COMPOST TEA PRODUCTION PRACTICES, MICROBIAL PROPERTIES, AND PLANT DISEASE SUPPRESSION

Steven J. Scheuerell

Oregon State University

Dept. of Botany and Plant Pathology, 2082 Cordley Hall, Corvallis, OR 97331.

scheuers@science.oregonstate.edu

Introduction

Compost tea is produced by mixing compost with water and culturing for a defined period, either actively aerating (aerated compost tea, ACT) or not (non-aerated compost tea, NCT) and with or without additives that are intended to increase microbial population densities during production (NOSB, 2004; Scheuerell and Mahaffee, 2002). Prior to application, additional nutrients and adjuvants, such as spreader-stickers, may be added. Application to soils and/or plants is done with conventional spray equipment and all types of irrigation systems. The application system determines the need for filtering compost tea before application. Material large enough to clog filters and nozzles is removed, but this can reduce microbial populations attached to particulate organic matter suspended in the compost tea.

Compost tea has evolved from historical horticultural practices such as steeping manure or plants in water, with the liquid applied to crop plants for nutritional and plant health reasons. In recent decades, the majority of published studies examining compost tea have focused on foliar plant disease suppression using liquid material produced by steeping compost in water for several days to weeks. This material was originally termed 'compost extracts' by Dr. Weltzien at the University of Bonn, Germany, who initiated this modern field of study (reviewed in Weltzien, 1991). More recently, experimentation with aerated compost tea, made with an assortment of mechanical compost tea brewers, has grown in popularity in the United States, with global interest also increasing (Diver, 2003; Ingham, 2003; Scheuerell and Mahaffee, 2002). An important distinction between NCT and ACT is that ACT uses compost, water, and nutrient additives to greatly increase microbial populations over a 12-36 hour period, while NCT uses greater quantities of compost, typically doesn't add separate nutrient additives, and is produced over several days to several weeks. In addition to the source of compost and the use of active aeration, a number of compost tea production parameters will affect the final biological and chemical properties of compost tea (Table1). The utility of compost tea as a plant production tool is further impacted by application parameters such as addition of spray adjuvants, and application rates and timing (Table 1).

Table 1. Compost tea production and application parameters that influence compost tea properties and function. Adopted from Scheuerell and Mahaffee (2002).

Production Parameters	
Fermentation vessel	Dimensions, manufacturer and model if applicable
Compost	Feedstocks, age, stability, % moisture, available nutrients, microbial analysis, either volume and bulk density used or weight used per unit water
Water source	volume, initial and final temperature
Nutrient additives	Types, concentrations, timing when added
Dissolved oxygen	Stirring, agitation, and/or aeration
Temperature	Water temperature at start and throughout production
Production duration	Method of storage, if not used immediately
Application Parameters	
Filtration	Material and mesh size used for filtering
Dilution ratio	Water source
Adjuvants	Nutrients, surfactants, stickers, UV stabilizers, microorganisms
Application equipment	Make, model, nozzle specifications, pressure
Application	Rate, time of day, weather, interval between applications

To date, available studies on the horticultural uses of compost tea have focused on using compost tea for plant disease control, with considerably more information available on the efficacy of NCT compared to ACT (reviewed in Weltzien, 1991 and Scheuerell and Mahaffee, 2002). Very little information is available on plant nutrient responses or effects of compost tea on the microbiological quality of treated plants (NOSB, 2004). This paper will briefly cover three current areas of compost tea research: the effect of compost tea production practices on the resulting microflora; the use of compost tea as a drench for controlling seedling damping-off diseases; and concerns of multiplying bacterial human pathogens in compost tea.

Effect of aeration and nutrient additives on compost tea bacterial populations

The microflora of NCT (Weltzien, 1991) and ACT (Ingham, 2003) have been described as being dominated by bacteria, therefore it is of interest to understand how manipulating compost tea production process enrich and/or select for individual bacterial populations. Given that compost is microbiological diverse, the materials and methods used to produce compost tea are selective forces that affect bacterial and overall microbial diversity, abundance, and evenness of microbial populations in compost tea. Published studies that describe compost tea microflora have relied on traditional culturing methods or direct microscopic examination. Both methods have severe limitations for describing bacterial diversity. Many bacteria do not readily grow on culture media, and bacterial morphology provides limited differentiation of genotypes. However, tracking populations of culturable and total bacteria in compost tea can indicate how different compost tea production practices affect bacterial population density and what proportion of the total bacterial population is culturable verses non-culturable. In addition, using direct microscopic examination with staining techniques that differentiate metabolically active cells can indicate how different compost tea production practices affect the proportion of total microbial cells in compost tea that are metabolically active.

