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Compost Teas: Microbial Hygiene and Quality In Relation to Method of Preparation

W. Brinton, P. Storms, E. Evans, and J. Hill*
Woods End Research Laboratory

Introduction

There has been a considerable amount of debate about compost teas since we first published a review paper from our European work in this journal (*BIODYNAMICS* 1995). At that time, little or no significant research had appeared in the United States, or was confined to the efforts of small growers who were not widely recognized. Biodynamic growers have always prepared extracts and teas to some extent, such as comfrey tea, or steepages of biodynamic preparations, applied as soil sprays, root dips, or to composts. With the earlier article, we sought to focus attention on the preparation of extracts, popularly called "teas," from mature composts, possibly containing some manures, and steeped non-mechanically for several days, which are then applied in undiluted extracts to plant surfaces to effect some measure of disease control (Brinton 1995; Brinton et al. 1996).

A significant basis for this effort was our laboratory partnership in Bonn, Germany with A. Tränkner, a colleague of H. Weltzien, whose pioneering work at Friedrich-Wilhelm University on compost extracts first appeared in the English-speaking world in the late 1980s, and which may have triggered the growth of compost tea research here. Even so, the effort dates to Weltzien's own early interest in soil suppression of plant diseases (Weltzien 1963). In 1986, Weltzien presented some of his findings on compost extracts at the International IFOAM conference held at University of California, Santa Cruz. At this same event we presented some of our own work concerning how to make quality potting

mixes from composts (Brinton and Tresemer 1986). Weltzien is no stranger to the U.S. and has been a frequent visitor in the Dakotas where he and his wife have worked on projects with Native Americans. Somewhere in this time frame is possibly when the American developments with compost extracts began. Weltzien and his colleagues and numerous German doctoral candidates, have presented a variety of findings in publications and journals worldwide since that time (see Weltzien list in references).

The changes and in many cases apparent distortions of Weltzien's early work that took place since then in the U.S. are difficult to trace clearly. These changes led ultimately to a crisis point this past year with the formation of a national Task Force convened under the direction of the USDA, called the NOSB Task Force on Compost Teas, whose report recently appeared (USDA-GOV 2004). Reports of odorous teas, teas apparently containing *E. coli,* and general public concern about risk of contamination of food crops by live bacterial cultures, were the root causes for the formation of the Task Force. Several investigations of compost teas were undertaken in a short period (Bess et al 2002; Duffy et al 2004; Millner et al. 2003). These studies and our own reported herein were mostly conducted to determine whether compost teas could be unsafe in terms of bacteriologic risks, especially as regards *E. coli*. Clearly the early work of Weltzien and our own work with Tränkner focused on efficacy studies in the field with varying crop pathogen systems; in other words, showing how and under what circumstances quality composts could be prepared and used to control plant fungal diseases. The current situation largely eclipses this beneficial approach with bacterial concerns. This is not surprising, since the concerns about foodborne bacterial poisoning have forced themselves into the forefront, and are likely to be with us for some time (Mead et al. 1999). Organic and biodynamic growers who use these practices must now exert new attention toward hygienic management and potential consumer impact.

One of the reasons to perform an independent compost tea study was to attempt to discern if the more recent emphasis in the US on mechanically aerated, "brewed" teas had any advantages. The proponents of these new approaches advocate, among other actions, a drastic shortening of the European approach to the brew phase to as little as twelve to twenty-four hours, which seems more convenient, plus the addition of molasses and other adjuvants to enhance and raise bacterial counts to very high levels, which might result in more disease control. Further, some of these approaches emphasize various ratios of microbes in the brews, allegedly based on the concept of improving biodiversity of soils and treated plant surfaces.

