When the first commercial brewer (Micro-Brewer) was released, testing indicated that tea needed to be made and then used. With further testing, however, we showed that if the tea is well-aerated, with maximum levels of oxygen in the tea, and the organisms have used up most of the easy-to-use food resources, then the tea will remain aerobic for 6 to 8 hours. After 8 hours, aerobic activity falls rapidly, most likely resulting from the lack of oxygen in the liquid.

If, however, the liquid is kept aerated, then holding time can be increased, up to three to five days, although numbers of active and total organisms falls off at an ever-increasing rate. At the end of three days, a ten-fold reduction in numbers, and a 90% reduction in activity occurred (work performed for ARDECO, Inc. 1995). This is acceptable for a soil application, but not for a foliar application. Active organisms are necessary for foliar protection. If bacterial and fungal foods are added to the tea at 48 to 72 hours, depending on the number of active organisms, how much food was present in the tea recipe to begin, and the number of organisms extracted, then the activity of the organisms can be extended. By the end of five days total, however, a

serious reduction in diversity of the organisms occurs, so these teas would be less likely to benefit plants than younger, more diverse teas. More testing remains to be performed however on this point.

Addition of foods to tea can help maintain shelf life of a tea, but aeration must be continued. Any large tank with aeration can be used to hold the tea, but adding food resources will likely out-strip the ability of aeration to maintain aerobic conditions. The best thing is to keep the tea in the maker, and continue the aeration if it becomes necessary to add food to maintain activity of the organisms in the tank.

Plate count assessments cannot be used to determine this kind of information since plate counts allow spores and dormant individuals, as well as active organisms to grow. In fact, in a recent test, leaves that contained very few active organisms and leaves that contained a high number of active organisms gave the same plate count numbers. This is because very few of the organisms that live on leaves grow in any plate count medium. During the incubation of the plates, dormant individuals, including spores, came to life on plate media, and a similar number of spores appeared to be present on each set of leaves.

Put-to-sleep tea. Certain materials can be added to tea to push the organisms into dormancy. DNA fingerprinting showed that nearly 50% of the species of bacteria or fungi being examined were lost when 3% phosphoric acid was added to initiate dormancy in the active organisms. The organisms in a tea MUST be dormant if the tea is placed in a sealed container, or the respiration of the organisms will cause the bottle to expand and perhaps explode. Thus, teas which are "put-to-sleep" are better for soil applications, because the organisms have time to wake up before they have to start to function, whereas on leaves, the organisms must be immediately active to protect the leaf surface.

Foliar Applications. Typically, applications for preventative control of foliar diseases are 5 gallons of tea per acre (50 L/ha) every two weeks, starting at two weeks before bud break and continuing until all danger of loss of crop yield due to disease is past. If disease is observed, make a tea and spray immediately onto the affected areas, drenching the area. Typically this results in protection of the leaf surfaces by the tea organisms and the disease is consumed or out-competed. In a few cases, when the infection was severe, repeated application was required to bring back the condition of health.

For preventative applications, the 5 gallons (50 L) can be diluted in however much water is desired, as long as 5 gallons per acre (50 L/ha) is applied. Tea must be applied to both top and bottom of leaves, blossoms, stems, etc., or sprayed directly into the top layer of soil. Recent work by John Buckerfield in Australia indicates that coverage with a mulch layer improves organism survival (most particularly earthworms if they are applied in worm compost) and increases the benefit of single-applications.

Control of Existing Disease Conditions. To control already existing foliar diseases, generally the infected foliage has to be drenched with maximum amounts of tea every three days until the disease is controlled. Tea is not a panacea that will cure everything. The mechanism for protection has to be understood, and tea correctly applied to deal with the CAUSE of the problem.

For example, in the author's yard, admittedly not a replicated study, but still of interest, a single application of undiluted tea was made to the roses on May 15, 1999. No black spot or mildew was observed throughout the summer, in fact, none until mid-July, 2000, a full year and three months after the single application. This yard receives no pesticide or inorganic fertilizer applications, which may be a reason that a single application was effective for more than a year. But mildew was noticed on the roses in July 2000. A single application of un-diluted tea immediately applied slowed the mildew down, but did not get rid of it. Three days later, a second application was made by drenching the infected areas with undiluted tea, and still, the problem was not controlled, although there was no spread of infection. A third application of undiluted tea, again, three days later controlled the mildew to the point that no visible symptoms were apparent. Already wilted leaves could not be brought back to life and were removed. This suggests that even once disease appears, by concentrating applications of organisms on infected, but not yet dead areas, recovery is possible, but not guaranteed.

Soil Applications. To protect against soil diseases reaching the roots, a sample of soil must be taken and the foodweb assessed. Then, make a tea that is appropriate to return the missing organism(s) to the soil and apply at 5 gallons to the acre (50 L/ha). After 2-4 weeks, take another soil sample for analysis to make certain the organisms survived application to the soil (total biomass gives this information), and they had food to stay alive (activity gives this information). If the organisms are not present, a

chemical residue is indicated, and needs to be remediated. Apply a tea with organisms that will degrade common pesticide residues, with the foods those organisms require to decompose residues. If the right organisms are present, but not active, then only the specific foods are needed, such as sugars for bacteria, or humic acids for fungi.

Compost Tea Appropriate to the Plant

The requirements of plants for the organisms that most benefit their growth need to be recognized. There are different organisms for different plants, and the plant feeds the organisms needed. The organisms needed by different plants can be supplied by applying compost and compost tea.

Compost and compost teas need to be defined relative to the specific plant and soil to which they are applied. Soil rich in organic matter with a healthy foodweb will be adequate for plant growth. A tea less rich in food resources can be used in this instance. Soil lacking organic matter will need a good set of beneficial microorganisms and food to feed those organisms in order to get good plant growth.

Compost or compost tea will supply the organisms that do the work the plant needs. The plant will feed those organisms. The organisms will supply the micro- and macro-nutrients that the plant requires, in a form that is easy for the plant to take up. Compost tea can also contain nutrients that plants can take-up through the foliage.

Compost and compost tea will increase the diversity of bacteria and fungi, protozoa and beneficial nematodes, even in soils high in organic matter. Just because a soil has lots of organic matter does not mean the full complement of organisms beneficial to the plant are present. Chemicals that kill the beneficial bacteria and fungi on the plant's leaves, stems and blossoms need a compost tea containing those microorganisms in order to replenish the plant's defenses. Similarly, a low organic matter soil will require a compost or compost tea with high numbers of beneficial microorganisms, as well as sugars, soluble kelp, carbohydrate material, humic acids and algal exudates to increase the food resources for the microorganisms.

Compost tea should contain nutrients to feed the bacteria and fungi, as well as micronutrients that the plant can absorb. Growers of plants, no matter how large or small the area involved, should ask:

"What does the plant require in terms of nutrients, bacteria and fungi to protect the plant from disease-causing microorganisms? Does the plant require nutrients to be retained in the soil around the plant? What is needed to make those nutrients available back to the plant? Which organisms decompose any toxic or leftover residues that may be present in the soil? How can I build soil structure so air diffuses into the root zone and prevents fungal root rot diseases? How do I improve water-holding in the root soil? How can I get the roots of my plants growing down 5, to 10, to 15 feet deep into the soil?"

The answer to the above questions always lies with the soil organisms. Always consider, however, that you need to know something about your soil. For example, if the soil is high in humic acids and other recalcitrant materials (those resistant to decomposition or decay, such as woody materials, bark, straw, old manure, oak leaves or conifer needles), then the soil is likely to be fungal-dominated, regardless of sand/silt/clay ratios. In this case, the recipe chosen should enhance bacterial biomass in order to balance the fungal-to-bacterial biomass ratio. Conversely, if the organic matter in the planting medium is not slow to decay (e.g., green residues, green leaves, fresh manure), then the tea recipe should be one that selects more for fungal biomass, again, to balance the fungal-to-bacterial biomass ratio.

The balance of fungi to bacteria must be viewed with respect to the needs of the plant. For example, trees require a fungal-dominated soil, while row crops and grass need an equal balance of fungi to bacteria. Based on the limited testing that has been done, we have determined that teas applied to foliage should always be bacterial in nature.

The Right Compost

It is critical to start with compost or vermicompost that will produce the desired microbial balance. If the tea needs to be more fungal, compost high in fungal biomass should be chosen. Generally, compost

high in volume of woody material (resistant to rapid decay) will probably be fungal-dominated.

A typical fungal compost recipe contains 25% manure, 30% green material and 45% woody material. Fungal composts typically need less turning because the chunkiness of the woody material allows better air diffusion. Thus, piles without the high N and with more woody material typically do not reach temperatures above 150° F (65° C). Turning is needed only to homogenize the pile and spread the growing organisms evenly throughout the materials.

If bacterial tea is indicated, use compost made with 25% manure, 45% green material and 30% woody material. Each composter needs to work the best combination out for themselves, with their own starting materials. The quantity and source of manure is important. The higher the level of N in the manure, the faster the pile heats. If too much N is present, the pile may heat above 180° F (85° C), and may combust. Turning becomes critical for cooling the pile and bacteria are selected as fungi are killed during the turning process.

Again, the size of the particles in a compost pile is important. If green or woody material is finely chopped, then the N in that material is more readily available to the microbes, the bacteria will bloom, increasing temperature and rapidly using up the oxygen. To prevent anaerobic conditions, compost with finely chopped material will require air to be pumped in or turned at least once per day.

The Right Foods

If you aren't sure what your plants need, make a tea that contains both bacteria and fungi, as well as protozoa, and let the plant do the selecting. Simple sugars to encourage bacteria growth; while soluble kelp (surface area) and humic acids (foods) enhance the growth of fungi.

ADD NOTHING THAT CONTAINS A PRESERVATIVE!! What are preservatives? Anything we use to prevent microbial growth, such as antibiotics, chlorine, fumigants, sterilants, alcohol, benzoate, benzene, phenols, terpenes, iodine, etc. When in doubt, ASK!

The selection for the preferred microbial community, given a compost of say equal bacterial to fungal biomass, can be made by adding components to the tea solution before the tea brewing process begins.

Additives that help bacteria most are simple sugars, syrups such as molasses, cane syrup, sugar beet syrup, spoiled carrot juice, apple juice from applesauce production, and yeasts (vitamin addition).

Materials that help fungi more than bacteria are things like fruit pulp (the cellulose in the pulp generally helps fungi more than bacteria but bacteria will grow on the sugar portion of the pulp), soluble kelp (protein and micronutrients), humic acids, or other high cellulose containing pulp material. Plant extracts, such as comfrey, nettle or dandelion "soups" can also be added to enhance the micronutrient content of a tea. Anecdotal information from growers suggests that comfrey is high in Ca, N and K, and thus alleviates nutrient stress if plants are lacking these nutrients. Comfrey has been chopped and added to the compost before it is composted, or after composting is finished (dangerous if there is any disease on the comfrey that could spread through the compost), to the compost basket during the tea brewing operation, or as a brewed soup (stuff a bucket full of comfrey leaves, add water, churn the leaves in the bucket for a day or so, then add the liquid to the water at the start of the brew process). In each instance, significant benefit to plant production was observed, most likely explained by improved Ca uptake by the plant. However, these were not replicated studies, and to fully accept this type of work, controlled scientific studies are required.