Research was conducted to relate compost tea production practices to the culturable, active, and total bacterial cells in compost tea. A large number of compost teas were prepared with or without aeration and with or without nutrient additives to enrich microbial populations.

Culturable bacteria were enumerated on 5% trypticase soy broth agar (1.5 g Difco trypticase soy broth and 15 g agar/liter with 100 ug/ml cycloheximide), after incubation at 22°C. Determination of metabolically active cells was done by staining with fluorescein diacetate (FDA), total cells with 4,6-diamidino-2-phenylindole (DAPI), followed by enumeration using epifluorescent microscopy with appropriate filters for each stain. Methodological details are contained in Scheuerell and Mahaffee (2004).

Producing compost tea with or without aeration and nutrient additives greatly affected the total bacterial population density and proportion of the total population that was metabolically active or culturable (Figure 1). This data set includes compost teas made from several sources of compost. These composts had different bacterial population densities (data not shown). This difference was responsible for the large range of bacterial populations in both NCT and ACT made without nutrient additives. Clearly,

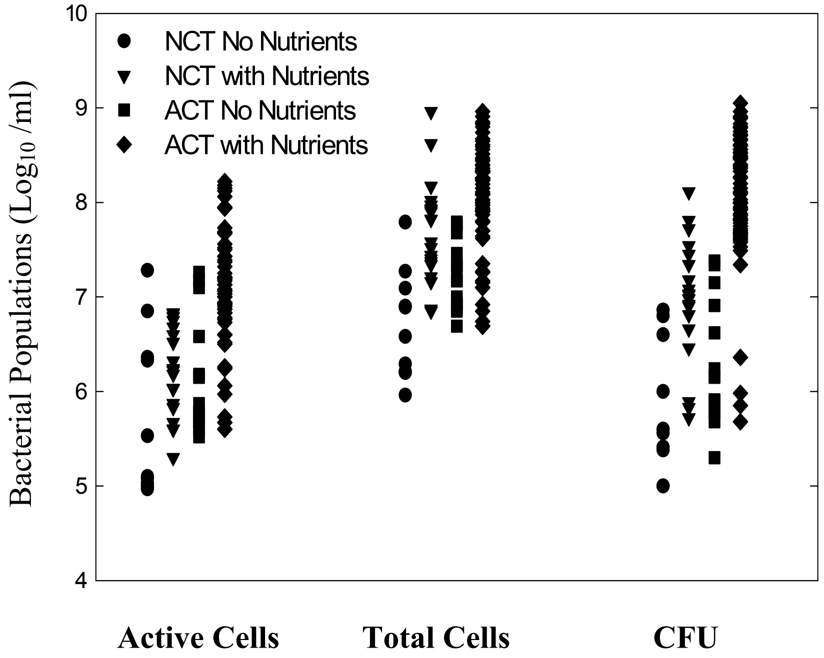

Fig. 1. The influence of aeration and nutrients additives during compost tea production on bacterial population measurements. NCT- not aerated, ACT- aerated. When indicated, NCT and ACT made with nutrients including combinations of 0.12% w/v soluble kelp concentrate, 0.25% v/v humic acids, 0.30% glacial rock dust, or 0.5%,1.0%, and 1.5% v/v bacterial nutrient solution (Soil Soup, Inc, Edmonds, WA). Active and total cells determined by direct counting after staining with Fluorescein diacetate and DAPI, respectively. CFU determined on 5% TSBA media with 100 ppm cycloheximide. Data from Scheuerell, 2002.

