FINAL RESEARCH REPORT TO THE CERES TRUST FUND, January 2017

Title: Unraveling the mystery of compost teas used for organic disease and insect pest management.

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Introduction and justification

Watery fermented extracts (teas) of compost are commonly applied to plants and soil to increase plant or soil health, provide nutrients and to protect plants from diseases or herbivorous insects. Compost tea is a microbe- and nutrient-rich tool for organic crop production that can be easily prepared by a grower on-farm from locally available materials. Using local composts and ingredients would reduce production costs as well as the carbon footprint of organic farming. Since pest management is more challenging in organic agriculture due to limited control options, compost teas may have utility, particularly as a maintenance measure to prevent diseases from ever taking hold. However, high variability in disease control is observed with different substrates and brewing methods and control may not be commercially acceptable. There is conflicting information on which ingredients and methods are most suitable to obtain compost teas with disease suppressive properties. While there are many purported claims of the benefits of compost teas, few science-based recommendations are available for organic growers who prepare their own compost teas. Therefore this proposal aims to aid organic growers by determining characteristics of compost teas that make them more useful and reliable for disease and insect pest management. The specific objectives of the project were to:

1) Develop bioassays for evaluating disease and insect pest suppression by compost teas,

2) Evaluate grower-produced compost teas to examine variability between batches and/or recipes,
3) Evaluate the effects of substrate, brewing method and time, addition of biocontrol agents and adjuvants on disease and insect suppressiveness,
4) Examine the mechanism(s) of disease and insect suppression.

The research reported in this grant was conducted from 2011-2016. While the Ceres Trust grant officially ended in 2014, we continued our work with funding from the Michigan State Horticultural Society to answer the original questions in this grant proposal. In light of the limitations of greenhouse bioassays, we decided that field trials were needed to more definitively answer the original questions in this grant proposal.

Conclusions and take-home messages

- Compost teas were more effective against diseases than insects in bioassays; we did not see obvious effects on insects in field trials but indirect effects cannot be ruled out.
- Field trials were better indicators of compost tea efficiency than greenhouse assays due to the cumulative effect of multiple sprays over the growing season.
- Disease suppression was influenced by substrate, with manure-based compost teas being somewhat more effective than plant-based compost teas in our trials.
- There was no consistent difference between aerated and non-aerated teas made from the same compost: aeration is not needed for disease suppression.
- Disease suppression was achieved with or without additives such as fish emulsion and kelp extract; additives were not needed.
- Compost tea batches were fairly consistent provided similar conditions were maintained. Previous issues with grower batch consistency were traced back to variability in brewing ingredients and procedures.
- Efficacy of compost teas also varied by disease; *Colletotrichum* fungi were not affected
- The most common microbes found in compost teas were bacteria, including soil bacteria which were antagonistic to fungi in bioassays.
- Compost teas applied to grape leaves significantly increased bacterial counts on the leaf surface for about a week, which seems to support the application of weekly sprays
- Longer brewing times enhanced disease suppressiveness; we decided on optimal brewing times of 48 hours for aerated and 14 days for non-aerated compost teas
- Foliar sprays were more effective for foliar disease control than soil drenches.
- Thorough coverage is important for disease control as we believe that most of the activity is due to contact with fungal pathogens. Spray volumes of 50-100 gal/acre are recommended, depending on the crop and canopy. Leaf and fruit surfaces need to be well-covered, almost to the point of run-off.
- The best disease control was achieved by using undiluted compost teas applied weekly during the growing season (compost teas were made using 1 part compost to 5 parts water). However, even diluted teas and sprays every 14 days provided some disease suppression.
- Adding Nufilm-P adjuvant to compost tea spray improved disease control; this may be due to better retention of compost teas or disease suppressive activity of NuFilm P itself.
- Compost teas can be produced for about $2 in compost material per acre, compared to commercial biological control agents that may cost $40-$50 per acre.

Overall conclusion

Compost teas can be used as an inexpensive and environmentally benign tool for reducing plant diseases and as a dilute fertilzer. They should be integrated with other methods of disease control such as dormant sprays, sanitation and (organic) fungicides as they may not hold up under high disease pressure.

Results by objective:

1) ***Develop bioassays for evaluating disease and insect pest suppression by compost teas***

a) *Spore germination bioassays*

A number of bioassays assessing fungal growth on agar in the presence of compost teas and spore germination bioassays were conducted for the plant-pathogenic fungi *Colletotrichum acutatum, Phomopsis viticola* and *Botrytis cinerea.* The assays on agar and with *C. acutatum* and *P. viticola* did not work well for various reasons. *Botrytis cinerea* was chosen because it had consistent spore germination and was easy to visualize under the microscope (Fig. 1). For the assay, a conidial suspension was prepared in a sterile solution of 1% glucose to enhance germination. Slides were incubated at room temperature in the dark for 24-48 hours. Conidia were microscopically observed for germination and compared to a negative control (sterile distilled water with 1% glucose). These experiments are described in more detail in the 2011 progress report.