Use cold-water grown kelp, not warm-water grown kelp. Cold-water kelp absorbs and retains more nutrients during growth than warm-water kelps, resulting in greater micronutrient benefits.

Some spices have properties that inhibit specific microbes. While a great deal more testing is required to document efficacy, materials like garlic oil, onion oil, orange oil, citric oils, cinnamon, and oregano have been reported to reduce *E. coli* counts in teas. Testing needs to be performed.

Many interesting ingredients have been used in teas, but their benefit has rarely been documented. The special elixir that works wonders for one grower may have little or no benefit, or sometimes be detrimental, to other plants. The explanation lies in the biology and the chemistry of the plant, the soil, and the tea. The biology may have been right for your friend's squash, but isn't right for your indoor

citrus tree. When in doubt, test the tea on part of the plant, or in a small area of your field.

Table 9. Examples of Food Resources for Different Organism Groups.

Product Name/Company	Group Fed	Application Rate per 50 gal (200 L) of tea
BACTERIAL		
Simple sugars	Bacteria at low concentrations, fungi at high concentration (syrup)	600 ml (1 pint) to 4 L (1 gal)
Kelp	Bacterial foods, Fungal surfaces	0.1 to 1%
Fish Hydrolysate / Neptune's Harvest, Organic Gem	Fungi, important to have bones, scales and cartilage liquefied using enzymes, not heat or acid	0.01% to 1%; add carefully, can drive teas anaerobic!
Fruit Pulp	Fungi and Bacteria	0.1 to 1%; test in your system to determine effect
Humic acids / Terra Vita, Eco-Nutrients, Hydralume	Fungi (as humics broken down, then bacterial food is released)	1 to 15 oz, depending on product
FUNGI		
Humic acids (see above)	Fungi (some bacteria)	600 ml (1 pint) to 1 gal (4 L)
Protein Meals / Soybean meal, Oatmeal, Barley meal, Feathermeal, etc	Fungi	Test in your system
Rock dust, powder	Mineral nutrients for all organisms, surfaces for fungi	Test in your system; look at the mineral needs of the plants
Spices / Garlic, orange oil, citrus, cinnamon, lemon, onion, oregano, soy	Inhibitors of specific microbial groups	Test in your system
Vitazyme / Vital Earth Resources	Fungi	1 to 5 oz
Yeast (brewers, bakers, wine, champagne)	Complex mix of proteins, minerals, vitamins for both bacteria and fungi, and plants	Test in your system
Yucca / Desert King, Helena Chemical Co.	Fungi (some bacteria)	100 to 600 ml (brewers of foaming*)

*1 US gallon = 3.8 L, or round up to 4 L.

Recipes

Most compost tea machine makers have food kits that match the aeration abilities of their machines. Use their food kits until you can assess the effect of adding or subtracting food resources using, for example, a light microscope. A reasonable investment is learning to use a microscope to recognize the sets of organisms.

For those who wish to test the impacts of different foods on organism growth, the following recipes are based on 50-gallon (200 L) compost tea making machines.

Ingredient amounts should be maintained at the same ratio per volume of water as in the following recipes, even if compost volume is not linear. The same amount of food per unit liquid is still required, regardless of the inoculum amount (which is not linear; see below). With high amounts of sugar, make certain that adequate aeration is provided or the tea can become anaerobic within just a few hours.

There are two parameters to consider in Table 10.

1. Category of plant that is closest to the one you want to grow,
2. Soil type that is closest to the three listed in the table.

For example, tomatoes are in the grass/row crop category, while strawberries, grapevines, kiwi, rhododendron, and snowbrush fall in the berry/vine/shrub category. Deciduous trees include poplar, almond, peach, citrus, coffee, apple, avocado and olive. Conifers include pines and most evergreens. It should be noted that some cedars actually fall in the deciduous category. Epiphytic plants and palms most likely fall in that category as well.

Table 10. The Kind of Tea Needed for Different Plants and Soil Types.

Soil Type	Plant types				
	Broccoli, cabbage, cole (strongly bacterial)	Row Crops, Grasses (slightly bacterial)	Berries (Equal bacteria and fungi)	Deciduous Trees, Vines (2-10 times more fungal)	Conifers (100+ more fungal than bacterial)
Sand	Need both bacteria and fungi to build good soil structure.	Need mostly fungal activity, some bacteria to build soil structure.	Need to help fungi to the maximum, since fungi are most likely lacking.	Help fungi to the maximum extent; fungi most likely to be seriously lacking.	Mycorrhizal fungi usually needed, fungi need maximum help, bacteria usually are fine.
Loam	Need to improve bacteria significantly; some fungi needed.	Need both bacteria and fungi to build good soil structure.	Need to really push fungi, since fungi are most likely lacking.	Compaction is tough to overcome, fungi need to be helped extensively.	Check mycorrhizal fungi; improve fungi to maximum amount.
Clay	Need mostly bacteria to form microaggregates and get nutrient cycling going.	Need both bacteria and fungi; check Ca:Mg ratio.	Need to improve both bacteria and fungi; check Ca:Mg ratio.	Check Ca:Mg, look for hydrides, fungi need maximum help.	Maximize fungi, check mycorrhizae.

Most plants can be colonized by mycorrhizal fungi, except for strongly bacterial-dominated plants such as broccoli, most kales, cabbage, cauliflower (i.e., many brassicas). Most other plants either do better in low nutrient conditions or are obligately mycorrhizal. Thus, mycorrhizal colonization of roots should be checked by taking root samples from several plants and sending them into a soil biology lab (such as Soil Foodweb Inc., www.soilfoodweb.com, or Efrén Cazares lab, mycoroots@atfbi.com, to determine the percent of the root system colonized by mycorrhizal fungi. Deciduous trees require VAM inoculum, while conifers need ectomycorrhizal inoculum, or a combination of VAM and ectomycorrhizal fungi. Blueberry needs arcticoid mycorrhizal fungi, but no inoculum of these mycorrhizal fungi is available

commercially. In this case, or for other plants with limited species requirements, take soil from the surface near an existing healthy plant growing in a native system and use this as an inoculum.

Water versus Compost Volumes and Extraction Efficiency. Extraction efficiency does not relate to the volume of water used for extraction but rather to the efficiency with which the water pulls the organisms from the compost. Lower pressure is acceptable if, at the same time, the particles of compost move against each other and organisms are pulled from the compost. Thus, the compost has to be free to move in the container. A very small amount of compost might be acceptable, if the extraction conditions are optimal with respect to water flow THROUGH the compost, and movement of the compost in the container.

Initially use the compost amount recommended by the person you buy the tea machine from, and then test your own machine to determine what amount of compost gives you the best extraction. Use the Qualitative assessment methods until you have your recipe determined.

For Example:

Run a tea brew with 1 pound of compost in the machine, and look at what is in the tea at 8 hours, 24 hours and 48 hours, using the qualitative assay. Then make a tea with 5 pounds, and observe the biology in the tea. Then 10 pounds, 20 pounds, 30 pounds, etc. When the number of organisms in the compost does not increase from one amount to the next higher amount of compost, the optimal amount of compost has been found.

Brewing Time. The brewing time must be long enough and/or have enough mixing to extract the desired soluble nutrients (food resources used by the microorganisms and micronutrients). If brewed too long, the microorganisms may go to sleep and not be active.

When to Add Materials. Soluble materials should be added to the water at the beginning of the brew cycle, unless otherwise noted in the recipe. If mechanical parts can clog, non-soluble materials should be placed in the compost container. Mycorrhizal spore suspensions should be added to the tea at the end of the brewing cycle, not at the beginning, because the spores will begin to germinate in the tea after several hours. Mycorrhizal spores are sensitive to pressure just after they germinate and the pressure involved with mixing will kill them.

Commercial versus Indigenous Organisms. Indigenous microorganisms are clearly the best choice for any particular system; therefore develop beneficial microorganisms adapted to your conditions. One way to get the indigenous beneficial microorganisms into the tea is to add a pound of soil from highly productive soil or composts to the compost container. Be sure the soil has not had recent inorganic fertilizer or pesticide applications. If a tea turns out well, save a small amount of the tea, or the soil to which the tea was added, as an inoculum for the next batch of tea. This will keep improving the beneficial microorganisms.

Fine-Tuning Your Recipes. Follow directions on labels of various products for most food resources. Test products to determine whether they are helping to grow organisms, or are harmful to them.

Make a tea with minimal additives, such as just kelp and a little molasses. Place the same amount of tea in each of two, or three or more clean containers. To the "control" container, add only water, equal to what you add with the product you are testing. To the next container, add the smallest amount of the product possible that should have an effect. To the next container, add double that amount. Then add triple to a fourth container of tea. Let the organisms have a few hours to grow before testing. Let them brew for 24 hours, and check the biology again. Which amount of product had the highest biomass of bacteria and fungi? Protozoa? Nematodes? If the control had the greatest, then the product is detrimental. If the container with double or triple amounts had highest organism's biomass, then that tells you which amount to test in the real tea brews.

The following recipes are all based on 50 gallons of water, degassed if required to remove chlorine, and checked for extraction of the compost (brown color released into brew before adding molasses or kelps).

The Basic, Starting-point, Bacterial Tea (based on 50 gal tea maker)
15 pounds (7 kg) bacterial compost

16 ounces (500 mL) black strap molasses (Dry molasses does not substitute)
8 ounces (250 g) soluble cold-water kelp (additional proteins)
1 to 6 ounces (30 to 200 mL) liquid, filtered plant extract material (for example, yucca extracts, nettle soup, dandelion wine, comfrey tea), proteins, fruit juices, fruit pulp, fish emulsion
Add nothing with a preservative or antibiotic in it!

Concoctions that become anaerobic can be added to recipes like this one that call for plant extracts, because the anaerobic decomposition products will be consumed and converted into aerobic, plant-beneficial compounds during the brewing process. Of course, the brewing process must remain highly aerobic, so use a machine or method that provides a high rate of aeration and thorough mixing.

Dry molasses lacks a significant component of more complex sugars, so if using dry products, add a greater amount of dry molasses. There are fewer types of sugar in dry molasses, so use a second type of sugar such as corn syrup, maple syrup, or starch.

This yields a moderately bacterial tea. Addition of kelp adds micronutrients and some bacterial as well as fungal food.

Equal Ratio Fungi to Bacteria Tea (based on 50 gal tea)

15 pounds (7 kg) 1:1 fungal to bacterial biomass ratio compost
16 ounces (500 mL) humic acids
8 ounces (250 g) soluble kelp
Fish hydrolysate, soybean meal, feathermeal, oatmeal, or other high complex protein materials (see label on packages), fruit pulp

Add nothing with a preservative or antibiotic in it!