selecting compost with greater bacterial density results in compost tea with greater bacterial population densities when nutrient additives are not used. In addition to compost source, when nutrient additives are used to produce NCT or ACT, the type and concentration of nutrient sources greatly influences the final total or culturable bacterial population density. It should be noted that using nutrient additives generally results in different proportions of active bacterial cells in NCT compared to ACT. NCT produced with nutrient additives becomes anaerobic with notable production of reduced organic compounds. These conditions, and considering that the NCT are produced over a longer period that allows for depletion of available nutrients, results in a lower proportion of total bacteria being metabolically active in NCT produced with nutrient additives compared to ACT. For ACT produced with nutrient additives that are highly labile, such as molasses-based formulations, the added nutrients selectively enrich culturable bacteria. In contrast, producing ACT with added rock dust and/or humic acids selectively enriches non-culturable bacteria. This can be seen in Figure 1, in the culturable (CFU) counts of ACT with nutrients, there are four isolated data points that have corresponding total counts approximately 10-fold greater. These ACT were produced with rock dust and/or humic acids. When molasses-based nutrient solutions or soluble kelp are added with the rock dust or humic acids, then the total and culturable bacterial population are equivalent. This indicates that ACT production utilizing relatively high concentrations of labile nutrients to increase microbial populations selectively enriches culturable bacteria. This should not be surprising given that these conditions are similar to culturing bacteria on growth medium at relatively constant temperatures.

Further work is needed to better understand how compost tea production practices impact the microbial diversity and abundance of compost tea. Efforts should focus on molecular methods that enable microbial diversity and abundance to be tracked from compost through the compost tea production process to better understand how practices such as aeration and nutrient additives affect the resulting microbial community.

Drenching with compost tea to suppress damping-off diseases of seedlings

Compost tea is being used increasingly as an alternative plant disease control measure in commercial horticulture (Diver, 2001; Scheuerell and Mahaffee, 2002). Compared to the numerous reports on the use of compost tea for managing foliar diseases, very little information exists on the use of compost tea to manage root rot diseases. Considering that various root rot diseases have been suppressed by incorporating compost into soil or soil-less growing media (reviewed in Hoitink et al, 1993), further work on the use of compost tea to control root rot diseases is warranted. Under certain circumstances the use of compost tea has advantages over incorporating compost, particularly for greenhouse production of transplants in soil-less media, or when soil analysis indicates that incorporating high rates of compost associated with disease suppression could lead to excessive nutrient application. The potential benefits of using compost tea instead of compost for greenhouse production of transplants in soil-less media are related to balancing the biological, chemical, and physical properties required to suppress disease and produce quality transplants. While numerous types of compost have been demonstrated to increase the microbial activity of soil-less media to levels associated with suppression of seedling damping-off, adding large quantities of compost may not provide the ideal chemical and physical properties needed to manipulate production quality and timing. Compost tea production materials and practices can be varied to produce a liquid with high microbial activity and desired ranges of plant nutrients. Being a liquid, compost tea has very little affect on soil-less media physical properties, such as porosity.

It has been proposed that increasing the population of total and active bacteria in ACT will generally increase the level of plant disease suppression (Ingham, 2003). However, published evidence supporting these assertions is lacking. Investigations using compost tea for the suppression of damping-off caused by *Pythium ultimum* in soil-less media were initiated with the goal of determining if compost tea could be used to deliver sufficient populations of bacteria to achieve disease suppression. Prior to this investigation, only one study involving

Pythium spp. and compost tea had been published; it determined that pea seeds soaked in NCT, dried, and sown two days later had reduced disease symptoms on seedlings caused by *P. ultimum* (Tränkner, 1992). Heat treating the NCT negated all suppression of pathogen growth *in vitro*, indicating the likely role of the NCT microflora in disease suppression (Tränkner, 1992).

The current study used NCT and ACT, produced with and without nutrient additives, to drench peat-perlite growing media that was inoculated with *Pythium ultimum* and planted with cucumber seeds. Compost teas were produced with three different compost types to assess whether compost source affected disease suppression. When used in compost tea production, nutrient additives consisted of soluble kelp, humic acids, and rock dust (termed fungal nutrients), or a molasses-based nutrient solution (termed bacterial nutrients). Further details on methodology can be found in Scheuerell and Mahaffee (2004).