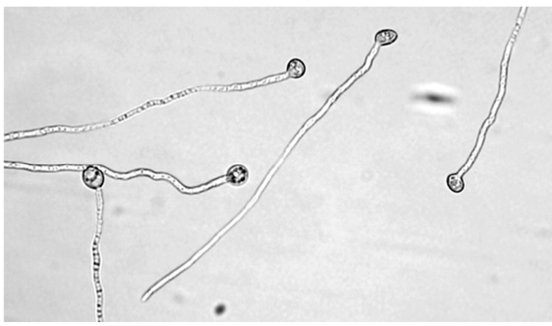


Figure1. Germination of *Botrytis cinerea* conidia in sterile distilled water amended with glucose 1%. Note long germtubes.

b) *Plant-disease bioassays*

A large number of bioassays (see Table below) were conducted with compost teas for suppression of Botrytis gray mold (*Botrytis cinerea*) of leaf lettuce, kale, grape, and geranium; powdery mildew (*Podosphaera xanthii*), anthracnose (*Colletotrichum orbiculare*) and damping off (*Rhizoctonia solani*) on cucumber; anthracnose (*Colletotrichum graminicola*) on corn; and root rot/damping off (*Pythium ultimum* and *Rhizoctonia solani*) on dry beans. While we had success in obtaining various diseases, results were not always consistent from one experiment to the next, plants did not grow well at certain times of the year or were attacked by another pest, infection conditions were suboptimal or disease symptoms were difficult to rate due natural senescence of leaves or the indirect effects of some compost teas on plant growth, making it difficult to separate the direct from indirect effects. In general, while the anthracnose assays worked well and were reproducible, the anthracnose pathogens (*Colletotrichum* spp.) were not affected by compost teas, making them less useful for comparing compost teas. Kale and lettuce did not always become infected with *Botrytis cinerea* for unknown reasons. Cucumber powdery mildew worked fairly well although there appeared to be a fertilizer effect especially from manure-based compost teas. In the *damping off/root rot assays*, it was difficult to achieve consistency as sometimes there was too much and sometimes too little disease pressure. Overall, manure-based compost teas like Buffaloam seemed to work best and aerated vs non-aerated teas made from the same compost were similar. It was decided that field trials, although more laborious, would provide the best and most natural evaluation of compost tea performance.

Date	Assay	Host	Pathogen	Treatments	Conclusion
4/5/2013	Assay development using various concentrations of *Colletotrichum graminicola* on corn	Corn	*Colletotrichum graminicola*	Various concentrations of the pathogen	Found that 10^3 or 10^3.5 was a good inoculation concentration for the pathogen
4/15/2013	*The use of CT to suppress Colletotrichum graminicola* on corn	Corn	*Colletotrichum graminicola*	Aerated and nonaerated CTs	Corn plants collapsed due to a soil fungal infection ([possibly Fusarium). It was decided corn be dropped from future experiments.
10/22/ 2013	The use of CT to suppress *Colletotrichum orbiculare* germination using glucose	microscope slide	*Colletotrichum orbiculare*	Aerated and nonaerated CTs, additives, mixed composts	CT with glucose added were able to suppress spore germination where CTs without were not. Hyphal length of pathogens was longer than the control in CTs without glucose and shorter with glucose.
4/10/2013	The use of CT to suppress *Colletotrichum orbiculare* germination using spinach extract	microscope slide	*Colletotrichum orbiculare*	Aerated and nonaerated CTs	Some CTs were able to significantly reduce the germination of the pathogens in the 1/10 and 1/100 concentrations of spinach extract.
4/17/2013	The use of CT to suppress *Colletotrichum orbiculare* on cucumbers I	Cucumber	*Colletotrichum orbiculare*	Aerated and nonaerated CTs	No CTs suppressed the pathogen and some CTs with high bacterial numbers increased the disease severity.
5/20/2013	The use of CT to suppress *Colletotrichum orbiculare* on cucumbers II	Cucumber	*Colletotrichum orbiculare*	Aerated and nonaerated CTs	No CTs suppressed the pathogen and some CTs with high bacterial numbers increased the disease severity.
6/5/2013	*Colletotrichum orbiculare* fungicide assay	Cucumber	*Colletotrichum orbiculare*	Conventional fungicides, One nonaerated CT	Topsin M showed the highest degree of control. Quadris and Switch showed significant control, but lower than Topsin M
8/27/2013	The use of CT to suppress *Colletotrichum orbiculare* on cucumbers III	Cucumber	*Colletotrichum orbiculare*	Aerated and nonaerated CTs	*C. orbiculare* was not found on any of the plants including the control
10/15/2013	The use of CT to suppress *Colletotrichum orbiculare* on cucumbers IV	Cucumber	*Colletotrichum orbiculare*	Aerated and nonaerated CTs, additives, mixed composts	No CTs suppressed the pathogen and some CTs with high bacterial numbers increased the disease severity.
2/24/2014	The use of CT to suppress *Colletotrichum orbiculare* on cucumbers V	Cucumber	*Colletotrichum orbiculare*	Aerated, nonaerated and extracted CTs, additives	No CTs suppressed the pathogen and some CTs with high bacterial numbers increased the disease severity.
6/24/2014	The use of CTs to suppress *Pythium ultimum* on the roots of dry beans assay	Dry bean	*Pythium ultimum*	One Aerated CT	Plants were infected and detrimentally affected by the inoculation with *P. ultimum.*