Humic acids select for beneficial fungi, but any fungal food could be substituted here. Make certain to obtain a mixture containing many humic acids, rather than a limited set (i.e., 3 to 5 humic acids). Rock dusts, rock powders, or rock flours can be beneficial as well, although these grainy materials can harm mechanical pumps. Fish hydrolysate should be tested for their ability to serve as fungal food resources before using extensively. Fish emulsions do not have the oils that help fungi grow, so an emulsion is more beneficial as a bacterial food than a fungal food.

Fungal Tea

20 pounds (9 kg) fungal compost
1 pint humic acids (600 mL)
4 oz (100 mL) yucca high saponin content)
8 ounces (250 g) soluble kelp,
8 oz (250 g) Fish hydrolysate, additional proteins

Add nothing with a preservative or antibiotic in it!

Make sure the compost is mature and has not been disturbed or turned for a week or more.

Mycorrhizal Inoculum

The concentration of spores needed has not been well established for different plant species. A range of 50 to 100 spores per gram soil is probably adequate to establish colonization. Since mycorrhizal spores germinate and begin to grow within a few hours of addition to most teas, add the spores to the spray tank, holding tank, injection system, etc. For row crops, vegetables, grass, most berries, shrubs, and deciduous trees, vesicular-arbuscular mycorrhizal fungi (VAM) are the mycorrhizal fungi of choice, while conifers and some late-successional deciduous trees require ectomycorrhizal fungi.

Grower Experiences

In the past examples of experiences that growers have had with compost tea have been put in the manual. Instead, we would like to have people check the SFI e-zine, or call us to learn more about local tea production and tea centers.

Check the Soil Foodweb Inc web site, www.soilfoodweb.com updates and links to compost tea production.

Scientific Papers or Abstracts

Experiences in Natural Golf-Course Practices at Bandon Dunes Resort

Presented at Golf Consultants International, 2000 in Frankfurt, Dec. 5

Speaker: Troy Russell, Superintendent at Bandon Dunes Resort, Bandon, OR, 97411, USA

ABSTRACT:

The unique location of the BDR in the dunes, right at the Pacific Ocean, and in an environmentally protected area, required a natural approach on the golf course practices. The challenge was to research what natural practices are available and carefully apply, check results and gain reproducible results and experiences. The basis of our NGCP (Natural Golf Course Practices) is founded on the properties of the most natural system. To return the system to the most natural system, materials were applied that would bring the natural system back into place most rapidly, for example, the use of compost, which contains humic acids, a wide spectrum of beneficial microorganisms and last but not least, organic matter. The other components of this system are minerals, which can be added as organic or inorganic forms. The challenge was to copy nature on an industrial scale and in a fashion, suitable for easy golf course or management. After gaining a 2-year experience, I feel confident and am happy to share those experiences with you.

Two student posters, the first where they actually determined the biology – all of it, not just bacteria – in the tea and showed the tea they made was in good to very good range. As result, the tea suppressed disease.

Gangaiah, C., Carey, E. and Tisserat, N.A. Kansas State University
Suppression of Septoria Leaf Spot Disease of Tomato Using Aerated Compost Tea
ASHS 2004 annual meeting. <http://www.ashs.org/annualmeeting/conference/index.lasso>
Poster Board #292

Abstract: Compost teas, made using an aerated brewing process, have been reported to have potential for controlling a range of plant diseases and improving crop health. Septoria leaf spot of tomato, caused by the fungus *Septoria lycopersici*, is a common and destructive disease of tomato in Kansas. A field trial was conducted at Wichita, Kansas during Summer 2003 to evaluate the potential of pre-plant compost, and compost tea applied as a foliar spray or through drip fertigation, to control Septoria leaf spot of tomato. The experimental design included three factors: Pre-plant application of 13N-13P-13K or vermicompost; fertigation with CaNO₃ or compost tea; and foliar spray with compost tea, fungicide (Dithane) or water. A split plot design was used with fertigation treatments as main plots and the other two factors as sub-plots. There were 3 replications. Tomato cultivar Merced was used and individual plots consisted of 5 plants grown on beds covered with red plastic mulch and supported by stake and weave system. Aerated compost tea was brewed weekly using a vermicompost-based recipe including alfalfa pellets, molasses, humic acid, fish emulsion and yucca extract and applied to plots starting 2 weeks after transplanting. Disease incidence and severity were recorded weekly for 3 weeks following the appearance of disease. Plots were harvested twice weekly and counts of No. 1, No 2 and cull grade tomatoes were recorded. There were no effects of pre-plant or fertigation treatments on Septoria leaf spot disease, but there was a significant effect due to foliar sprays, with mean severity of compost-tea-sprayed plots (26.3%) and fungicide-sprayed plots (31.9%) significantly lower than water-sprayed plots (45.9%) at trial termination.

No assessment of the biology in this one – did they actually make good tea?

Joslin, K. Taber, H. Helland, S. and Gleason, M. Iowa State University
Control of the Foliar Disease, *Septoria lycopersici*, in Organic Tomato Production
Poster Board #290

Abstract: Disease management in organic tomato production poses one of the greatest challenges for organic producers in humid climates. Both organic and conventional tomato growers have relied on copper (Cu) fungicides to control many diseases, including *Septoria lycopersici* common in tomato production. Concerns have been raised regarding the use of Cu fungicides, because of their potential to cause plant damage and toxicity to beneficial organisms. The objectives of this research were to: 1) investigate the efficacy of compost tea made from either windrow composted cattle manure (WCCM) or vermicomposted cattle manure (VCM), and 2) compare the efficacy of organic fungicides with conventional fungicides to control *S. lycopersici* in organic tomatoes. Treatments included 1) a control, 2) a conventional treatment in which fungicide applications of Bravo plus Cu and Quadris plus Cu were alternated, 3) copper fungicide (Champion), 4) Serenade TM Fungicide (*Bacillus subtilis*), 5) WCCM compost tea, and 6) VCM compost tea. Disease pressure was mostly from the bacteria speck/spot complex. Disease severity was significantly ($P < 0.05$) reduced and marketable yield was 60% higher with the two Cu treatments (No. 2 and 3), compared to other treatments. A follow-up greenhouse experiment is in progress and will be presented with the field data.

The following shows that having mixes of organisms can result in disease organism suppression.

Utkhed, R. and Koch, C. 2004. Biological treatments to control bacterial canker of greenhouse tomatoes. *BIOCONTROL* 49: 305-315.

Experiments were conducted to determine the effects of treatments on *Clavibacter michiganensis* subsp. *michiganensis* in vitro and on young seedlings inoculated with the pathogen under greenhouse conditions. Lysozyme was bactericidal at 10 g/l concentration in vitro. Tomato plants treated with lysozyme at 10 g/l and 100 g/l showed significantly higher plant height compared with the inoculated control plants, and plants in these treatments were as tall as those observed in untreated uninoculated control plants. Treatments with *B. subtilis* (Quadra 136) and *Trichoderma harzianum* (RootShield(R)), lysozyme, vermicompost, *Rhodosporidium diobovatum* (S33), *B. subtilis* (Quadra 137) applied as a spray at 0.3 g/l, 0.6 g/l, 10 g/l, concentrated, 1 x 10⁹ (9) CFU/ml, and 0.5 g/l, respectively, have the ability to prevent the incidence of bacterial canker of tomato plants caused by *C. michiganensis* subsp. *michiganensis* under greenhouse conditions.

This is an interesting paper. It is the basis for the NOP being paranoid about molasses. They rather miss the point that fungi, protozoa and nematodes, i.e., the whole food web, just might have something to do with suppression. There are other things in this world than just bacteria!

Scheutrell, S. and Mahaffee, W. 2004. Compost Tea as a Container Medium Drench for Suppressing Seeding Damping Off Caused by *Pythium ultimum*. *Phytopathology* 94:1156-1163.
Compost tea is being used increasingly in agricultural production to control plant diseases. However, there has been limited investigation relating disease control efficacy to various compost tea production methods, particularly compost tea produced using active aeration and additives to increase microbial population densities in compost tea. Aerated compost tea (ACT) and nonaerated compost tea (NACT) produced with or without additives was investigated for the suppression of damping off of cucumber by *Pythium ultimum*. Compost tea was used to drench soil less container medium inoculated with *Pythium ultimum*. Effect on damping off ranged from not suppressive to consistently suppressive depending on the method used to produce the tea. The most consistent formulation for damping off suppression was ACT produced with kelp and humic acid additives. Producing ACT with a molasses-based additive inconsistently suppressed damping off; evidence suggests that residual nutrients can interfere with disease suppression. Heating or diluting compost tea negated suppression. Across all compost tea samples, there was no significant relationship of bacterial populations measured as active cells, total cells or CFU with disease suppression. However for all ACT produced without the molasses-based additive, there was a threshold of bacterial-based population density (6 log base 10 cells per ml, 7.48 log base 10 total cells per ml, or 7 log base 10 CFU) above which compost teas were suppressive.

This is one of the two "papers" used by the USDA to support their statement that compost tea should be viewed as being raw manure. No one in their right mind would produce compost tea in a sealed container such as used in this "research". What was the point of these people's work? Trying to discredit the growing industry of compost tea? Why would any this "journal" accept such an inaccurate paper?

Duffy, B. Sarreal, C., Ravva, S. and Stanker, L. 2004. Effect of molasses on regrowth of E-coli O157:H7 and Salmonella in compost teas. *COMPOST SCIENCE & UTILIZATION*, 12:93-96.

Compost water extracts (compost teas) are gaining popularity among organic growers, largely because of their disease suppressive activity when applied to foliage or soil. Production methods often include addition of supplemental constituents, particularly molasses, to stimulate plant-beneficial microbial populations. We have found that molasses amendments also favor regrowth of human pathogenic bacteria, raising public health concerns about potential contamination of treated crops, particularly produce intended for fresh consumption. Using disease outbreak strains marked with green fluorescent protein (GFP) and spontaneous antibiotic-resistance, we found that regrowth of *Salmonella enterica* serovar Thompson and *Escherichia coli* O157:H7 was positively correlated with molasses concentration. For *Salmonella*, regrowth was also dependent on the type of starter compost material used. *Salmonella* populations increased from 1 at time 0 to over 1000 CFU ml(-1) in dairy manure compost!

t tea with 1% molasses, and from 1 at time 0 to over 350,000 CFU ml-1 in chicken manure compost tea by 72 h. *E. coli* populations increased from 1 at time 0 to approximately 1000 CFU ml(-1) in both types of tea by 72 h. Pathogen regrowth did not occur when molasses was eliminated or kept to 0.2%.