The most consistent compost tea formula for suppressing damping-off was ACT produced with the fungal nutrients; this combination suppressed damping-off in 13 out of 13 repeated experiments (Figure 2), regardless of compost type used to make compost tea. Further results indicated that the rock dust could be omitted without changing disease suppression. The fungal nutrient additive did not suppress damping-off when mixed in water and drenched onto infested growing media. Producing ACT without nutrient additives or with the bacterial additive resulted in inconsistent suppression of cucumber seedling damping-off over repeated experiments (Figure 2). When ACT was produced with a combination of bacterial and fungal

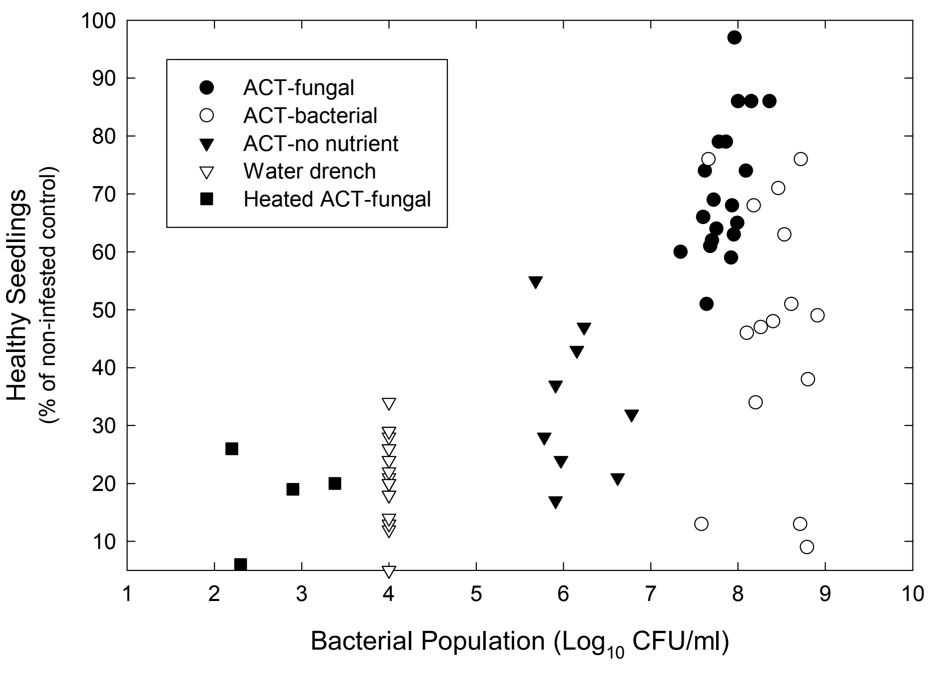

Fig. 2. Relationship of the average number of healthy cucumber seedlings grown in peat-perlite growing media infested with *Pythium ultimum* to bacterial population of aerated compost teas (ACT). ACT made with no added nutrients; kelp, humic acids, and rock dust (fungal); molasses-based nutrient solution (bacterial). Heated ACT-fungal treatments were heated to 95 C for 30 minutes then cooled to 25 C prior to drenching. Bacteria enumerated on 5% TSBAcyc^{100}. The water drench control treatments from 15 experiments are all placed at the average cfu recorded from four tap water samples. Data from Scheuerell (2002).

additives, damping-off was not suppressed over three bioassays (data not shown). Suppression of damping-off of cucumber was also observed with ACT produced with fungal additive in composted fir bark:peat-perlite growing medium (1:1 v/v), indicating that this could be used with various soil-less media. Further experiments were conducted to expand upon the relationship observed between increasing seedling health and bacterial population densities in ACT. When ACT made with the molasses-based nutrient solution were excluded, all other compost teas made without additives or with single components or combinations of the fungal nutrient mixture (kelp, humics, rock dust) clearly developed a positive relationship between increasing bacterial concentrations and plant health. This was the case whether bacterial populations in compost tea were measured as culturable, active, or total cells (Figure 3).

Non-aerated compost tea produced without nutrient additives did not suppress damping-off. Repeated experiments using NCT made with either the fungal or bacterial nutrient additives resulted in inconsistent suppression of damping-off. While NCT made with nutrient additives does provide measurable benefits, the use of nutrient additives results in the production of offensive odors. Further work using NCT made without nutrient additives, but with greater quantities of quality compost could result in better disease suppression than observed in this study.