	development				The one CT tested showed some suppression.
7/14/2014	The use of CTs to suppress *Pythium ultimum* on the roots of dry beans assay development II	Dry bean	*Pythium ultimum*	Aerated and nonaerated designer CTs	A number of CTs were significantly different in their health rating from the control. Only CT D8 was found to significantly better in root and total mass.
10/2/2014	The use of CTs to suppress *Pythium ultimum* on the roots of dry beans assay development III	Dry bean	*Pythium ultimum*	Aerated and nonaerated designer CTs and one biocontrol addative	A number of CTs were significantly different in their health rating, shoot mass, root mass, and total mass
8/14/2013	*Rhizoctonia solani* root-rot development assay	Cucumber	*Rhizoctonia solani*	Various concentrations of the pathogen, Aerated and nonaerated CTs	It was found that at 1/8 tsp rate of the pathogen, the two CTs tested were partially able to suppress the pathogen.
12/18/2013	*Rhizoctonia solani* root-rot development assay	Cucumber	*Rhizoctonia solani*	Aerated and nonaerated CTs, additives	None of the plants, including the control showed signs of disease. It may be that the pathogen strain was not sufficiently virulent.
1/29/2014	*Rhizoctonia solani* root-rot development assay	Cucumber	*Rhizoctonia solani*	Aerated and nonaerated CTs, additives, preactivation	CTs did not show suppression of the pathogen according to the disease severity rating. CTs did show an increase in biomass compared to the control
10/2/2013	*Rhizoctonia solani* damping-off development assay	Cucumber / black bean	*Rhizoctonia solani*	Various concentrations of inoculating with *R. solani* as a slurry	Various levels of germination and disease severity
11/19/2013	*Rhizoctonia solani* damping-off development assay	Cucumbers	*Rhizoctonia solani*	Various concentrations of *R. solani* inoculated ground up barley and aerated and nonaerated CTs	None of the treatments showed signs of damping off
3/20/2014	*Rhizoctonia solani* damping-off development assay	Cucumbers	*Rhizoctonia solani*	Two levels of increased concentrations of *R. solani* inoculated ground up barley and aerated and nonaerated CTs	No significant difference between the controls and the CT treatments

4/4/2013	*Botrytis cinerea* spore germination assay development	microscope slide	*Botrytis cinerea*	Various concentrations of *B. cinerea* and bean and spinach leaf extract	Was found that spinach leaf extract at 1/100 is best for germination assay
4/13/2013	*Botrytis cinerea* spore germination assay	microscope slide	*Botrytis cinerea*	various concentrations of *B. cinerea* and bean and spinach leaf extract, aerated and nonaerated CTs	Most aerated and nonaerated CTs are able to suppress B. cinera germination in a spinach extract in a 1/10 and 1/100 dilution. However the 1/100 spinach dillution showed a much higher degree of suppression.
4/22/2013	*Botrytis cinerea* spore germination assay	microscope slide	*Botrytis cinerea*	Various concentrations of *B. cinerea* and bean and spinach leaf extract, aerated and nonaerated CTs	All aerated and nonaerated CTs were able to suppress B cinera germination. Nonaerated Buffaloam composts suppression was much greater than the other composts.
9/3/2014	*Botrytis cinerea* spore germination assay	microscope slide	*Botrytis cinerea*	Aerated CTs and biocontrol addatives	All CTs with and without additives and biocontrols were able to significantly suppress *B. cinerea spore* germination. Four of the six CT treatments showed no germination. The ACT TP with biocontrols showed some germination and showed longer hyphal lengths of the spores that were germinated compared to the water control.
9/25/2014	*Botrytis cinerea* spore germination assay	microscope slide	*Botrytis cinerea*	Aerated CTs and biocontrol addatives	All the treatments showed control of *B. cinerea* germination compared to the water control. Seven of the treatment showed nearly a 100% contol. The two biocontrols on their own showed 79% and 49% control compared to the 39% control in the water treatment.
10/22/2014	*Botrytis cinerea* spore germination assay	microscope slide	*Botrytis cinerea*	Designer aerated and nonaerated CTs, biocontrol addatives.	All the treatments showed control of *B. cinerea* germination compared to the water control with the exception of the biocontrol Serenade on its own. 15 of the 21 treatments showed more than 90% control. The water control had a 48% germination rate.