A drawback to these new approaches is the apparent backlash against traditional European methods. Workers who had focused for years on the scientific, yet field-oriented European approaches to brewing teas found that these methods were suddenly being labeled "anaerobic" in the U.S. or that the teas thus produced possessed incorrect "bacterial-fungal ratios", a topic rarely if ever discussed in the original German research, and also not supported by scientific literature in the U.S. Had something been overlooked? Were some teas now dangerous? Or was this similar to the debate regarding aerobic versus anaerobic composting that spread across America in the late 1980s and early 1990s. In that school of thought, proper "aerobic" composts were felt to require the turning of piles as often as three times a day, up to thirty times in the life of a compost pile. Any grower not so doing was held to have a condition that was "anaerobic." This controversy led in part to several studies on pile turning versus compost quality. The USDA funded one such study, and an excerpt of it was published in this journal (Brinton 1997). There was no scientific basis to conclude that the enhanced turning promoted an extra aerobic state or significantly improved compost quality – in fact, more turning resulted in significantly increased losses of nitrogen and organic matter. A similar study supported by Agriculture Canada reached the same conclusions (Jobin et al 1993). Thus, the research team felt there was a chance that we would not be able to support scientifically the new claims and charges being made with the new tea methods.

In our compost tea project we partly wished to compare the European versus the newer US approach, and further, to confirm if *E. coli* could become a problem in either or both systems. Our work with compost indicated that many immature composts are available on the market, with little or no quality testing behind them. We wanted to compare the European approach, in which mature compost is steeped in a barrel of water with gentle stirring over days, to modern technological approaches involving mechanical extractors and added agents as provided by "tea equipment companies." The attraction of the latter is that anyone can buy a piece of equipment along with the compost and the inoculant to make suitable compost tea. One participant in our study team represented a large national distributor of garden care products. Their view was that once someone bought such equipment (which possibly their company would sell), then they most likely would revert to using their own composts and additives rather than keep buying the needed ingredients. Thus, we also wanted to test these purchased compost units by substituting our own farm-made compost, with and without using the commercial additives.

We split tea production so that an independent party was also manufacturing the teas for our study using instructions provided with the equipment.

The resulting objective in this tea study focused mostly on convenience and consumer safety. Unfortunately, whether the tea produced is efficacious or not against plant disease was not evaluated. We would refer readers to the many published papers and grower reports, to get a sense of the practice and results.

To summarize, in this study our goals were:

a) to evaluate whether two of the commercially available compost tea brewing systems could present a potential pathogen risk to consumers when using them at home as directed, and as modified by using compost readily at hand;
b) to measure normal and expected bacterial (including *E. coli*) and fungal growth and die-off in various teas by monitoring aerobic plate counts, anaerobic plate counts and fungal plate counts in the commercial and other teas;
c) to compare the effects of mechanical aeration (commercial systems) or lack of aeration ("European" system) on the four microbiological parameters listed above and upon the actual percentage of dissolved oxygen in the tea.

For the study a commercial research strain of *E. coli* (American Type Culture Collection source) was used as the source for inoculated indicator organisms, as a test for possible pathogen reproduction. The most probable number (MPN) of *E. coli* at zero hours, twenty-four hours and seventy-two hours was studied in the assembled teas and their ingredients (compost and nutrient additives), and the water used in their formulation. We also conducted side tests making comfrey teas indoors and outdoors, as is practiced in gardening. We also see the need to perform future tests for biodynamic preparation 500, which may be considered a form of "compost tea" and also the similar horn-manure extracts.

Materials and methods

Tea Preparation (A-F)

A-Two commercial tea extraction units ("s-1" and "s-2") were provided by the manufacturers for the project, and were represented as current, best-available technology as of June 1, 2003. The units were set up for compost tea extractions according to product directions provided with the equipment. Both commercial products provide with the unit a standard compost (unknown source) plus a "nutrient" source that is added when the compost is placed into the unit with water. One manufacturer included a newer nutrient formulation that lacks molasses (This modification was presumably based on recent information, because the use of molasses is now understood to promote excessively rapid colonization of possibly pathenogenic microorganisms in brews). Both units are designed to provide constant bubbling aeration for up to twenty-four hours, employing differing modes of action. One unit sucks air from the top and expresses it into the solution through a central rapid-whirling mixer; the other unit forces air to the bottom of the unit and bubbles it upward via holes in a circular ring.