Note in the following paper, they do not in any way determine what is in the "compost extracts" that they prepared. Rather like throwing a handful of dark stuff in water, and hoping it will cure your headache. What proof did they have that the "composts" they used were even composts at all?

Al-Dahmani, J.H., Abbasi, P.A., Miller, S.A. and Hoitnik, H.A.J. 2003. Suppression of bacterial spot of tomato with foliar sprays of compost extracts under greenhouse and field conditions. *PLANT DISEASE*. 87:913-919.

The efficacy of foliar sprays with compost water extracts (compost extracts) in reducing the severity of bacterial spot of tomato caused by *Xanthomonas vesicatoria* was investigated. Extracts prepared from composted cow manure, composted pine bark, an organic farm compost, or composted yard waste, applied as foliar sprays on tomato transplants, resulted in a moderate but statistically significant reduction in the severity of bacterial spot. The population of *X. vesicatoria* in infected leaves was reduced significantly by extracts prepared from composted cow manure. Efficacy of the water extracts was not affected by oxygen concentrations in the suspension during extraction, compost maturity, or sterilization by filtration or autoclaving. The degree of control provided by foliar sprays with the most effective compost extracts did not differ from that obtained with the plant activator acibenzolar-S-methyl. In the field in two growing seasons, foliar sprays with compost water extracts did not reduce the severity of foliar diseases, including bacterial spot. During the 1997 season, when the severity of bacterial spot in the field was high, foliar sprays with compost water extracts significantly reduced the incidence of bacterial spot on tomato fruit. Amending plot soil with several rates of composted yard waste did not lead to additional control of fruit disease over those only sprayed with extracts. Foliar sprays with a mixture of chlorothalonil and copper hydroxide or with acibenzolar-S-methyl reduced the severity of bacterial spot as well as incidence of spot on fruit.

Ingham, E. 1998. Anaerobic bacteria and compost tea. *BioCycle* 39: 86

The writer discusses anaerobic bacteria and its impact on plant growth. Composters are concerned that the presence of bacteria that can grow without oxygen or in a low oxygen environment poses a problem in compost or compost tea. In the writer's opinion, the presence of bacteria is not a problem, as long as they are not growing. The elimination of anaerobic conditions and the products of anaerobic metabolism are also discussed.

Ingham, E. 1999. Part I. What is compost tea? Part I. *BioCycle* 40: 74-75.

The writer discusses compost tea. Compost tea is a liquid extract of compost that contains all of the soluble nutrients, both organic and inorganic, and a large portion of the organisms, such as bacteria, fungi, protozoa, and nematodes, that are present in the compost. The benefits provided by the tea depend on what can be extracted from the compost; it is very important that the tea contains organisms. A major advantage of compost tea is that it can be applied through the irrigation system or through a spray rig.

Ingham, E. 1999. Part II. Making a high quality compost tea. *BioCycle*: 40: 94.
The writer discusses the major factors that influence the quality of compost tea, which can be inconsistent from batch to batch. These include the mesh size of the bag or filter, steep time, and water recirculation and aeration. Factors contributing to a wide diversity of bacteria, fungi, protozoa, and nematodes desirable in compost tea are also addressed.

Brinton, W.F.; Tränkner, A.; and Droffner, M. 1996. Investigations into liquid compost extracts. *BioCycle* 37:68-70

In a review of the use of liquid extracts of compost for the control of pathogenic fungi in plants, variables in producing and applying such compost teas are considered. Compost teas coat plant surfaces with live bacteria, suppressing both the germination and the growth of plant pathogenic organisms. The maturity of the compost and the nature of its source constituents are major factors in the effectiveness of compost tea treatments.

Bess, V.H. 2000. Understanding compost tea. *BioCycle* 41: 71-72

The potential benefits of compost tea, a range of different preparations made using compost as a starting material and producing a liquid extract or a liquid version of the original compost, are discussed. The performance of these solutions depends on their preparation, compost quality, microbiology, storage, and application methods.

Scheuerell, S. 2003. Understanding How Compost Tea Can Control Disease. *BioCycle* 44: 20-5

Grobe, Karin. 2003. Golf Courses Find Value in Compost Tea Programs. *BioCycle* 44:22-23. San Francisco's Integrated Pest Management program is using compost tea as an effective tool for suppression of turf diseases as well as overall reduction of synthetic fertilizers. The tea is brewed in two 100-gallon and one 25-gallon brewers from Growing Solutions, is diluted with an equal volume of dechlorinated water, and applied at a rate of 2 gallons per 1,000 square feet every 2 weeks. The effects of a compost tea trial on golf course greens in San Francisco over a one-year period yielded positive results.

Wickland, L.; Murray, T.; and Jimerson, J. 2001. Brewing up solutions to pest problems. *BioCycle* 42:64-66.

The writers discuss the combined efforts of Washington State University Cooperative Extension and a Whatcom County grower to evaluate compost tea in the suppression of plant diseases. In April 2000, Alison Kutz-Trounman of Cascade Cuts gave the university an opportunity to test the efficacy of compost teas as a valuable integrated pest management strategy. In 2 of the 3 trials, control plants had a greater incidence of disease than plants treated with aerobic tea or anaerobic tea. However, statistical differences did not emerge until 6 to 8 weeks after germination, so the practical benefits of using compost tea to suppress root diseases may be marginal.

Blair, M. and Koch, J. 2001. Sustainable practices thrive in a national park. *BioCycle* 42: 51-52

The benefits of a composting project at the Presidio, which is part of the Golden Gate National Park in San Francisco, California, are discussed. The Presidio Trust took on the composting project for economic reasons and is now reaping the benefits. The eventual goal is to recycle 100 percent of the organic waste produced in the park, thereby saving the Presidio Trust \$100,000 per year. Using help from various organizations, small trials were started. Recipes and uses for the quality compost were found. The next stage was to expand the production of quality compost from 100 to 2,000 cubic yards per year. Studies are being conducted to see if the compost increases the survival rate of transplanted native plants grown on site to restore the habitat. A compost tea has also been made and is being used on the Presidio's golf course as top dressing. Schoolchildren from San Francisco come every week to help with and learn about composting.

Touart, A.P. 2000. Time for (compost) tea in the Northwest. *BioCycle* 41: 74-77

The potential of compost tea to provide nutrients and combat infection in plants and crops is discussed. Two Northwest companies are working toward the large-scale production and supply of compost tea—Growing Solutions Inc. of Eugene, Oregon, and Soilsoup Inc. of Seattle, Washington. The effectiveness of compost tea as demonstrated by experimentation is considered.

Naylor, L. 2001. Using compost tea on golf courses. *BioCycle* 42 24-25.

Potential health hazards that may be associated with the use of compost tea on golf courses are addressed in a question and answer format. Compost tea contains microorganisms that have been active in the composting process but can include human and animal pathogens, especially if made from improperly composted materials. However, it is unlikely that incidental contact with areas treated with compost tea would result in illness.

Salter, C. 2001. Teas versus leachate. *BioCycle* 42: 24

The differences between compost tea and compost leachate are addressed in a question and answer format. Compost tea is derived from finished compost and implies a more deliberate extraction process, whereas compost leachate formation is passive and secondary to the composting process.

Experimental Results

SARE grant (2001)

This work being done with the Sustainable Studies Institute, Eugene, OR. In this experiment, we are working with three different vineyard cooperators in the Willamette Valley. One is in McMinnville, OR, the second in Wren, OR, and the third in Monroe, OR. The experimental design was application of a good compost tea to five rows of the vineyards every two weeks, application to a different set of five rows every week, compared with the control which is the rest of the vineyard using the grower's normal practices. During the summer, anaerobic teas were made and applied once. We intended to find strongly fungal materials and apply a strongly fungal tea, but the problems with extraction and compost quality have proven too difficult, and this application will be a part of the next year's study.

Three 12 gallon Micro-Brewers were donated to the Sustainable Studies Institute for use in this study. Initially the teas made were barely acceptable in terms of bacterial biomass, and were almost completely lacking in fungal component. The compost being used was changed, because initially, worm compost was mixed with some strongly fungal mushroom compost, but the mushroom compost was shown to contain many inhibitory compounds which killed the other organisms in the tea. The next compost used was a combination of strongly fungal worm compost and strongly fungal thermal compost, but as it became difficult to afford the thermal compost, strictly fungal worm compost was used. These are the joys of having budgets.

Application starting times in the spring varied in each vineyard, because of growers' practices. This wasn't the experimental design, but there are times when practicality overcomes any other consideration. Because we were limited in the amount of tea being made per batch, each vineyard diluted the tea to the correct amount to cover the rows within their vineyard. At the Monroe vineyard, this meant the tea was diluted 1:5, at Wren tea was diluted 1:1 and at the McMinnville vineyard, no dilution was used, but two rows were not sprayed, and thus became the untreated control.

In mid-June, a mildew alert was released by the OSU Extension Service, indicating that mildew was in epidemic proportions and all growers should be aware that it was perfect conditions for mildew outbreaks to occur. None of the vineyards, at either application rate, reported mildew.

The last week of July, the tractor at the Monroe vineyard broke down, and no tea was applied for three weeks. During the week of August 5, 2001, mildew was found in the block that had been last sprayed the week of July 20, and had only received tea sprays every two weeks. Small levels of mildew were found in the weekly block, which had not been sprayed since the week of July 20. Clearly, maintaining protection was critical. The block with high levels of mildew was sprayed with fungicide, which ended the mildew infestation, and the block went back to normal tea applications. No further mildew spread was observed. In the weekly block, since the tractor had been fixed, tea application ended the mildew outbreak.

In the Wren vineyard, in the block sprayed every other week, mildew was found on some grapes during the week of August 5. Therefore, tea application was increased to once a week, and increased to no dilution in both blocks. Once the danger of infection was over, the tea applications returned to weekly and bi-weekly.

No mildew was observed in the McMinnville vineyard, except in the untreated control areas. Once mildew was observed, tea sprays were initiated and no further mildew was observed.

The results from the trials were that grapes in the tea-treated areas were ready for harvest weeks before conventional grapes were ready to be picked. This reduction in ripening time is significant with respect to being able to initiate wine-making operations in the late summer.

The anaerobic tea tested the weeks of August 12 and 19 did not result in any improvement in organism coverage on leaf surfaces.

These results clearly show the importance of dose-rates, and that the level of bacteria and fungi on the leaf surfaces is critical.

SARE grant (2002)

Powdery mildew was a serious disease problem at vineyards in the Willamette Valley of Oregon in 2002, as it was in 2001. In the vineyards used for this study, powdery mildew outbreaks were largely controlled, or their severity reduced, in areas sprayed weekly with compost tea. Organism biomass in the teas, and therefore leaf surface coverage by microorganisms, particularly fungi, was not sufficient to prevent infection. Weekly compost tea applications reduced the number of applications to one to as many as three applications of chemical fungicide needed to control powdery mildew over the summer growing season.