2/17/2014	CTs to suppress *Botrytis cinerea* on Kale	Kale	*Botrytis cinerea*	Aerated and nonaerated CTs, additives, preactivation	No apparent suppression of the disease by CTs
4/9/2014	CTs to suppress *Botrytis cinerea* on geranium cuttings	Geranium cuttings	*Botrytis cinerea*	Aerated and nonaerated CTs	The CTs did not suppress the disease
9/3/2014	CTs to suppress *Botrytis cinerea* germination on grape leaves	Grape leaves	*Botrytis cinerea*	Aerated CTs, biocontrol addatives	There was no significant difference between the CTs and the control
10/8/2013	CTs to suppress Powdery mildew on cucumbers I	Cucumber	Powdery mildew	Aerated CTs, additives, mixed compost, lacto bacilli	There was a significant difference between some compost teas and the controls
10/23/2013	CTs to suppress Powdery mildew on cucumbers II	Cucumber	Powdery mildew	Aerated and nonaerated CTs, additives, mixed compost, lacto bacilli	There was a significant difference between some compost teas and the controls
11/18/2013	CTs to suppress Powdery mildew on cucumbers III	Cucumber	Powdery mildew	Aerated and nonaerated CTs, addatives, mixed compost	There was a significant difference between some compost teas and the controls
11/29/2013	CTs to suppress Powdery mildew on cucumbers IV	Cucumber	Powdery mildew	Aerated and nonaerated CTs additives, mixed compost, folier and drench	There was a significant difference between some compost teas and the controls
2/17/2014	CTs to suppress Powdery mildew on cucumbers V	Cucumber	Powdery mildew	Aerated and nonaerated CTs additives, mixed compost, foliar and drench	There was a significant difference between some compost teas and the controls
5/30/2014	Designer CTs to suppress Powdery mildew on cucumbers	Cucumber	Powdery mildew	Multi designer composts aerated and nonaerated CTs	There was a significant difference between some compost teas and the controls
8/29/2014	Designer CTs to suppress Powdery mildew on cucumbers	Cucumber	Powdery mildew	Multi designer composts aerated and nonaerated CTs	There was a significant difference between a number of the compost teas and the negative control for disease rating, true leaves, and leaves killed
8/20/2014	CTs to suppress Powdery mildew on detached cucumber leaves	Cucumber	Powdery mildew	Aerated and nonaerated CTs	There was a significant difference between some compost teas and the controls

Figure 2. Healthy kale plants (left) and infected with *Botrytis cinerea* (right).

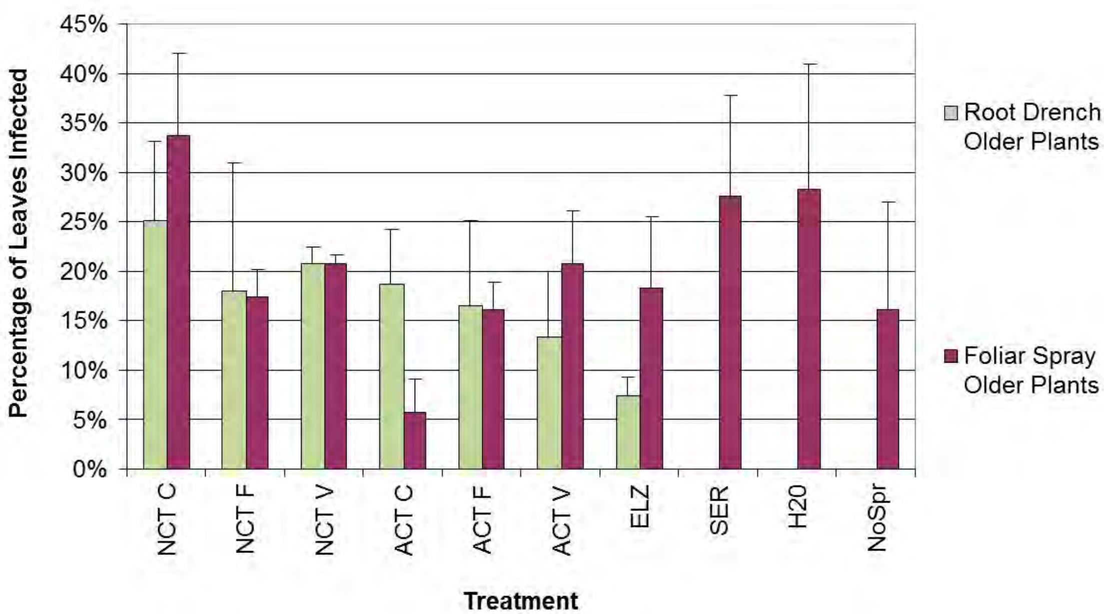


Figure 3. Example of results from kale bioassay for evaluation of compost teas for control of gray mold (caused by *Botrytis cinerea*) . (NCT C= nonaerated Tuthill compost, stored in coldroom; NCT F = nonaerated Tuthill compost, fresh; NCTV = nonaerated Vermicompost; ACT C = aerated Tuthill compost, stored in coldroom; ACT F = aerated Tuthill compost, fresh; ACTV = aerated Vermicompost; ELZ = compost tea from Elzinga-Hoeksema greenhouses, prepared with Morgan's Blend compost mix; SER = Serenade biofiungicide (Bacillus subtilis) – not applied as drench; H2O is water control (not applied as drench), and NoSpr = the non-inoculated control was not sprayed or treated with a root drench.