B: In addition to commercial units, a European method was established based on Brinton's review of prevailing practice (Brinton Report to Compost Tea Task Force 2003). This employed no additives other than stable compost, and was prepared without aeration equipment by once daily stirring in loosely covered vessels.

C: Time-0 sub-samples of each compost tea were taken immediately after the start of the trial by on-site sampling of the slurry into sterile containers, which were immediately refrigerated. At twenty-four hours, the teas were all resampled (Time-24 samples) and together with the refrigerated Time-0 sample, taken into the lab and microbiological tests commenced immediately. At forty-eight hours (or seventy-two hours from set-up), the laboratory staff resampled and analyzed the remaining tea, which had been stored, loosely covered, at room temperature in the lab. The purpose of this was to assess degradation after termination of aeration. Aeration of these teas only occurred during the first twenty-four hours after their preparation.

D: The same set-up and handling processes were repeated the following week after inoculating the teas on-site at day zero with 1 ml 10^8 *E. coli* in TSB (made to the turbidity of 0.5 McFarland standard).

E: The following week, a third trial was initiated as before, for the two s-1 and s-2 units, by substituting an immature compost from Woods End lab's recent archive instead of the compost that was shipped with the product. This was to partly fulfill objective (b) of our stated goal, i.e., to evaluate a scenario in which a homeowner would use their own compost instead of constantly re-purchasing the compost plus nutrients from the manufacturers of the tea equipment.

F: In the lab, five European-style compost teas were set using a 5:1 (volume) water to compost proportion (one was actually comfrey tea). Three composts were mature and two were immature (using the Solvita®Maturity Test ranking)(Changa et al. 2003). One-gallon batches were prepared. As noted in (b) above the European method uses neither supplemental aeration nor added nutrients, but does involve stirring once each day.

G: In the lab, the nutrients and the composts for s1 and s2

were mixed separately with sterile Phosphate Buffered Water in the same ratio as the compost teas. These were also analyzed separately after zero, forty-eight, and seventy-two hours.

H: The on-site water and the laboratory water, as well as the immature composts and the mature composts, were all initially tested for the presence of *E.coli*.

Microbiological Tests:

Sample-groups A-E above were analyzed for:

1) *E. coli* using 3 tube MPN at dilutions 10^{-1}–10^{-4} starting with LST Broth and finishing with EC+MUG Broth as in Standard Methods #9221F.
2) Aerobic bacterial levels (Aerobic Plate Count) using pour plates at five serial dilutions (with Phosphate Buffered Water) ranging from -1 to -16 with Standard Plate Count Agar (Difco) and incubated at 35˚ C for forty-eight hours.
3) Anaerobic bacterial levels (Anaerobic Plate Count) using pour plates at five serial dilutions with Phosphate Buffered Water ranging from -1 to -14 with Anaerobic Agar (Difco) incubated at 35˚ C for forty-eight hours in anaerobic chambers using Oxoid Anaerobic Indicators and MGC AnaeroPack-Anaero to guarantee and monitor lack of oxygen.
4) Total viable fungi – including yeast (Fungal Plate Count) – using pour plates at serial dilutions with Phosphate Buffered Water ranging from -2 to -10, made with Malt Extract Agar (Sigma) with added Streptomycin sulfate (100 mg/L MEA) incubated at 25˚ C for 120 hours. For samples that received added *E. coli,* the bacterial levels sometimes exceeded the ability of the Streptomycin to inhibit them. This created the possibility that fungal plate counts similar to aerobic plate counts might be reflecting the *E.coli* and not yeasts.

Sample group F was only tested for *E.coli*. A three-tube three-row MPN was set using the same media (double strength in row 1) as in No. (1) above.