Changes in soil microorganisms between 2001 and 2002 were also documented. In general, bacterial activity was higher in 2002. Fungal biomass declined in some areas sprayed with compost tea. Organism biomass in soils from conventionally-treated areas followed similar patterns, however, so most likely these changes are in fact seasonally related and not the result of compost tea application. Thus, it is clear that SOIL organism biomass changes were due to other environmental factors or management practices, and not to the application of compost tea. Foliar sprays did not significantly improve soil biology in this two year study.

Miscommunications and inconsistencies between protocols and application rates in the different vineyards have made it clear that all sites must be under the control and the responsibility of one grant-paid person, not the manager of each vineyard. Next year, a project manager will be responsible for all treatment applications and sample collection.

Compost tea and disease suppression

Compost teas applied to Wren, Broadly Vineyards and Reeds and Reynolds vineyard contained similar levels of total bacterial biomass, active bacterial biomass, total fungal biomass, and active fungal biomass. Few of the teas contained the 10 micrograms of fungal biomass found to be sufficient for disease suppression in 2001.

When teas were applied to leaves, percent coverage of the leaf surface by bacteria increased significantly relative to pre-spray samples and unsprayed controls. Percent coverage by fungi did not increase relative to pre-spray samples or unsprayed controls, and very rarely reached the 2 - 5% level found to give effective disease control in 2001.

Leaf samples from R & R were not replicated due to miscommunications. In a sample taken on 11 July, 60% of the leaf surface was covered with organisms, mostly bacteria. A sample taken on 11 Sept. showed only 3% leaf surface coverage, probably due to the presence of a desiccant sprayed on 10 Sept. to control the powdery mildew fungus.

As in 2001, disease pressure was higher from powdery mildew (PM) than from botrytis. In 2002, the disease was first found at Wren on 25 July, in both the weekly and biweekly spray plots. The first application of fungicide was made on July 27. The fungicide was applied three more times in August. Due to the late frost this spring at the Wren vineyard, and reduced investment by the vineyard manager, the usual cultural practice of thinning vines had not been performed in the rows being sprayed with compost tea as of 31 July. On 5 September, the vineyard manager noted that most of the fruit on the vines sprayed biweekly had been lost to PM, but these rows were not scheduled to be harvested, because of the late frost.

At Broadly vineyard, PM was found on 19 July in the plot sprayed biweekly. On 23 July, the disease was found in both weekly and biweekly spray plots. Fungicide applications began on 23 July. On 8 August, PM was present in both treatment areas, but was more prevalent in the biweekly spray plots.

At the R & R vineyard, PM was first noted on 20 May in the CONVENTIONALLY-treated area. This area of the vineyard received seven applications of fungicide. On 16 July, PM was found in both plots sprayed with compost tea. This area received only one application of fungicide, on 23 July, followed by two applications of compost tea at twice the normal rate. These measures halted the progress of the PM outbreak in the tea-sprayed plots.

Changes in soil microorganisms

Soil samples taken from the Wren and Broadly vineyards in April 2001 were compared to those taken in April and May 2002 (Table 1). Total bacterial biomass did not change significantly, whereas active

bacterial biomass increased in both tea-sprayed plots and the control plots. Total fungal biomass decreased in the both the plots sprayed weekly with compost tea and in the control plots. Numbers of protozoa (flagellates, amoebae and ciliates) showed mixed trends, none of which were significant. The number of nematodes in the plots receiving biweekly tea sprays and in the control decreased significantly from 2001 to 2002, most of the decrease being in the plant-parasitic category.

Table 11. Soil microorganism biomass and numbers from Wren and Broadly vineyards (Means, with standard errors* in parentheses).

	Dry Weight of 1 gram Fresh Material	Active Bacterial Biomass ($\mu\text{g/g}$)	Total Bacterial Biomass ($\mu\text{g/g}$)	Active Fungal Biomass ($\mu\text{g/g}$)	Total Fungal Biomass ($\mu\text{g/g}$)	Hyphal Diameter (μm)	Flagellates	Protozoa Numbers/g	Amoebae	Ciliates	Total Nematode Numbers (#/g)
2001											
Biweekly Tea spray	0.76 (0.02)	14.4 (1.80)	192 (4.55)	14.8 (5.03)	136 (13.9)	2.58 (0.08)	6481 (2161)	1494 (627)	71 (29)	6.17 (1.73)	
Weekly Tea spray	0.77 (0.02)	9.05 (1.71)	196 (5.73)	19.2 (5.55)	174 (17.2)	2.67 (0.11)	2627 (826)	2308 (756)	89 (62)	2.30 (0.65)	
Conventional	0.76 (0.01)	16.9 (1.90)	155 (18.0)	64.7 (30.4)	713 (421)	3.92** (0.91)	13888 (9246)	10164 (7070)	134 (93)	7.12 (3.60)	
2002											
Biweekly Tea spray	0.82 (0.04)	56.1 (32.2)	180 (29.6)	12.1 (3.56)	75.0 (53.2)	2.50 (0.00)	33895 (33165)	10087 (6071)	20 (13)	0.53 (0.11)	
Weekly Tea spray	0.81 (0.03)	62.8 (32.3)	173 (41.5)	11.9 (2.62)	56.3 (35.8)	2.50 (0.00)	27560 (26825)	640 (95)	18 (18)	1.49 (1.34)	
Conventional	0.82 (0.02)	41.5 (20.4)	166 (19.3)	14.2 (2.30)	47.3 (31.4)	2.50 (0.00)	3025 (258)	16704 (16125)	45 (10)	1.64 (1.31)	

* In 2001, $n = 6$; in 2002, $n = 2$. ** One sample with an average fungal diameter of 8 micrometers was included.

Soil samples from the R & R vineyard were unreplicated. Between October 2001 and June 2002, total bacterial biomass tended to decrease. Total fungal biomass was lower in all plots in 2002, whereas active fungal biomass was higher in plots receiving weekly tea sprays.

In 2002, compost teas were produced using 100-gallon brewers from EPM Inc., of Cottage Grove, OR. Tea applications continued on the same vineyards as in 2001. The same treatment plots were used in 2002 as in 2001. Compost teas were applied weekly and biweekly to plots at each vineyard, and a third plot received conventional management practices. Applications began during the last week of April. The Wren vineyard received its last frost on May 8.

The project coordinator brewed and applied compost teas at these vineyards, located sources of compost, and worked to solve mechanical difficulties with brewers and sprayers. Between mid-May and mid-June, the EPM tea maker at Sunbow Farm was leaking and could not be used, so a tea maker manufactured by Compara International, Holland, was located and used. For two weeks in August, no teas were brewed due to difficulty obtaining compost that was suitable for the project. It was immediately after this two week period that mildew outbreaks occurred in the vineyard.

Application rates of compost tea varied occasionally from the standard of 25 gal/acre. At the R & R vineyard, two teas were sprayed at 50 gal/acre in a successful attempt to halt the progress of a mildew outbreak. At Broadly, three teas were applied at 38 gal/acre to both tea plots because the sprayer setting had been changed while the unit was being serviced.

During 2002, miscommunications occurred regarding sampling and consistency in applying compost tea treatments between vineyards. Communication was not maintained as well as expected. We have learned that the growers who are involved in the project must be willing to follow the experimental protocol, even if the crops in the treated areas are jeopardized. Irregularities due to mechanical problems and weather will always occur, but changes in management practices and treatments need to be controlled. In further studies, one single project manager should be solely responsible for making compost and applying teas, and collecting samples.

Micro-Brewer Experiment #1.

Using a prototype of the Micro-Brewer, the Soil Microbial Biomass Service at Oregon State University used compost provided by Ron Stewart of Columbia Gorge Organic Fruit Company. The classic study on the effects of improved soil diversity on plant production was performed by Ingham et al., 1985, but the entire literature is reviewed in Killham, 1994, Coleman and Crossley, 1995, Sylvia et al., 1998.

Microorganism biomass was assessed using direct methods. Both fungal and bacterial biomass were determined using fluorescent stains and UV epi-fluorescent microscopy or Differential Interference Microscopy (DIC). Diversity was assessed by morphological characteristics during direct microscopic examination and colony morphology on spread plates. Protozoan numbers and species diversity were determined from MPN plates; each well examined directly using DIC to allow identification to genus. Nematodes were identified following concentration of the tea using a 5 μm mesh size screen sieve, and identification to genus by direct examination using DIC.

In the brewer, the quantity of beneficial organisms was improved and pathogens were not found. The maximum bacterial, fungal, protozoan and nematode numbers occurred between 18 and 24 hours in the brewing cycle.

Grape Foliar Experiments. There are beneficial bacteria and fungi on leaf surfaces that protect plants from disease as well as produce and retain nutrients (Andrews, J.H. et al., 1991). The following data demonstrates that this protective biofilm inoculated onto a detached leaf surface by compost tea suppresses disease.

Table 12. Relation between leaf coverage and prevention of Botrytis on wine grapes.

% of grape leaf covered by tea bacteria	% of grape leaf challenged by <i>Botrytis cinerea</i>	Visual observation of grey mould growth on leaf surface
0% (No tea, water only)	70%	Visible growth of mold occupying 1/3 of leaf surface
10% tea	70%	One spot of mold, 1/2 inch in diameter
20% tea	70%	One spot of mold, 1/2 inch in diameter
30% tea	70%	Barely noticeable growth of mold, less than 1/4 inch in diameter
60% tea	70%	Barely noticeable growth of mold, less than 1/4 inch in diameter
90% tea	70%	Barely noticeable mycelial strands on surface, no visible colony growth
90% tea	0%	No Botrytis; No visible signs of disease on leaf

Territorial Seed Experiment, Summer 2000 – During the summer of 2000, tomato seedlings were grown in the greenhouse and planted in three fields in different areas of the upper Willamette Valley near Cottage Grove, OR. Four different treatments were applied to plots in these three fields:

- (1) Conventional practices,
- (2) A single foliar/soil drench immediately after planting,
- (3) Tomato planting tray soil soaked with tea before planting, and Foliar/soil drench at planting, foliar tea applied every 10 days to 2 weeks.

Tea was made using the standard Bacterial Tea recipe and using buffalo compost with a strong fungal component. Results from this work will be published in a scientific journal. However, several conclusions can be drawn from these results:

Using Good Compost is critical – Compost stored in a barrel and watered several days before use was tested, it was found to have become anaerobic based on active bacteria, total bacteria and protozoan analysis. The compost was tested two different times, and tea was made from that compost using an early-design Microb-Brewer. The tea produced contained very few organisms of any kind, because the compost contained few organisms of any kind. Leaf surfaces were tested for coverage by the beneficial organisms, and leaf surfaces were found to be not adequately covered – only 22 to 30% coverage. This is not adequate to exclude or inhibit disease-causing organisms from the leaf surfaces.