Plant-insect bioassays

Insect bioassays are described in detail in previous progress reports. A preliminary experiment was run with blueberry aphids (*Illinoia pepperi*) on blueberry plants (*Vaccinium corymbosum*). Aphids were individually transferred onto young shoots of potted blueberry plants from leaves of infested plants using small paintbrushes. Compost teas were applied with a hand-held sprayer until runoff. Aphids were counted 0, 18, 46 and 64 h after the start of the experiment. In the end, blueberry aphids on blueberry plants were not selected as a model insect bioassay due to their finicky nature, making them difficult to work with. In addition, the perennial nature of the plant and the length of time to obtain new blueberry shoots for the bioassay were considered too problematic for an efficient assay. Instead, bird-cherry oat aphids (*Rhopalosiphum padi*) on barley (*Hordeum vulgare*) were selected for the bioassay. A colony of these aphids was established. Special care had to be taken to avoid infestation by parasitic wasps.

Experiments with bird cherry oat aphids
Barley (cv. Conlon) (seed obtained from Johnny's Selected Seeds in Waterville, ME) was grown in 4" square pots in a growth chamber with an 18- hour photoperiod, maintained at 27°C, and a relative humidity of approximately 80%. Aphid-infested barley leaves were draped over 1-week-old barley plants, allowing aphids to crawl onto the new plants by themselves, thus decreasing the chance of injury during transfer. Aphids (Fig. 4) were placed on the plants 1 day prior to treatment. A number of different aerated and non-aerated compost teas were prepared

Figure 4. Bird cherry oat aphid on barley leaves (left). Magnification of aphids (right, IPM Images) (right).

and sprayed on the plants. The treatments were as follows:

1. Water control **(H2O)**
2. Aerated Compost Tea from Elzinga **(ELZ)**
3. Vermicompost compost tea (24-h aerated fermentation) **(ACTV)**
4. Tuthill (from cold storage) compost tea (24-h aerated fermentation) **(ACTC)**
5. Tuthill (fresh) compost tea (24-h aerated fermentation) **(ACTF)**
6. Vermicompost compost tea (14-day non-aerated fermentation) **(NCTV)**
7. Tuthill (from cold storage) compost tea (14-day non-aerated fermentation) **(NCTC)**
8. Tuthill (fresh) compost tea (14-day non-aerated fermentation) **(NCTF).**

Aphid numbers were initially quite low, then increasing rapidly at 8 days (Fig. 5B). There were no significant differences between the treatments as aphid populations increased in all treatments, although the number of aphids tended to be somewhat lower in most compost tea treatments compared to the water control. In a second trial, results were similar and there was no significant effect of compost tea treatment on the bird cherry oat aphids.