Results

About presence of E. coli in test samples

Escherichia coli is the bacterium commonly used to indicate fecal contamination of soil, water, and so on. It is one small strain within the group of "fecal coliform" bacteria. Of the members of this group, *E. coli* is "more indicative of recent fecal contamination and unsanitary processing in food than the whole fecal coliform group." (FDA/CFSAN BAM Online September 2002)

Since *E. coli* does represent a large part of the normal and necessary bacteria in the intestines of all birds and mammals, when it is found in foods or water or compost tea it suggests contact between fecal matter and those materials. The contact could have been direct, as in animal manure, or indirect – as from soiled human hands. Microorganisms that also inhabit the intestines cause many human diseases; hence, the presence of *E. coli* indicates the possible presence of any or all of those pathogens. *E.coli* can be (but usually isn't) a pathogen; certain strains or varieties of *E.coli* do cause very serious diarrhea, kidney failure, blood infections, bladder infections and more. These varieties dwell in the intestines along with the non-threatening *E. coli*. Furthermore, *E. coli* presence correlates closely with other pathogens and pathogen indicators such as fecal streptococcus, *E. coli* 0157-H7, and *Clostridium perfringens* (Brinton 2004).

General Findings

No *E. coli* was found in the two complete unamended commercial compost teas, their components, or in the European tea at time-0. There was no increase of *E coli* during twenty-four hours of aeration, and none after, when aerators were halted thirty-six additional hours (see Table 1 on page 5).

However, both the commercial teas, and their components, when "spiked" with *E.coli,* were clearly able to support the growth of *E. coli*. In one method the *E. coli* count declined after the aerator was turned off. This is also seen in later trials.

Both total aerobic and anaerobic bacteria counts increased during extraction with the mechanical aerator units, and aerobic bacteria increased in the European method without mechanical aeration. The ratio of aerobic to anaerobic bacteria declined over time in the S1 and S2 aeration batches and increased significantly in the European method samples. In Unit S2, aerobic bacteria increased dramatically after the unit was turned off. Fungi increased too over time. *E coli* added to the European method had declined by seventy-two hours. These data suggest that simple explanations as are common in the popular press do not aid us in understanding what is happening; they certainly also contradict the notion that by not stirring a tea it automatically goes "anaerobic."

In Table 2 (page 5), we show commercial tea units in which we substituted immature compost for the compost that is shipped with the units. This handling would satisfy our objective (a) in the introduction, where an individual would use his or her own composts to make tea. As seen in Table 2, these treatments appeared to suppress *E. coli* growth within seventy-two hours, even after aeration was stopped at twenty-four hours. In this particular immature compost,

Table 1. Microbiological traits of aerated and European technology teas

Analysis		S-1 machine method		S-2 machine method		European method	
Test – time in hours		as is	with *E. coli*	as is	with *E. coli*	as is	with *E. coli*
E. coli MPN	0	<3	>11,000	<3	>11,000	<3	240
	24	<3	>11,000	<3	>11,000	<3	NA
	72	<3	7.4	<3	7.4	<3	4
Aerobic PC	0	4.20E + 09	1.30E + 10	6.00E + 05	>1.5E + 12	6.60E + 05	1.20E + 12
	24	2.20E + 10	6.80E + 09	5.80E + 06	1.5E + 12	5.50E + 09	NA
	72	5.50E + 09	1.00E + 06	2.80E + 12	>1.5E + 12	6.00E + 11	NA
Anaerobic PC	0	1.40E + 05	1.50E + 09	4.00E + 02	2.20E + 09	5.00E + 05	1.20E + 12
	24	6.40E + 07	5.00E + 07	1.50E + 04	3.60E + 09	3.30E + 03	NA
	72	3.60E + 07	1.00E + 05	2.00E + 11	NA	2.50E + 04	NA
Total fungi	0	3.30E + 03	3.50E + 09	3.00E + 02	2.20E + 09	3.30E + 03	1.20E + 05
	24	5.40E + 05	1.60E + 11	1.30E + 03	4.40E + 09	9.00E + 02	NA
	72	1.20E + 05	7.00E + 04	1.60E + 05	4.00E + 11	1.80E + 03	NA

Note: designations such as 1.00E + 07 mean 1 x 10^7.