It is interesting to consider why ACT made with the molasses-based nutrient solution had on average the greatest bacterial population densities, but resulted in erratic disease suppression (Figure 1). It was hypothesized that residual nutrients from the molasses-based nutrient formula in ACT were stimulating *Pythium* and negating biological control. When small concentrations of molasses were added just before drenching, the suppressive ACT-fungal formulation lost most of its disease suppressive capacity (Figure 4). This is consistent with observations that noted a reduction of hyphal lysis of *P. aphanidermatum* by antagonistic bacteria in separated cattle manure-compost medium when labile nutrients were added (Mandelbaum and Hadar, 1990). Amending the container medium with a glucose-asparagine mixture (3.36:1 w/w), amended at 0.5% wet weight, reduced hyphal lysis to 18% over a 24 h period compared to 80% lysis for non-amended compost medium (Mandelbaum and Hadar, 1990). Additionally, drenching the glucose-asparagine mixture (1% solution in water) onto the compost medium negated cucumber damping-off suppression (Mandelbaum and Hadar, 1990). For compost tea used as a drench to control damping-off caused by pathogens that are efficient saprophytes, it is critical to either avoid the use of stimulatory nutrient additives when making compost tea, or make the compost tea over a sufficiently long period to ensure attenuation of available nutrients. In this work, attaining consistent biological control required producing ACT with nutrient additives in order to grow sufficient bacterial populations densities associated with disease suppression. While using nutrient additives can increase beneficial organisms, care must be taken to avoid increasing non-target organisms.

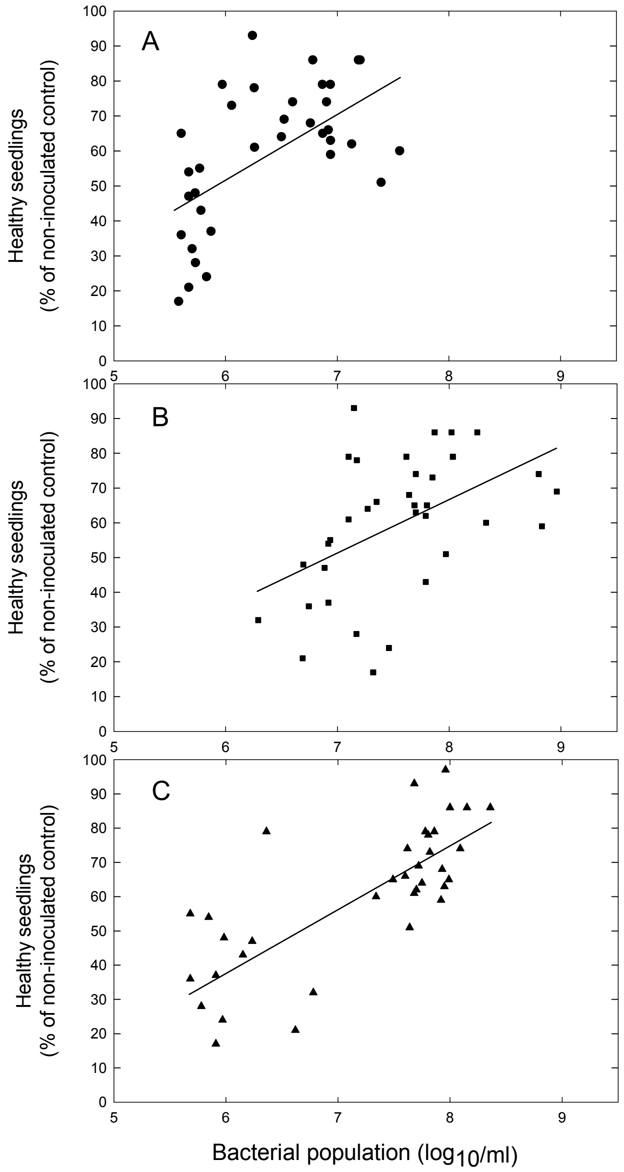

Fig. 3. Relationship of bacterial populations of aerated compost teas (ACT) to healthy cucumber seedlings in *P. ultimum* damping-off bioassays. For each compost tea drench treatment, healthy seedlings scaled to percentage of non-inoculated control (% healthy seedlings = treatment mean healthy seedlings/non-inoculated control mean healthy seedlings). ACT with bacterial additive not included. All ACT produced either without additives or with single components, binary combinations of components, or all fungal additive components (0.12% w/v powdered soluble kelp, 0.25% v/v humic acids, 0.30% w/v glacial rock dust). There was a significant linear relationship ($P < 0.05$ with $R^2 = 0.36$, 0.22 and 0.57 for A, B, and C, respectively. A) •Active bacterial cells measured by staining with fluorescein diacetate. B) ▪ Total bacterial cells measured by staining with DAPI. C) ▲ Bacterial CFU cultured on 5% trypticase soy broth agar amended with 100 ppm cycloheximide. Figure reproduced from Scheuerell and Mahaffee (2004).