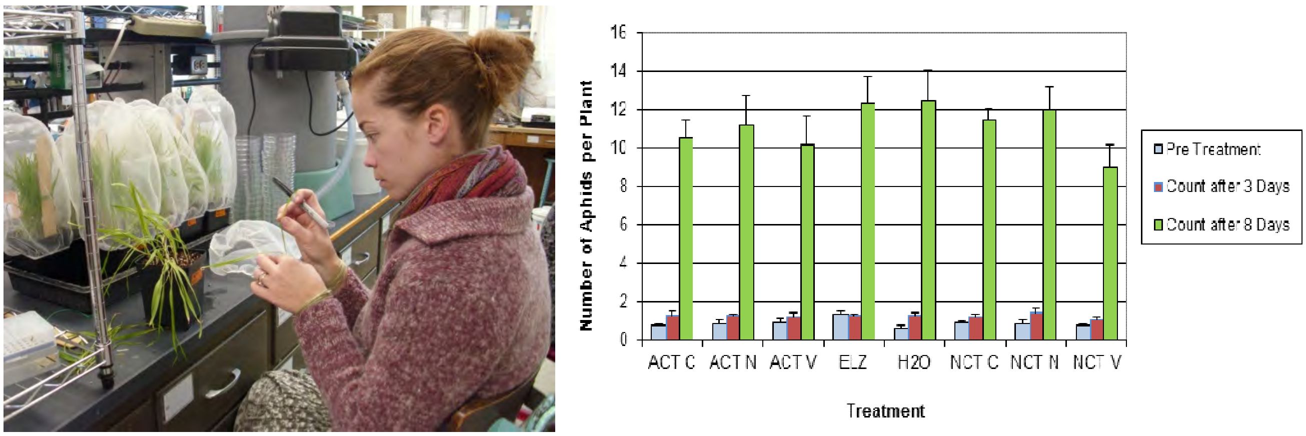


Figure 5. A) Graduate student Brooke Comer counting bird-cherry oat aphids on barley plants. Note pots of barley covered with mesh bags to prevent cross-over of aphids between pots. B) Number of bird cherry oat aphids per barley plant after foliar treatment of plants with compost teas. Aphids were counted before spraying the plants and 3 and 8 days later. H2O indicates the water control.

An experiment was also conducted to investigate the effect of adding Mycotrol O (*Beauveria bassiana*, an insect-pathogenic fungus) alone and in combination with compost teas:

1) Mycotrol O at recommended application rate (1:400 ratio- so 2.5 ml Mycotrol to 1 liter water - using Tween 20 as an surfactant)
2) Compost tea- aerated 24 hours, compost pre-activated with Mycotrol O 5 days prior to being used in compost tea (1.23 ml per 2 lb compost)
3) Mycotrol O at a same concentration used to amend the compost for compost tea
4) Compost tea- aerated 24 hours
5) Water control

There were 8 replications per treatment. Aphids were allowed to get established and were counted prior to application of treatments. Sprays were applied foliarly with hand-sprayers. Plants were maintained in a growth chamber. Aphid populations generally increased at the first count after 2 days but then decreased at 11 days, primarily due to leaf senescence. Although the water control had the highest aphid populations at both rating times, the differences among treatments were not statistically significant due to high variability in aphid populations. Adding Mycotrol (*Beauveria bassiana*, an insect-parasitic fungus) resulted in the lowest number of aphids compared to the water control and other treatments and was evident in fungal infection (“white fuzzy aphids) and death of aphids. However, none of the treatments were particularly strong. The experiments with bird cherry oat aphid suggest that there is limited efficacy of compost teas against this insect. The first experiment with the blueberry aphid on blueberries seemed more promising but was only replicated in a limited fashion. Due to the limited effectiveness of compost teas against insects, we decided to focus our efforts on disease control.

2) ***Evaluate grower-produced compost teas to examine variability between batches and/or recipes***

   a) *Batch consistency of grower-produced compost teas*

We assessed the variability of the compost tea produced at Elzinga & Hoeksema Greenhouses in Kalamazoo, Michigan. The compost tea was brewed from a 1:1 mix of the commercial Morgan's Blend Compost (Morgan Composting, Sears, MI) and soil potting mix. The blended compost was "pre-activated" with oat flakes for 5 days to stimulate fungal growth. After pre-activation, the compost (8 lb) was fermented for 24 hours using a 25-gallon aerated Compost Tea System (Growing Solutions, Inc., Eugene, OR). The following additives were used prior to fermentation:

- 8 oz of the Growing Solutions catalyst
- 2 oz of Drammatic "O" liquid fertilizer (Dramm Corporation, Manitowoc, WI)
- 2 oz of Humax (JH Biotech, Inc., Ventura, CA)
- 1 oz of Acadian seaplant kelp meal (100% *Ascophyllum nodosum*, Acadian Seaplants Limited, Nova Scotia, Canada)

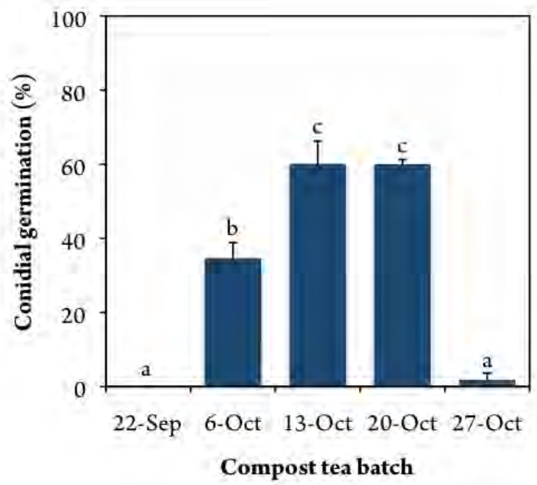


Figure 6. Conidial germination of *Botrytis cinerea* when in contact with different batches of grower-produced compost tea, fermented for 24 hours under aerobic conditions.