Table 2. Compost tea units with immature composts

Analysis		S-1 food + unripe compost		S-2 machine method	
MPN or CFU/ml		as is	*E. coli* added	as is	*E. coli* added
E. coli MPN	0	2100	>11,000	<3	>11,000
	24	750	>11,000	<3	>11,000
	72	93	7.4	<3	7.4
Aerobic PC	0	8.60E + 12	1.30E + 10	6.00E + 05	>1.5E + 12
	24	2.40E + 10	6.80E + 09	5.80E + 06	1.5E + 12
	72	1.56E + 06	1.00E + 06	2.80E + 12	>1.5E + 12
Anaerobic PC	0	2.00E + 09	1.50E + 09	4.00E + 02	2.20E + 09
	24	1.00E + 07	5.00E + 07	1.50E + 04	3.60E + 09
	72	1.60E + 05	1.00E + 05	2.00E + 11	NA
Aerobic:anaerobic ratio	0	4.30E + 03	3.50E + 09	3.00E + 02	2.20E + 09
	24	2.40E + 03	1.60E + 11	1.30E + 03	4.40E + 09
	72	1.00E + 01	7.00E + 04	1.60E + 05	4.00E + 11
Total fungi	0	9.00E + 11	2.70E + 05	6.00E + 04	8.00E + 02
	24	2.50E + 07	NA	1.80E + 11	NA
	72	1.70E + 07	NA	NA	NA

the initial tests showed <3 MPN *E. coli* per gram wet weight. However, when added to the compost to make tea, the *E.coli* was able to grow. The most likely explanation has to do with sampling from the compost source relative to sample heterogeneity.

In Table 3 (page 6) we show a similar scenario, but this time the commercial compost tea units are run with only the compost provided with the unit as sold, and no nutrient inoculation. These results showed that both composts provided had no measurable *E. coli*. In fact, the added *E. coli* died off after seventy-two hours in these teas (even though the aeration units were turned off after twenty-four hours). Note that we added no molasses or other inoculum to these batches.

One of the composts – S1 – had significantly more fungi than bacteria when the tea was set up, but the amounts of fungi diminished steadily thereafter. Both compost teas gave significantly more aerobic bacteria counts after three days standing than after twenty-four hours of mechanical extraction. These and other results support the European view that longer extractions give better performance; indeed, in Weltzien and Tränkner's work, better disease control almost always resulted from the longer brewed teas.

In Table 4 (page 6),we show the nutrient source only,

Table 3. Aerator technology compost only w/o nutrients

Test trait	hours brew	S-1 food + unripe compost		S-2 machine method	
		as is	with *E. coli*	as is	with *E. coli*
E. coli MPN	0	<3	2.40E + 03	NA	NA
	24	<3	>11,000	<3	2.40E + 02
	72	<3	NA	<3	NA
Aerobic PC	0	2.10E + 09	7.80E + 10	6.00E + 05	5.6E + 11
(mpn/ml)	24	NA	NA	NA	NA
	72	2.20E + 07	NA	2.50E + 11	NA
Anaerobic PC	0	3.40E + 03	7.20E + 07	2.00E + 02	3.50E + 07
(mpn/ml)	24	NA	NA	NA	NA
	72	9.00E + 02	NA	7.80E + 03	NA
Aerobic:anaerobic ratio	0	6.2E + 05	1.00E + 00	3.00E + 03	1.60E + 04
	24	NA	NA	NA	NA
	72	2.40E + 06	NA	3.20E + 09	NA
Total fungi	0	9.00E + 02	3.10E + 03	2.00E + 02	9.00E + 02
(mpn/ml)	24	3.10E + 03	NA	1.20E + 03	NA
	72	1.00E + 03	NA	1.80E + 03	NA