This demonstrates the importance of knowing that the compost contains the organisms needed, that the tea contains the organisms needed, as well as the leaves. When designing a testing scheme, it is probably most useful to test leaf organism coverage (Leaf Organism Assay). Results are returned from the lab within 24 hours, so you know whether you achieved adequate coverage or not. If coverage was not adequate, and if disease-organism spores or cells are dispersing, an immediate re-spray of better compost tea is indicated. You may also want to investigate where along the tea making process tea quality is being reduced. Is the compost good compost? Does it contain the organisms needed for the application you are using it for? This is bacteria and fungi for foliar sprays; bacteria, fungi, protozoa and nematodes for soil applications.

Seasonal Variation in Organism Activity on Leaves – Through the summer, leaf coverage was monitored in the Territorial Seed Company tomato trials. Following spraying of each tea, as documented by analysis of the compost, the organisms in the tea (good biomass of bacteria, fungi, protozoa and nematodes present in the tea produced by the Microb-Brewer) and the leaf surfaces (Leaf Organism Assay), leaf surfaces were monitored immediately, 24 hours and 48

hours after spraying. Results indicated that through the summer, survival of the organisms on the leaf surfaces varied with weather conditions. In cool, rainy weather, the organisms did not remain active on the leaf surfaces for more than 25 hours. During warm, dry weather, the organisms on the tomato leaves remained very active and increased in number.

More studies of organism survival on leaf surfaces need to be performed to indicate how often tea sprays need to be performed in different weather conditions. In warm, dry weather, sprays may only need to be done once every two to three weeks. In cool, rainy weather, stickers may need to be added to the tank to improve retention on leaves. It may be a good idea to assess combinations of dormant oils and teas, to see if combinations of this kind would improve growth on leaves during wet, cool periods. Addition of yucca (a product called Saponyl from Helena Chemical Company which does not contain preservatives) to tea in other trials appeared to improve organism survival on the leaf surface, as well as increase their ability to remain on the leaf surface through rainy conditions.

Potato Trials at Oregon State University

Potato field plots were established a number of years ago at the Oregon State University Lewis Brown Farm just outside Corvallis, OR. These plots were maintained by Dr. A. Mosely, Department of Agronomy, Oregon State University. A number of treatments were within the experimental design, but to three plots within the randomized design, compost tea was the only application made to the potato plants during the summer besides routine and standard irrigation water. Compost tea, made with a Microb-Brewer, and using the standard Bacterial Tea recipe, was applied every 10 to 14 days to three plots. Controls using standard conventional practices were maintained. Wilt inoculum (Dr. M. Powelson, Oregon State University) was applied to all plots during the late summer. The results of these trials will be published in scientific journals. However, several conclusions can be drawn from the trials.

Tea from Different Composts versus % Disease Suppression – The kind of compost used to make tea made a difference in level of disease-organism incidence on both leaves and tubers. The best reduction in foliar disease occurred when still-warm (100° F), moisture-maintained (54% moisture) compost was used. This compost contained highly active bacterial populations, which transferred to the tea and grew rapidly during the 20-hour tea brewing cycle. Fungal biomass, protozoa and nematode numbers were low in this tea, however. This tea was not effective at controlling tuber infection, based on no significant difference from the control tubers with 60% of tuber surfaces covered with disease-organism as assessed by visual surface inspection and confirmed by plating on PDA. However, the tea made from older, fully mature compost that was at ambient temperature, but also with good moisture levels (45%), was effective at controlling tuber disease-organisms levels (reduced to less than 3% of tubers with disease-organisms infecting their surfaces.) This mature compost tea had fewer active bacteria than the immature tea, but also contained good numbers of fungal biomass, protozoa and nematodes. This tea reduced the presence of foliar infection as well, but not quite as well as the immature compost tea.

It is important to recognize that the set of organisms in the tea can vary, and that this may influence the application for which the tea is best suited. The tea containing all the organisms would be more generally useful, but the tea with high bacterial activity was the most useful at reducing the presence of foliar disease-organisms on the leaf surfaces. Thus, for a foliar application, immature compost might be the best choice, while for a soil application, mature, more fungal dominated compost with higher numbers of protozoa and nematodes would be the better choice.

Glossary

Abiotic—Not biotic; not related to life or specific life conditions. Usually meaning physical or chemical factors, such as temperature, humidity, inorganic chemicals.

Aerobacter—A specific genus of bacteria, most of which are strictly aerobic bacteria.

Aerobe—Any organism requiring atmospheric concentrations of molecular oxygen as the final acceptor in metabolism.

Anaerobe—Any organism requiring reduced oxygen concentrations, or elevated carbon dioxide concentrations in order to be able to perform metabolic processes. Strict anaerobes typically are killed by even the slightest oxygen concentrations, while facultative anaerobes can function in both aerobic and anaerobic conditions, but use very different metabolic pathways depending on oxygen concentration.

Bacillus—A specific genus of bacteria, typically Gram-positive, rod-shaped, aerobic, spore-forming bacteria, often occurring in chainlike formations. Used generically, any rod-shaped, chain-forming bacterium.

Bacteria—Unicellular microorganisms, occurring in many forms, existing either as free-living organisms or as parasites, with a broad range of biochemical, often pathogenic properties.

Beneficial Organisms—Non-pathogenic life; often improving the growth of a desired organism in a more-or-less mutualistic association where both organisms benefit from the presence of the other.

Butyric Acid—A volatile organic acid produced through the incomplete anaerobic oxidation of organic matter, typically identified as sour milk smell.

Decomposition—The process of conversion of organic material from one form to another, generally with biomass production by the organism doing the decomposition, production of metabolic waste products and carbon dioxide.

Disease Suppression—The ability to inhibit, compete with, or consume disease-causing organisms preventing them from causing disease.

Exudates—Simple sugars, proteins, carbohydrates, hormones released by plants into the environment, typically for the express purpose of encouraging the growth of bacteria and fungi which form a biological shield around the plant, preventing disease-causing organisms from detecting the root.

Facultative Anaerobe—Organisms that can perform metabolism using either oxygen or inorganic molecules as the final electron acceptor in metabolism. These organisms generally switch from aerobic to anaerobic metabolism at low oxygen concentrations.

Fermentation—A specific group decomposition process that typically involves the production of carbon dioxide. Both aerobic and anaerobic processes can be included as fermentative process, although usually this term refers to anaerobic fermentation where alcohol is produced. Wine or beer fermentation, for example.

Fermentor—A vessel used for fermentation processes, such as making beer, wine. Broadly applied, any container in which metabolic processes are being performed.

Fulvic Acid—A particular fraction of complex humus material composed of medium molecular weight long-chain organic compounds, typically 2000 to 6000 dalton length chains. Of the recalcitrant humic materials, these can be used by bacteria. Turnover times may be 100 to 300 years in soil.

Fungi—Plants of the division Thallophyta, lacking chlorophyll, ranging in form from a single cell to a body mass of branched filamentous hyphae that often produce specialized fruiting bodies and including the yeasts, molds, smuts, and mushrooms.

Foodweb—The set of organism relationships, often based on who-eats-who, or which organisms cycle a particular nutrient within an ecological community.

Humic Acids—A particular fraction of complex humus, composed of extremely recalcitrant, high molecular weight, very long-chain organic compounds typically 6,000 to 600,000 daltons in lengths and highly structured in a three-dimensional manner. Very resistant to decomposition, and highly condensed. Turnover time in soil may be 300 to 3000 years.

Humics—The mixture of all recalcitrant, long-turnover time organic compounds in soil, includes both fulvic and humic fractions.

Metabolites—Organic compounds produced by metabolic processes.

Mycorrhizal Fungi—VAM are a set of mycorrhizal fungi that form arbuscules and vesicles within the roots of plants, while ectomycorrhizal fungi form a net, called the Hartig net, within the first one-to-two cell layers of feeder roots and send rhizomorphs along the root surface. Host ranges of row crops for VAM are quite broad; the important factor in understanding its choosing species of VAM is climate. When growing conifers, ectomycorrhizal fungal experts should be consulted.

Nematodes—Any of various worms of the phylum Nematoda having unsegmented threadlike bodies. There are four major functional groups in soil including bacterial-feeding, fungal-feeding,

predatory (eat other nematodes) and root-feeding.

Nutrient Cycling—A biogeochemical cycle; the process of conversion of organic and inorganic material from one form to another, generally with the production of biomass by the organism doing the cycling, production of metabolic waste products which serve as the next step in the nutrient cycle, and carbon dioxide.

Nutrient Retention—The opposite of leaching, extraction or loss of nutrients. The least mobile nutrients will nearly always be the organic forms, and the most mobile, or leachable, are the mineral forms. Retention requires nutrients to be physically immobilized by inclusion in organic matter (in organisms or organism waste-products such as bacteria, fungi, plants or plant detritus) or by chemically binding on the surface of clay, sands, silts or organic matter.

Organism—A plant or animal; a system regarded as analogous to a living body.

Phenols—A benzene carbon ring structure with hydroxyl groups at various positions attached to the carbons in the ring, typically resistant to enzyme attack and therefore considered relatively resistant to decomposition. Many phenols have antibiotic or toxic capabilities.

Predator—An organism that consumes other living organisms, as opposed to a decomposer, for example, which consumes dead plant material, a primary producer that uses sunlight for energy.

Prey—An organism that is eaten by a predator.

Protozoa—A group of single-celled animals whose major prey group is bacteria. The three major groups of protozoa that occur in soil are the flagellates, the amoebae, and the ciliates. Amoebae can be separated into naked amoebae, and testate amoebae. Because bacteria contain much more N per unit C, N is released as ammonium, a plant available form of N.

Pseudomonas—A genus of bacteria, some species in this genus are plant-pathogens while some are extremely beneficial to the growth of some plants. Taxonomic revision of this group of species is underway.

Soil Aggregation—Soil particles (sand, silt, clay parent material) are bound together through the actions of microorganisms, and the space between these particles formed through the bonding action, and by the larger faunal organisms in soil. The more aggregated the soil, in both small and larger ped structures, determines in part how water, roots and nutrients will be held by that soil.

Soluble—Capable of being dissolved in water; in solution.

Strict Anaerobe—Organisms that performs metabolism using oxidized forms of nutrients (carbon dioxide, nitrate, nitrite, sulfate, sulfite, etc.) as the final electron acceptor in metabolism. Strict anaerobes will be destroyed when they come in contact with di-oxygen, or ozone, as their membrane structure is broken down by these compounds.

Valeric Acid—A volatile organic acid produced through the incomplete anaerobic oxidation of organic matter, typically identified as a vomit smell.

Vortex Nozzle—Used in the Microb-Brewer, the Vortex Nozzle creates a high velocity atomization of tea and air within the chamber of the nozzle.

Recent Literature and Resources

by Steve Diver (reprinted by permission)

Compost Tea Brewing Manual. 2000. By Elaine R. Ingham. Soil Foodweb, Inc., Corvallis, OR. 60 pages.