We collected and tested four different batches of compost tea that were prepared on: September 22, October 6, 13, 20, and 27, 2011. These had inhibitory properties against conidial germination of *Botrytis cinerea* (from 40 to 100% inhibition) (Fig. 6). Significant differences were observed between the compost tea batches ($P < 0.001$). We later discovered that the person making the compost tea had not followed the exact same procedure each time and had introduced some variation which may explain the differences in disease suppressiveness of the tea batches. The need for reproducibility of compost teas is an important consideration.

   b) *Batch consistency under controlled conditions in the laboratory*

This experiment was conducted to verify consistency between brewing methods (aerated and non-aerated) and to compare various brewing parameters, such as electrical conductivity (EC), number of bacterial colonies, temperature, and oxygen level. Transplant and Dairy Doo composts were used for this experiment. All teas were made with 1 part compost and 5 parts water where the compost was placed in a paint strainer bag and suspended in water in inverted soda bottles. The aerated compost tea was brewed with aeration for 2 days and the Non-aerated compost was steeped without aeration for 14 days. The teas were brewed in three replicates and all the parameters were measured for each replicate. All the teas were brewed in four consecutive batches from the same composts. The number of bacterial colonies was measured by serially diluting the compost tea, plating on nutrient agar plates and incubating them for 3-5 days before counting the number of distinct colonies on the plate. Differences in temperature and oxygen content were not significant. There were no statistically significant differences in Electrical conductivity and number of bacterial colonies either but there are visual differences which are more related to the type of teas and brewing method (Fig. 7). Non-aerated teas displayed higher numbers of bacterial colonies as compared to the aerated teas, and Dairy Doo compost tea appeared to be richer in bacteria than Transplant compost tea in both brewing methods.

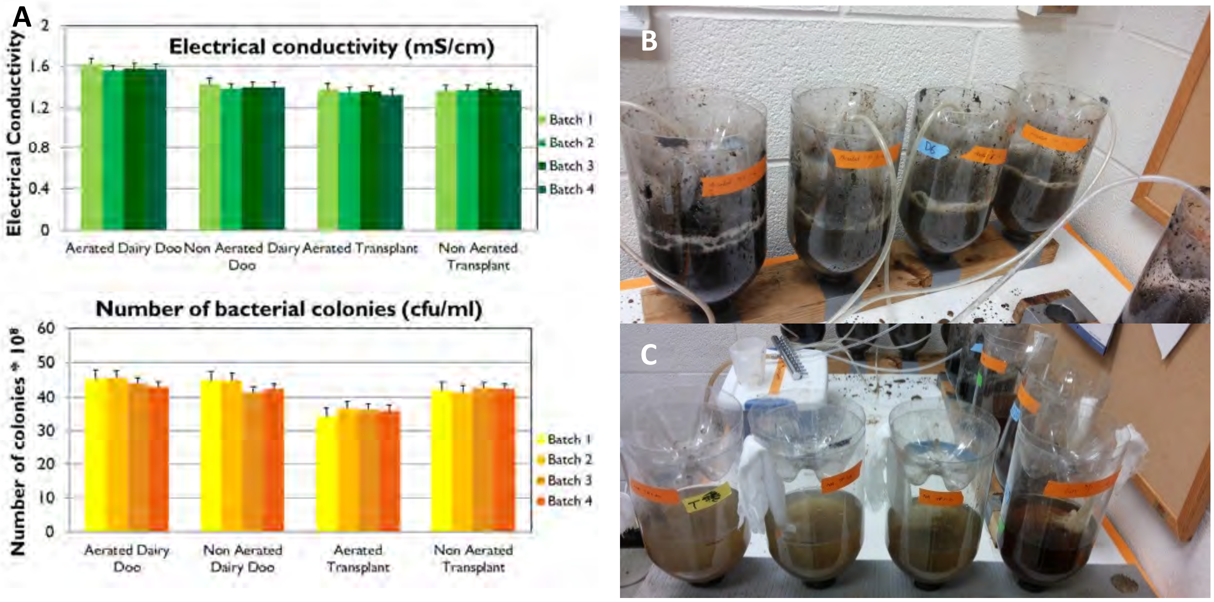


Figure 7. A) The differences in electrical conductivity and number of bacterial colonies among the various batches of compost tea and different brewing methods. Number of bacterial colonies is measured in colony forming units (cfu) per ml. B) The set-up for the aerated brewing method, and C) the non-aerated brewing system

3) Evaluate the effects of substrate, brewing method and time, addition of biocontrol agents and adjuvants on disease and insect suppressiveness

a) Experiments using the Botrytis spore germination assay,

The effects of substrate, brewing method and time, and the addition of biocontrol agents were studied and described in detail in the 2011 and 2012 progress reports. In general, compost source and brewing method affected inhibition of spore germination of *B. cinerea*, with non-aerated compost teas frequently being more effective than aerated compost teas. Brewing time was also a significant factor, with longer brewing periods generally producing better results. We therefore decided that for aerated compost teas, we would use 48 hours and for non-aerated teas 14 days as our guideline for future experiments.