Table 4. Commercial tea unit, nutrient source only

Test trait	hours brew	S-1 food + unripe compost		S-2 machine method	
		as is	with *E. coli*	as is	with *E. coli*
E. coli MPN	0	<3	NA	<3	NA
	24	<3	>11,000	NA	>11,000
	72	<3	>11,000	<3	>11,000
Aerobic PC	0	1.00E + 02	NA	<100	NA
(cfu/ml)	24	NA	NA	NA	NA
	72	<100	NA	2.90E + 08	NA
Anaerobic PC	0	1.00E + 02	NA	1.00E + 02	NA
(cfu/ml)	24	NA	NA	NA	NA
	72	<100	NA	9.00E + 03	NA

which is the food-inoculum provided with the two commercial units. There were relatively low counts of bacteria, especially in the S1 units, and in the S2 some more grew, especially later (after the aerators were turned off). In any event, *E. coli* certainly did not die off after being added – indeed these inocula may have favored their growth, compared to the die-off seen in Table 3.

A similar result is seen in that there is no evident *E. coli* in the standard compost, but with inoculation, the *E. coli* grew readily, at least in unit S1. Results were inconclusive in S2.

The European-style teas, which were made with mature compost known to contain some *E. coli,* also appeared to inhibit the growth of that *E. coli.* European-style teas made with immature composts also reduced the *E. coli* levels over time. Perhaps the absence of a readily available carbon substrate (i.e., no molasses) and the absence of active aeration provided harsher survival circumstances for *E. coli* replication. It is a very common error in literature on compost teas that "aerated teas" are thought to be "free of potential pathogens." This would only be true in the case of obligate anaerobes, such a *Clostridia* spp., whereas *E. coli* in contrast is readily cultured under aerobic conditions.

In Table 5, we observe our results with comfrey tea. The extract was prepared using a common organic gardening formula of a 1:10 fresh-weight:water mixture. This was first prepared outdoors in a 150-liter open-top container, with daily stirring. This tea was thus exposed to the environment in an area populated by birds and subjected to frequent human handling. The solution smelled very bad. When tested, this comfrey tea understandably had very high levels of *E.coli.* However, when the same tea was prepared in

Table 5. Comfrey tea prepared w/o mechanical aerator outdoors and in lab

Analysis	hours brew	outdoors	in lab
E. coli	0	NA	<3
mpn/ml	72	NA	<3
	120	NA	<3
	7200	>110000	NA
Aerobic	0	NA	1.10E + 05
(cfu/ml)	72	NA	>2.40E + 12
	120	NA	>1.80E + 12
	7200	4E + 12	NA
Anaerobic	0	NA	1.60E + 03
(cfu/ml)	72	NA	6.50E + 12
	120	NA	>2.20E + 12
	2400	4.40E + 11	NA
Aerobic:anaerobic ratio	0	NA	69
	72	NA	3.7
	120	NA	8200
	7200	9.1	NA
Total fungi/ml	0	NA	3.00E + 02
	72	NA	5.10E + 11
	120	NA	5.70E + 08
	7200	1.30E + 02	NA

the lab under more controlled conditions – using fresh harvested but un-washed leaves, touched only by sterile implements and made with well water (tested to be *E. coli*-free), and kept loosely covered – it showed absolutely no measurable *E. coli* over 120 hours. Both aerobic and anaerobic plate counts continued to rise over time in the laboratory extracted samples, without aeration. This indicates clearly that some simple practices in hygienic handling (washing tools before use, using clean water and providing protection from birds over-flying the tanks!) may be very helpful in enabling growers to prepare safe extracts.

In Table 6 (page 8), we show the European method repeated for two mature composts and one immature compost. Mature composts were Solvita 7–8 and immature, where used, were <6. *E. coli* counts in the mature composts, which were low and declined steadily during the tea preparation process. In the immature compost, *E. coli* was slightly higher, but also declined during the tea preparation, with stirring once per day. Thus we see no evidence that the original Weltzien-type approach to preparing tea extracts with reduced technology is anaerobic or leads to reproduction of pathogens.

It is clear from these findings that aerobic bacteria counts in the teas are variable but mostly very high, and increase or decrease slightly over time. Furthermore, the ratio of aerobic to anaerobic microbes is high to extremely high throughout. There is no evidence therefore of an increase in anaerobic activity. Finally, all these teas were odorless.