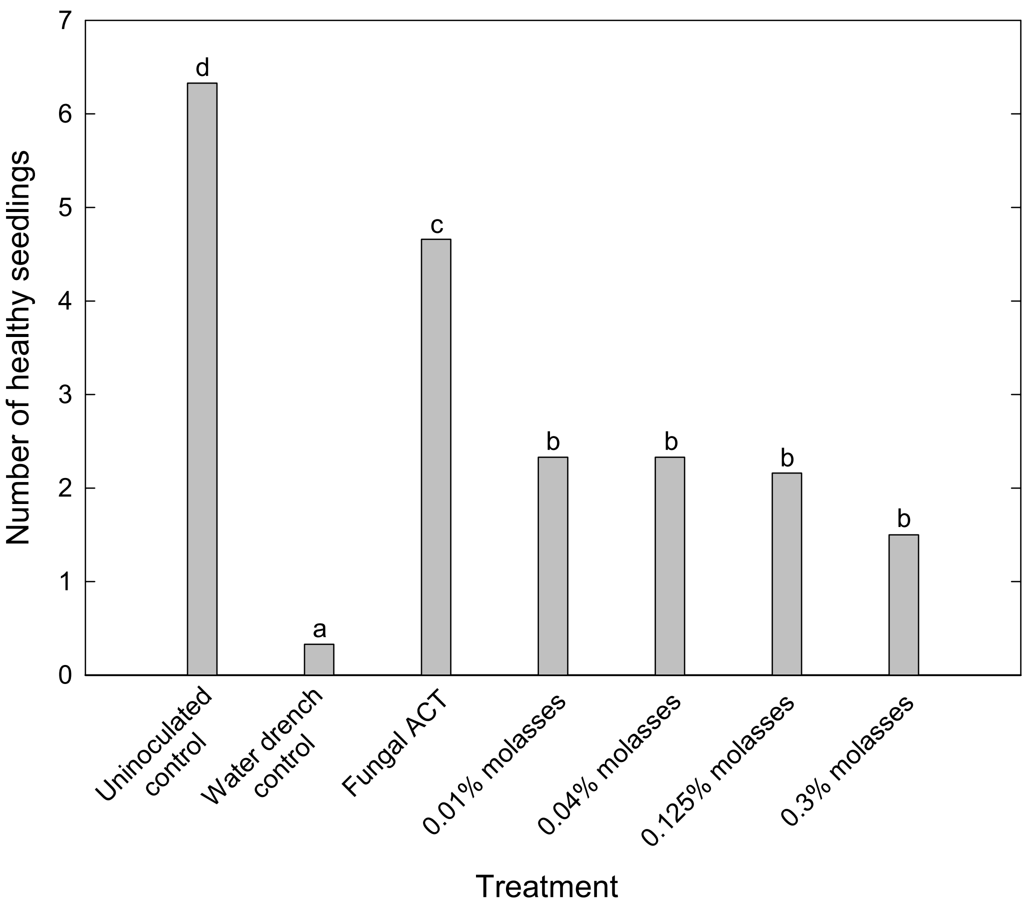

Fig. 4. Effect of tank mixing molasses with aerated compost tea (ACT) on seedling health. Compost tea drench treatments applied to six replicate pots each with eight cucumber seeds sown in *P. ultimum* inoculated peat-perlite growing medium. Mean healthy seedlings determined by summing the number of healthy seedlings for each pot (0-8) and averaging these six values. The fungal ACT drench was produced with 0.12% w/v soluble kelp, 0.25% v/v humic acids and 0.30% w/v glacial rock dust. Bars with the same letters are not significantly different ($P = 0.05$, Duncan's multiple range test). Reproduced from Scheuerell and Mahaffee (2004).