<http://www.soilfoodweb.com/multimedia/compostteamanual.html>

I highly recommend this manual to anybody who plans to make and use compost teas. Written by Dr. Elaine Ingham, it provides a practical summary of compost teas underpinned with a scientific understanding of applied microbiology, including: how to use compost teas; factors affecting compost tea quality; beneficial organisms; compost tea production methods; application methods; matching compost teas to plants and soils; bacterial vs. fungal dominated compost teas; compost tea recipes; microbial food resources for different micro-organism groups; and experimental results.

Organic Farming Research Foundation

Information Bulletin No. 9, Winter 2001

<http://www.ofrf.org/publications/news/ib9.pdf>

The Winter 2001 issue contains a special report on OFRF-funded compost tea research, pages 8-20. This is a 1,896K PDF file, so be patient waiting for it to download. Included among the items in the compost tea issue is "Benefits of Compost Tea: A Review of the Research Literature." It lists 53 citations, but the full report—see below—contains 88 references in total. Other items include: "Apparatus and Experimental Protocol for Organic Compost Teas", which describes and illustrates a homemade on-farm compost tea brewer; and "Effectiveness of Compost Tea Extracts as Disease Suppressants in Fresh Market Crops," which describes looked at the effectiveness on compost teas to suppress diseases on strawberries, lettuce, leeks, and broccoli in British Columbia.

Effectiveness of Compost Extracts as Disease Suppressants in Fresh Market Crops in British Columbia

Sylvia Welke, OFRF Grant Report 99-31

<http://www.ofrf.org/publications/Grant%20reports/99Spr.1of11.Welke99-31.IB9.pdf>

The full OFRF report reviewed above; a 10-page PDF download.

Organic Teas from Composts and Manures

Richard Merrill, OFRF Grant Report 97-40

<http://www.ofrf.org/publications/Grant%20reports/97Fall.1of5a.Merrill97-40.IB9.pdf>

The full OFRF report reviewed above; a 51-page PDF download, with 88 literature references in the bibliography, "Selected References for Organic Tea Extract Studies."

Compost Tea for Organic Farming and Gardening.

By William Quarles. The IPM Practitioner.

Vol. 23, No. 9 (September). p. 1-8.

The September 2001 issue of *The IPM Practitioner*—the monthly journal from Bio-Integral Resource Center—featured compost teas. An 8-page reprint is available for \$7.50 total

through:

Bio-Integral Resource Center (BIRC)

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birc@ige.org <http://www.birc.org>

Investigations into Liquid Compost Extracts ("Teas") for the Control of Plant Pathogenic Fungi

By William F. Brinton and Andreas Trankner, a

BioCycle conference paper http://www.woodsand.org/compost_tea.pdf

A 12-page PDF download, featuring the work of Dr. William Brinton of Woods End Research

Laboratory in Maine.

Compost Practices for Control of Grape Powdery Mildew (*Ucnula necator*)

By Andreas Trankner and William F. Brinton, a *Biodynamic* journal reprint

<http://www.woodsand.org/will2.pdf>

An 8-page PDF download, featuring the work of Dr. William Brinton of Woods End Research

Laboratory in Maine.

Compost Microbiology

Compost Microbiology and the Soil Food Web

California Integrated Waste Management Board

<http://www.ciwm.ca.gov/publications/default.asp?pubid=857>

<http://www.ciwm.ca.gov/publications/Organics/44200013.doc>

6-page MS-Word download

Dr. Elaine Ingham: The Soil Foodweb & Compost Teas

The Soil Foodweb

By Elaine Ingham

<http://www.soilfoodweb.com/>

Soil Foodweb Information

The Soil Foodweb Structure

Foodweb "Funtions" in a Living Soil: The Benefits to Plants and Soils

Soil Organisms: Why are they important?

By Elaine Ingham; article reprint at *Compara.nl*

http://www.compara.nl/soil_organisms.htm

The Soil Foodweb: It's Importance in Ecosystem Health

By Dr. Elaine Ingham; article reprint at *Don't Panic eat Organic*

<http://www.rain.org/~sals/ingham.html>

Dr. Ingham's Monthly E-Zine

<http://www.soilfoodweb.com/ezinearchives/>

Note: The SFI E-Zine is a great place to keep up with Dr. Elaine Ingham's latest comments and notes on compost teas.

Anaerobic Bacteria and Compost Tea

By Elaine Ingham, a *BioCycle* article reprint

<http://www.soilfoodweb.com/anaerobic.html>

Brewing Compost Tea

by Elaine R. Ingham, *Kitchen Gardener* magazine

<http://www.taunton.com/finegardening/pages/g00030.asp>

A Recipe for Tea: Start with a Good Compost

By Geraldine Warner, *The GoodFruit Grower*, March 2001

<http://www.goodfruit.com/archive/Mar1-01/feature8.html>

Content: Review of fungal dominated compost practices & compost teas from Elaine Ingham

Web Resource Collections on Soil Biology

Sustainable Soil Management: Web Links to Make Your Worms Happy!

Steve Diver, ATTRA

<http://ncatark.uark.edu/~steved/soil-links.html>

Content: Web resource list from ATTRA

Soil Biology Information Resources For Land Managers, Resource Professionals, and Educators

<http://www.statlab.iastate.edu/survey/SQSBinfo.htm>

Content: Web resource list from NRCS-Soil Quality Institute

Compost and Disease Suppression

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Compiled by Chloe Ringer, 1998

USDA Soil Microbial Lab, Beltsville, MD

<http://ncatark.uark.edu/~steved/compost-disease-biblio.html>

Disease Suppressive Potting Mixes, ATTRA

<http://www.attra.org/attra-pub/dspotmix.html>

Sustainable Management of Soil-borne Plant Disease, ATTRA

<http://www.attra.org/attra-pub/soilborne.html>

Suppressing Plant Diseases with Compost

By David Granatstein; The Compost Connection for Washington Agriculture

October 1997, No.5 <http://csanr.wsu.edu/compost/newsletter/compcos5.html>

On-Farm Composting: Plant Disease Control / On-Farm Composting - A Review of the Literature

Alberta Agriculture, Food and Rural Development

<http://www.agric.gov.ab.ca/sustain/compost/plantdisease.html>

Composts for Disease Suppression

UConn Integrated Pest Management

<http://www.hort.uconn.edu/ipm/general/htmls/composts.htm>

Microbial Ecology of Compost-Induced Disease Suppression

Eric Nelson et al; Proceedings of the 5th International PGPR Workshop

<http://www.ag.auburn.edu/argentina/pdfmanuscripts/nelson.pdf>

Disease Suppressive Compost as an Alternative to Methyl Bromide

Methyl Bromide Alternative Case Study, EPA 430-R-97-030

10 Case Studies, Volume 3, September 1997

<http://www.epa.gov/spdpublic/mbr/compost3.html>

Compost Teas: Regional Reports

Compost Tea Trials Final Report

Submitted to Office of Environmental Management, City of Seattle.

By Cascadia Consulting Group, March 8, 2001

<http://www.cityofseattle.net/environment/Documents/Final%20Compst%20Tea%20report.pdf>

A 53-page PDF download

Alternatives for Use & Management of "Compost Tea"

Clean Washington Center

<http://cwc.org/organics/cm002.htm>

Evaluation and Prioritization of Compost Facility Runoff Management Methods

http://cwc.org/organics/organic_htms/cm002rpt.htm

<http://cwc.org/organics/org002rpt.pdf>

53-page PDF download. Report addresses the reuse of a pasteurized compost leachate from city zoo for use as a "tea" to fertilize crops. The liquid plant food, a compost tea product called *Zoo Broo*, will be marketed along with the zoo's other compost product, *Zoo Doo*.

Evaluation of Compost "Tea" for Reuse Opportunities (1997 & 1998)

Clean Washington Center

<http://cwc.org/organics/cm981.htm>

Evaluation of Compost Facility Runoff for Beneficial Reuse, Phase 2

http://cwc.org/organics/organic_htms/cm981rpt.htm

<http://www.cwc.org/organics/org981rpt.pdf>

39-page PDF download. Phase 2 report on compost leachate reuse.

Compost Teas: Research Reports

Response of *Alternaria* spp. Blight and *Septoria* spp. Leaf Spot to Biological Disease Control

Agents in Tomatoes

Jeremy Barker Plotkin; OFRF on-farm research report <http://www.ofrf.org/scoar/plotkin.PDF>

Compost Cures All

By James Saper, (from

Sustainable Farming Magazine, Summer 1997, Vol. 7 No. 3)

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Carl Rosato; OFRF on-farm research report

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Paul Vossen and Doug Gubler; reprint from *UC Plant Protection Quarterly*

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University Research

Midwest BioSystems, Tampico, IL

<http://www.aeromasterequipment.com/research.html>

Compost Tea and Blossom Brown Rot

Washington State University

<http://septs.washington.edu/mulch/research/>

Compost Teas: The Worm Digest Quarterly

A Homemade Compost Tea Brewer

By S. Zorba Frankel

<http://www.wormdigest.org/articles/index.cgi?read=66>

Compost Teas: Brewing a Sweet Blend

By Kelly Slocum

<http://www.wormdigest.org/articles/index.cgi?read=65>

Compost Teas: Complementary ATTRA Resources

Compost Teas for Plant Disease Control

The 1998 ATTRA publication

<http://www.attra.org/attra-pub/comptea.html>

Compost Teas: A Tool for Rhizosphere-Phyllosphere Agriculture

[One slide per page — view on screen format; PPT.pdf = 4234K]

<http://ncatark.ark.edu/~stevcd/compost-tea-view.pdf>

Compost Teas: A Tool for Rhizosphere-Phyllosphere Agriculture

[Six slides per page — print for quick reference format; PPT.pdf = 1303K]

<http://ncatark.ark.edu/~stevcd/compost-tea-print.pdf>

The History of Compost Tea

Compost tea has been with us in some form since the Roman Empire (Cato, De Agricultura), and most likely, even earlier than that. The recipe and machinery used to produce tea, initially a big vat aerated by stirring the liquid occasionally, has changed through the years, however.

Historically, growers made compost tea, manure tea and plant teas - or tinctures - in various ways. Biodynamic growers have been using the "low tech" approach since Steiner recommended its use. Many of the BD preps he described are specifically for use in stirred teas. Making manure tea is a common practice in Biodynamics. Steiner's descriptions of tea making suggest using additives in low concentrations, most likely so that the tea does not go anaerobic, but brews often go through an anaerobic phase if growers are not careful, or brew when temperatures are too warm.

Once anaerobic, the tea needs to be brewed until the liquid returns to the aerobic phase. Thus, making tea can take weeks. While an aerobic-to-anaerobic-and-back-again tea can have quite useful effects, production takes too long for most growers, and can be fraught with problems if the products of anaerobic metabolism are not taken care of before use on plants.

Robert Catesano of CCOF (California Committee on Organic Farming) began the movement toward more hi-tech methods of brewing by adding air pumps and dripping the tea through the compost. But brewing methods remained fairly low-tech - dump some stuff in water and let it sit with only a few stirs - until the early 1990's when Karl Rubenberger started a revolution in the tea-making industry.