Discussion

The ultimate goal of this and other efforts is to have no *E. coli* present in compost teas. The newly recommended USDA-NOP standard is that teas shall possess no more than 126 cfu/100 ml of *E. coli* or no more than 33 cfu/100 ml of *enterococci*. Clearly, it is intended that compost teas will be applied to food plants, including those that may be consumed without thorough washing. According to this investigation, if a small amount of *E. coli* is introduced into a tea, its population levels will decrease to the point of extinction in 72– 120 hours. It is possible therefore that short-term brews, with added sugars, may in fact have represented one of the least safe practices. New concern about this has caused tea makers to start withdrawing at least molasses from their brews (personal communication, Bob Cantisano, 2003). Avoiding the introduction of unwanted microbes into tea is obviously the best approach. Our expectation of a large and continuing increase of *E.coli* populations in teas was not validated by evidence in the study, and only when large amounts of *E.coli* were added to the teas, did the levels remain high. These results were independent of the presence or absence of aeration.

Aerobic Bacterial Levels.

High levels of aerobic bacteria (10^{8-12} per ml) apparently endow fungal disease resistance to plants. This may be due to their ability to metabolize unusable molecules into forms that plants can absorb and assimilate. Boehm and Hoitink (1997) have argued that one must have sustained high microbial activity to confer disease control from composts, but they were not dealing with compost teas. Some more recent studies refined this view. They show that the disease suppression was only high at the beginning of the period of high microbial activity and that the species of bacteria do change, strongly suggesting that a particular group of bacteria causing the suppression is replaced by others in succession. This would mean that "lots of bacteria" aren't enough over time to maintain disease control. The expectation in the compost tea work was that the APC (aerobic plate count) would rise until either the oxygenation was stopped or the nutrient supply became low. The more rapid the rise in APC the more rapidly the fall would begin. Our data do support this prediction, although not overwhelmingly. Without active aeration, APC in the European method teas was predicted to increase more slowly than in the other teas; however, this was also not the case. It may be some time be-

Table 6. European method teas with various composts

Strain	hours brew	Euro mature–B cfu/ml	Euro mature–C cfu/ml	Euro immature–B cfu/ml
E. coli	0	7	4	940
	72	<3	3	94
	120	<3	3	2
Aerobes	0	1.90E + 09	2.40E + 11	2.60E + 05
	72	4.60E + 12	>1.40E + 12	9.40E + 07
	120	3.10E + 09	8.00E + 08	6.80E + 07
Anaerobes	0	4.60E + 03	1.20E + 05	8.00E + 04
	72	4.00E + 02	2.00E + 03	6.60E + 03
	120	1.00E + 01	2.80E + 03	2.00E + 02
Aerobic:anaerobic ratio	0	4.10E + 05	2.20E + 06	3.20E + 00
	72	1.20E + 09	7.00E + 11	1.40E + 05
	120	3.10E + 08	2.90E + 05	3.40E + 05
Total fungi	0	4.10E + 05	1.60E + 03	4.00E + 00
	72	1.20E + 07	1.00E + 02	1.40E + 03
	120	3.10E + 09	1.00E + 02	3.40E + 05

fore these relationships are understood and we have a clear sense which microbes and/or what set of factors is conferring control. Considering the complexity of the subject, a holistic expectation is appropriate. Certainly the impression one gains from the popular press that the means to make compost teas is all worked out and accessible through simple formulas or recipes, is not supported by any practical or scientific results.

Anaerobic Bacterial Levels

The anaerobic bacteria are generally considered to be undesirable: some produce objectionable odors that are also phytotoxic and others convert plant-nutrients into unusable compounds. However, anaerobes are not strictly reliant on fixed regimes; facultative organisms that can survive aerobic and anaerobic conditions are prominent in nature.