Effect of compost tea production practices on multiplication of human pathogens

In the United States, compost tea use by certified organic farms has been regulated under the USDA National Organic Program. No compost tea regulations exist for non-organic farms. When the National Organic Program was officially implemented in October, 2002, it did not specify allowable uses of compost tea by certified organic farmers. The NOP stated that compost tea didn't satisfy §205.203(c) of the National Organic Standards due to preliminary evidence indicating that human bacterial pathogens could multiply when inoculated into compost tea that was made with nutrient additives (Bess et al, 2002; Duffy et al, 2004). This standard is reprinted here.

National Organic Standards (excerpt)

§205.203 Soil fertility and crop nutrient management practice standard

(c) The producer must manage plant and animal materials to maintain or improve soil organic matter content in a manner that does not contribute to contamination of crops, soil, or water by plant nutrients, pathogenic organisms, heavy metals, or residues of prohibited substances.

This ruling resulted in compost tea being regulated the same as raw manure, with a 90/120 day pre-harvest application restriction placed on compost tea. This effectively eliminated most uses of compost tea for organic farmers. In response, the National Organic Standards Board (NOSB), which advises the NOP, formed the Compost Tea Task Force (CTTF) to assess compost tea production and use practices, and determine what is a reasonably safe use of compost tea. The final report (NOSB, 2004) has been posted on the NOSB web site http:// www.ams.usda.gov/nosb/meetings/CompostTeaTaskForceFinalReport.pdf
The CTTF inquiry affirmed the positive benefits that compost tea has had for organic and conventional farmers and made a strong call for more compost tea research. Regarding human pathogen concerns, it is important to note that all published and internal information available to the CTTF indicated that multiplication of pathogenic bacteria has only been observed when nutrient additives are used to produce compost tea (Scheuerell, member of CTTF). Equally important, many batches of compost tea have been made with nutrient additives without resulting in detectable populations of pathogens or indicator bacteria. This is why the CTTF determined that compost teas made with nutrient additives should be permitted, but only after quality assurance testing has been completed. To summarize the dual roles of preventing contamination and assuring that a compost tea production system isn't problematic, the first five recommendations of the CTTF are reprinted below.

1. Potable water must be used to make compost tea and for any dilution before application.

2. Equipment used to prepare compost tea must be sanitized before use with a sanitizing agent as defined by 21 CFR 178.1010.

3. Compost tea should be made with compliant compost or vermicompost, using the NOSB Compost Task Force Guidelines set forth on April 18, 2002, for thermal compost and vermicompost, or compost as defined in section 205.203 (c) (2) of the NOP rule. For compost tea, this applies to 100% plant feedstock materials in addition to manure feedstocks because non-manure compost feedstocks may harbor high levels of fecal bacteria (Epstein, 1997).

4. Compost tea made without compost tea additives can be applied without restriction.

5. Compost tea made with compost tea additives can be applied without restriction if the compost tea production system (same compost batch, additives, and equipment) has been pre-tested to produce compost tea that meets the EPA recommended recreational water quality guidelines for a bacterial indicator of fecal contamination (US EPA, 2000). These indicators and the passing criteria are *Escherichia coli* (126 CFU/100ml) or enterococci (33 CFU/100ml). At least two compost tea batches must be tested using accepted methodology (APHA-AWWA-WEF, 1999; US EPA, 2000), with the average population of indicator bacteria across compost tea batches used as the measurement of passing. Each new batch of compost would require that the system quality assurance pre-test be conducted again as indicated. After it passes again, compost tea from the system can be used without restriction.

   If compost tea made with compost tea additives has not been pre-tested for indicator bacteria, its use on food crops is restricted to the 90/120 day pre-harvest interval. Crops not intended for human consumption, ornamental plants, and grain crops intended for human consumption are exempt from bacterial testing and 90/120 day pre-harvest interval restrictions. In the view of the Task Force, educating producers about the potential for contamination and its impacts on public health and marketing, as well as how this recommended quality assurance testing system would avoid potential contamination will provide compelling incentives for producers to follow the rules.

At this time, it is unknown if and when the NOP will modify or adopt the recommendations put forward by the CTTF. Regardless, the task force report (NOSB, 2004), and recommendations contained within, are the most recent discussion of needed compost tea research and should serve as common sense guidelines for all producers and users of compost tea.