When Karl Rubenberger brought his hi-tech compost tea brewing machine to Dr. Elaine Ingham at Oregon State University in 1993, Dr. Ingham wanted to know why making tea in this way would be useful. And the collaboration between Rubenberger and Ingham began.

Dr. Ingham's career has been devoted to studying the biology in soil, compost and compost tea. Her professional career has been focused on learning about the "soil food web" which is the complex web of bacteria, fungi, protozoa, nematodes, microarthropods, earthworms and other soil critters that work together to feed plants, fight pathogens and pests, and improve soil structure.

This research is yielding some fascinating information. Different plants require different sets of organisms in the soil. Select for the plant you want by making certain the organisms in the soil support the needs of that plant. Once you have the right balance for the plant you want, you can maintain its growth and maximize productivity by building the soil and improving life in that soil. Weeds, brassicas, and early successional grass species grow best in soils dominated by bacterial biomass (there are fungi in bacterial-dominated soil, just more bacteria than fungi). Old-growth forests are at the other end of the scale, dominated by fungal biomass. There may actually be more bacteria in a fungal-dominated soil than in earlier stage of succession, but the fungi have even greater biomass than the bacteria in perennial systems. Most flowers and vegetables grow best in soils that have balanced bacterial and fungal biomass.

Compost and compost tea can be used to improve the soil and foliar life required to protect plants from the diseases that abound in pesticide and fertilizer degraded ecosystems. The most productive soils in the world are those with the most organic matter mixed through the surface soil horizons. This wealth of organic matter is used by beneficial bacteria, fungi, protozoa, nematodes and microarthropods to build soil structure.

Compost and compost teas need to be produced in oxygen-rich, aerobic environments. This ensures that the finished product is rich in nutrients and beneficial organisms. When compost (or compost tea) is made in anaerobic conditions, nutrients are lost to the atmosphere (which is why anaerobic compost stinks). The end product of anaerobic decomposition may also contain alcohol, phenols, organic acids and proteins that are toxic to plant tissues.

Compost tea applied to the foliage of plants increases the biological activity on the leaf surface layer, which increases the length of time the plant stomates are open. This increases the opportunity for nutrient uptake, which improves growth and boosts yields. When leaf surfaces are coated with a layer of beneficial bacteria and fungi, they are protected from disease-causing bacteria and fungi.

In 1996, Karl Rubenberger turned over production of his tea machine to a manufacturer, and commercial production of highly aerobic, 24-hour compost tea machines began. The original machine tested at OSU produced a water vortex to pull the organisms out of the compost, and had no pipes on the bottom of the machine. When bio-film developed, it could be seen easily and cleaned. But when the manufacturer decided the machine needed to look more professional, the machine was re-plumbed with solid PVC pipe material to replace the plastic tubing. These pipes could not be easily removed or cleaned.

After this change, teas began to arrive at Soil Foodweb Inc. with reduced fungal biomass, and the reason for the low activity and biomass could not be determined. The manufacturer blamed Soil Foodweb Inc for the problem, saying that the lab did not know what they were doing, and that the SFI methods were not reliable.

But the teas did not perform in the field the way they were expected to perform, so SFI kept trying to determine the reason for the lack of acceptable sets of organisms in the teas. Eventually, it was determined that thick, smelly, anaerobic bio-films developed in the pipes that had replaced the plastic tubing. The anaerobic products harmed the organisms, especially fungi which cannot tolerate anaerobic conditions and cannot compete with most anaerobic bacterial species.

The solution was simple: replace the solid pipes with plastic tubing, so when biofilm developed, it could be seen and removed by cleaning. Cleaning was made easier by easy-release connections, and the problem was solved.

The manufacturer of the Microb-Brewer decided to no longer make the Microb-Brewer, as the reputation of the Microb-Brewer had been harmed by the problems with the pipes. The new system that was developed had serious drawbacks, with bio-film formation and anaerobic conditions developing in the machine. The machine did not result in tea with decent fungal biomass, and again, SFI was blamed. The claim was made that fungi did not grow in tea, that SFI was just interested in making money because of the insistence that tea machines be tested, and finally, it was claimed that SFI testing was questionable. The bacteria, fungi, protozoa and nematodes are the reasons compost tea is beneficial to plant growth. If the tea contains no organisms, and the main benefit of tea is just the nutrients extracted, then it is easier to buy liquid organic materials. There is no need to brew for 24 hours to just extract nutrients from compost.

But compost tea is, of course, more than the soluble nutrients. Compost tea includes the whole set of organisms extracted from good compost, and specifically the beneficial organisms that grow in aerobic conditions.

Other people started to build good compost tea machines by 1998. Bruce Elliott, of EPM, put together and tested in a complete and thorough fashion, a 500 gallon machine. Many different food resources were tested, and a reliable, consistent, excellent fungal tea machine was made. With time, EPM has made 100 and 22 gallon machines, each one tested to make certain it produces tea with excellent levels of organisms. These machines pull the biology, and the soluble nutrients, from the composts used. The nutrient mixes developed for these machines enhance the beneficial organisms in the compost. While these machines use pumps through which the tea passes, a great deal of testing has been done to make certain the pumps are not harmful to the organisms.

In 1999, the Dutch company, Compara, built a tea brewer based on tube diffuser designs. A simple and easy-to-clean machine, the Compara Extractor is used through most of Europe for commercial compost tea production.

Leon Hussey was the next to develop a tea machine that works well, maintaining aeration and excellent organism growth in the tea. The 5 gallon "Keep-It-Simple" machine makes excellent tea in 12 hours. It is nearly impossible to overwhelm this tea machine with too much food resource, and as a result, *E. coli* will almost never grow in the tea. Only a combination of high foods and really poor compost will result in the tea having *E. coli* above acceptable levels. The Simpli-tea company which makes the KIS brewers, has added a 30 gallon machine. These machines use air bubblers to produce the tea, blowing air into the tea, which causes mixing through the compost, with adequate extraction of the organisms and foods from the compost.

The James Sottilo - Charlie Clarke machines were next on the market. These machines use tubes with outer liners of plastic with fine holes in it, through which the air is blown. The movement of air through the water column also mixes the water through the compost. These machines have been tested, and if the compost used contains the needed life, results in excellent organism production and growth.

The next tea brewer produced was by the Compost Tea Company in New Zealand, which has developed an industrial strength brewer for that country. Excellent results are typically seen using this large-scale air bubbler type brewer. Aeration is maintained by a variable speed blower that can be tied to the actual concentration of oxygen in the tea.

Compost Solutions in Coffs Harbour, New South Wales, Australia has also developed a good tea brewer, based on swirling air through the water, and moving the compost bag continuously through the first few hours of the brewing cycle. Nutri-Tech, and Tryton, in Lismore, New South Wales, and several other growers in Australia have built tea makers, which are undergoing testing at this time.

Dennis Hronek designed a compost tea extraction unit, which extracts the organisms from the compost very efficiently, and then grows the organisms while they are on the way to your field. The extractor units are amazing in their ability to remove the organisms from the compost without requiring a growth period.

Other compost tea making machines undergoing testing at this time are listed in the Contacts section. It is clear that the success of compost tea is engendering a great deal of interest, and commercial activity.

The lessons learned in these first few years of aerobic, highly consistent, 24-hour tea brews is that the machines have to be tested and proven to stay aerobic in order to produce tea containing aerobic organisms in high numbers and high diversity, with no toxic anaerobic materials produced.

In order to do this, machines have to be documented, in more than one run (means and standard deviations have to be given, or multiple runs with data from all runs shown), to remain aerobic, and to have adequate levels of active bacterial biomass, total bacterial biomass, active fungal biomass, total fungal biomass, flagellates, amoebae, ciliates and beneficial nematodes.

Without this documentation of consistent beneficial organism growth in the tea, machines calling themselves compost tea makers should be viewed with extreme skepticism. Anaerobic conditions in the tea will result in the loss of the beneficial fungi, followed then by loss of flagellates and amoebae. High ciliate numbers are indicative of the use of a poor compost. With loss of aerobic organisms resulting from anaerobic conditions, human pathogens cannot be prevented from growing in the tea.

If an anaerobic tea is held for longer than 24 hours, and oxygen allowed to diffuse back into the water over the course of several days to weeks, then the detrimental conditions can be alleviated. But it can take weeks to out-compete the human pathogens and decompose toxins produced during the anaerobic period.

Can "brought-back" tea be beneficial? Yes, if the bacteria now growing in the tea are quite beneficial species. The likelihood that the beneficial fungi will still be present, and be growing, is just about nil, however. Control of many foliar fungal pathogens will be difficult, because the beneficial fungi that protect the plants from those pathogens will have been lost.

Bacterial tea cannot be expected to give the benefits that a true compost tea gives, and buyers must be aware of the differences. Any compost tea machine must be able to substantiate that all of the organisms in the compost are extracted into the tea by that machine. If the compost has good organism numbers and diversity, those organisms will be extracted into the tea by compost tea machines. If the machine is not capable of extracting the organisms, then it is not a compost tea machine, and should not be called such.

Once growers are certain that the machine they have is capable of extracting the organisms, and will allow those organisms to survive (e.g., the tea stays aerobic), then the additives need to be assessed. Commercial machines should have data for their machines, and the grower should be able to achieve

good results (e.g., good active bacteria, active fungi, total bacteria and total fungi) the very first time they use a commercial tea brewer with its nutrient starter mix.

SFI tests teas made by growers using commercial tea machines. If the reports on the SFI website show that growers cannot obtain decent organism numbers using the directions the tea machine maker gives them, then that machine should be considered too risky to buy. Hype is something all growers have to learn to detect, and anyone offering a product without any solid data to back-up their claims will always let the grower down when the machine does not perform as promised. Talk to other growers about tea machines.

Good places to obtain information about making compost tea, the equipment needed to apply tea, foods that can be used in making compost tea, etc. are: compost_tea@yahoo.com (there's an underline between compost and tea in the name), and www.infctc.org

Over the next few years, Soil Foodweb Inc will continue to do research investigating the growth of different kinds of bacteria, fungi, protozoa and nematodes in soil, compost and compost tea. What are the conditions that allow different plant species to grow better than any other plant? How do you know that the conditions in your soil will give the best yields, the highest flavor, the best color and longest storage times? Which beneficial organisms are the best at protecting the plant from disease, or pests? All these issues have to be understood, and SFI is committed to investigate those issues. We want to supply the best, and least expensive, answers for all growers, no matter where they are in the world. A big order, but one we'll do our best to achieve, with your help.

Good brewing!

Elaine R. Ingham

"Hope is not a feeling. It is not the belief that things will turn out well, but the conviction that what we are doing makes sense, no matter how things turn out."
— Vaclav Havel, former President of the Czech Republic

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