Because of the low solubility of oxygen in water, the European teas would be expected to become a suitable anaerobic environment. However, without active aeration, these European teas did not develop large anaerobic bacterial counts as predicted. Even the teas allowed to steep for 120 hours did not support a large anaerobic population, or one that appeared appreciably different to the mechanically aerated teas.

It should be pointed out that the relative insolubility of oxygen in water (8.3–8.5 mg/L water at 25°C) prevents more than a minimum amount from dissolving, whether aerated or not. This same solubility factor may prevent the oxygen concentrations from plunging low enough to allow the obligate anaerobes to reproduce (some require as low as <0.18 mg/L air). Certainly the concept of physically frothing the water with high tech equipment, analogous to the early 1990s approach of beating composts continually to aid aeration, is inappropriate. Only so much oxygen will be absorbed, while the rest is thrown off. Growers who do not use the high tech approaches, therefore, need not feel that their simple approaches are incorrect. However, more care and caution with regard to hygiene is definitely in order. More chemistry and physics knowledge is needed to unravel the relationships of equipment and handling to hygiene and quality.

Total Viable Fungi

Certain fungi repress the growth of other fungi that parasitize plants. Other fungi are desired for their ability to degrade organic compounds into forms bacteria can use. It is most likely a favorable thing to have consistent levels of fungi in compost teas. This study however did not attempt to pursue fungal investigations to any particular extent, but only to observe levels as influenced by the various technologies and treatments.

We observed fungal stability in the teas throughout their recommended use time. The total numbers of fungi appear to go into some decline at seventy-two hours in the aerated teas but not the European teas. More work will have to be done to understand these influences.

Conclusions

This study represents a preliminary look at bacterial and fungal parameters in some compost teas prepared using two different technologies: two commercial brewing systems

both based on differing forms of mechanical aeration applied to a compost/nutrient solution and five compost/water mixtures with brief daily stirring. The study sought to see how *E. coli* population size would behave in these teas, and observe how great an impact mechanical aeration makes on the bacterial character of a compost tea.

a) The two commercial systems did produce *E. coli*-free teas.
b) The two commercial systems, and their isolated ingredients, when inoculated with *E. coli,* did support its growth.
c) *E. coli* should be prevented access to all compost teas by (1) clean handling techniques and (2) using composts that have no tested *E. coli* (very mature, no new manures, no exposure to fecal matter during storage).
d) At least for small-scale tea brewing, there seems to be equal growth of desirable microbes in both aerated and non-aerated systems.

Based on this, we believe there may be some misunderstanding about aeration of compost teas and about what constitute anaerobic conditions. Furthermore, we see no compelling evidence here that aerator equipment makes any contribution whatsoever to the making of 5–10 gallon (20–40 liter) batches of compost tea, as long as the compost is of reasonable quality. However, since growers may make teas outdoors, in improperly cleaned containers, or where animals and birds may have access, and exposure to dusts may occur, there may be increased opportunity for contamination. It is urged that growers and composters focus attention on the compost quality and hygienic circumstances surrounding their manufacture, while the actual form of technology may be of less significance.

Finally, in a certain sense, our study reveals, historically speaking, how a variety of early events shaped a new crisis that in turn is leading to new and improved understandings. Early concepts and popular misconceptions about microbes and aeration, plus the rapid adaptation of "brew thinking" in terms of how to grow as much bacteria as rapidly as possible, explains what many have come to regard now as a form of self-fulfilling prophecy. A very zealous early approach to enhanced brewing led among other things to very odorous teas (due especially to use of molasses and other additives), and culminated in the invention of tea extraction equipment designed to help fix the aerobic problem. Thus, the compost tea field in America has had an accidental and discontinuous development course. Perhaps much of the confusion could have been avoided if some attention had been paid to the wealth of previously published literature and if more cross-pollination had occurred between present-day producers and earlier practitioners.

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P. Storms is microbiologist, W. Brinton is agricultural chemist, and E. Evans is biologist for Woods End Research Laboratory; J. Hill is in the research department for Johnny's Selected Seeds of Albion, Maine. *William Brinton can be contacted at <will@woodsend.org>.