Summary

Growers and compost tea practitioners are rapidly expanding compost tea production and application practices. This expansion is occurring much faster than the capacity of traditional scientific research organizations to document the effects of compost tea. Like all agricultural tools, compost tea is not a silver bullet for solving widespread problems associated with depleted soils or unsustainable farming practices. However, produced with microbiological quality in mind, and integrated into holistically managed biological farming systems, compost tea can be used as a carrier to deliver plant nutrients and manage plant diseases. Researchers are urged to collaborate with farmers to document effects of compost tea on plant health, fertility, and microbiological quality to assist farmers in making informed decisions about compost tea in their production system.

Acknowledgements

The support of Dr. Walter Mahaffee at the USDA ARS Horticultural Crops Research Laboratory, USDA CRIS # 303-5358-22000-024-00D, and the Oregon Association of Nurseries and Oregon Department of Agriculture provided for the research.

References

American Public Health Association, American Water Works Association, Water Environment Federation. 1999. Standard methods for the examination of water and wastewater [CD-ROM]. 20th edition. New York.

Bess, V. H., R. B. S. Manes, and J. L. Snodgrass. 2002. *E. coli* survival in compost tea using different nutrient substrates. Proceedings 2002 International Symposium Composting and Compost Utilization.

Diver, S. 2001. Notes on Compost Teas: A 2001 Supplement to the ATTRA publication Compost Teas for Plant Disease Control. ATTRA, Fayetteville, AR. http://attra.ncat.org/attra-pub/compost-tea-notes.html

Duffy, B., C. Sarreal, R. Subbarao, and L. Stanker. 2004. Effect of molasses on Regrowth of *E. coli* O157:H7 and *Salmonella* in compost teas by B. Duffy, C. Sarreal, S. Ravva and L. Stanker Compost Science and Utilization, Vol. 12 (1):93-96.

Epstein, E. 1997. Pathogens, p. 213-245 *In*: The Science of Composting. Technomic Publishing Co., Inc., Lancaster, PA.

Hoitink, H. A. J., M. J. Boehm, and Y. Hadar. 1993. Mechanisms of suppression of soilborne plant pathogens in compost-amended substrates, p. 601-621. *In*: H. A. J. Hoitink and H. M.

Keener (eds.), Science and Engineering of Composting. Renaissance Publications, Worthington, OH.

Ingham, E.R. 2003. The Compost Tea Brewing Manual, 3rd Edition. Soil Food Web, Inc., Corvallis, OR.

Mandelbaum, R., and Hadar, Y. 1990. Effects of available carbon source on microbial activity and suppression of *Pythium aphanidermatum* in compost and peat container media. Phytopathology 80:794-804.

NOSB. 2004. Compost Tea Task Force Final Report. National Organic Standards Board. April 6, 2004. www.ams.usda.gov/nosb/meetings/CompostTeaTaskForceFinalReport.pdf

Scheuerell, S. 2002. Compost teas and compost amended container media. Ph.D. Dissertation. Oregon State University, Corvallis, OR.

Scheuerell, S. and W. Mahaffee. 2004. Compost tea as a container medium drench for suppressing seedling damping-off caused by *Pythium ultimum*. Phytopathology (In Press)

Scheuerell, S. and W. Mahaffee. 2002. Compost tea: Principles and prospects for plant disease control. Compost Science and Utilization 10(4):313-338.

US EPA, 2000. Improved Enumeration Methods for the Recreational Water Quality Indicators: Enterococci and *Escherichia coli*. United States Environmental Protection Agency. Office of Science and Technology, Washington, DC. EPA/821/R-97/004.

Tränkner, A. 1992. Use of agricultural and municipal organic wastes to develop suppressiveness to plant pathogens. Pages 35-42 in: Biological Control of Plant Diseases: Progress and Challenges for the Future**.** E. S. Tjamos**,** G. C. Papavizas, and R. J. Cook, eds. Plenum Press, New York.

Weltzien, H. C. 1991. Biocontrol of foliar fungal disease with compost extracts, p. 430-450. *In*: J. H. Andrews and S. S. Hirano (eds.), Microbial Ecology of Leaves. Springer-Verlag, New York.