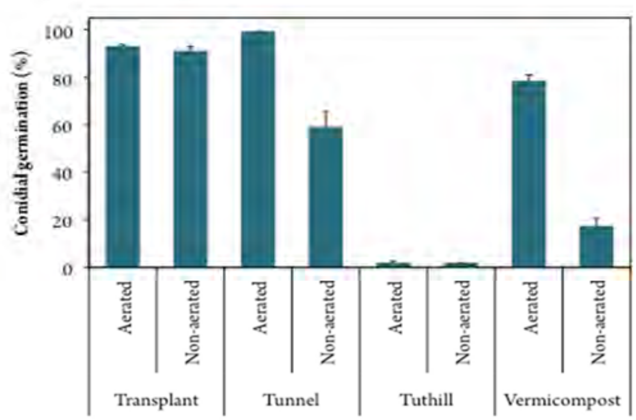


Figure 8. Conidial germination of Botrytis cinerea when place in contact with compost teas made from different composts (Transplant = plant-based, Tunnel = plant-based, Tuthill = manure + yardwaste + leaves, and Vermicompost = manure and food scraps). The compost teas were fermented for 24 hours under aerated and non-aerated conditions.

Of particular interest was the change in the Transplant compost tea which significantly increased its inhibitory properties as the fermentation progressed, regardless of the brewing method (non-aerated vs. aerated). Likewise, it was also interesting that the Tuthill compost tea remained highly effective against *B. cinerea*, regardless of the brewing method and time.

To test the efficacy of diluted compost teas to inhibit the germination of *B. cinerea*, we evaluated two 10-fold serial dilutions (i.e. 1:10 and 1:100). Our results demonstrated that diluted compost teas (aerated and non-aerated Tuthill compost tea and non-aerated vermicompost tea, have significantly reduced activity against *B. cinerea*. More diluted compost teas became gradually less effective.

Two composts were chosen to evaluate the effect of amending the fermentation with the biopesticide Serenade Max (AgraQuest, Inc., Davis, CA) at a rate of 3 lb/Acre (i.e. 7 g/L). We chose the Transplant and Tuthill composts due to their evident differences in biological activity against *B. cinerea*, the former having no significant pathogen-inhibitory properties. The addition of the biopesticide Serenade Max significantly improved the performance of the Transplant compost tea in terms of *B. cinerea* germination inhibition. Non-amended Transplant compost tea allowed *B. cinerea* to germinate (> 90% conidial germination) whereas Serenade-amended Transplant compost tea (either aerated or non-aerated) inhibited the germination of *B. cinerea* to below 6%. On the other hand, Serenade-amended Tuthill compost tea performed as well as the non-amended compost tea. This suggests that the addition of the biopesticide to the fermentation of Tuthill compost is not necessary.

Six different types of aerated vermicompost teas were evaluated to determine the variability in their inhibitory properties against *B. cinerea*. Types of vermicompost that were used in the fermentations: The vermicompost made with dairy manure was more effective at reducing *B. cinerea* spore germination than plant-based vermicomposts. Due to the trend towards

b) Grape field trial in 2013 for powdery mildew and downy mildew

The experiment was conducted in a mature vineyard at the MSU Clarksville Research Center in Clarksville, MI. Treatments were applied to 3-vine plots and were replicated 4 times in a randomized complete block design. Transplant (TP) compost tea was prepared from thermophilic compost made of equal parts straw, alfalfa hay, grass hay, peat, woodchips, and soil. Vermicompost tea was prepared from pre-consumer food waste and leaves fully composted by *Eisenia foetida*. Buffaloam compost tea was made from Buffaloam (Diamond Tail Ranch, Glendevey, CO), a buffalo manure-wood shaving mixture composted for over 1 year. Compost teas were made with both aerated and non-aerated brewing methods. For non-aerated tea, fermentation occurred over 10 days at room temperature with light hand stirring every other day. For aerated tea, bubbler stones connected to an aquarium pump in 1-gal buckets provided aeration for 24 to 48 hours at room temperature. All teas were made at 1 part compost to 5 parts water. The aerated transplant compost tea was also applied in concert with Serenade, a commercial formulation of the biocontrol agent *Bacillus subtilis*. All treatments were applied with the spreader-sticker NuFilm P, which was also applied as a treatment on its own. Positive and negative control treatments, untreated and a conventional fungicide regimen, respectively, were also used. Sprays were applied based on phenological stages, for a total of 9 sprays. Diseases were visually rated on 25 randomly selected leaves and clusters per plot. Disease incidence was calculated as % leaves or clusters with disease, severity was calculated as % area symptomatic on diseased plant parts only, and overall severity as incidence x severity)/100. For all diseases and respective plant parts, the compost tea treatments were statistically better than the untreated control. For downy mildew, both aerated and non-aerated Buffaloam compost tea and non-aerated vermicompost were statistically better than the conventional fungicide control. The aerated Buffaloam compost tea statistically controlled disease better than the conventional fungicide for powdery mildew on the leaf as well. While NuFilm P provided some disease control by itself, the combination of compost teas + NuFilm P was generally more effective.

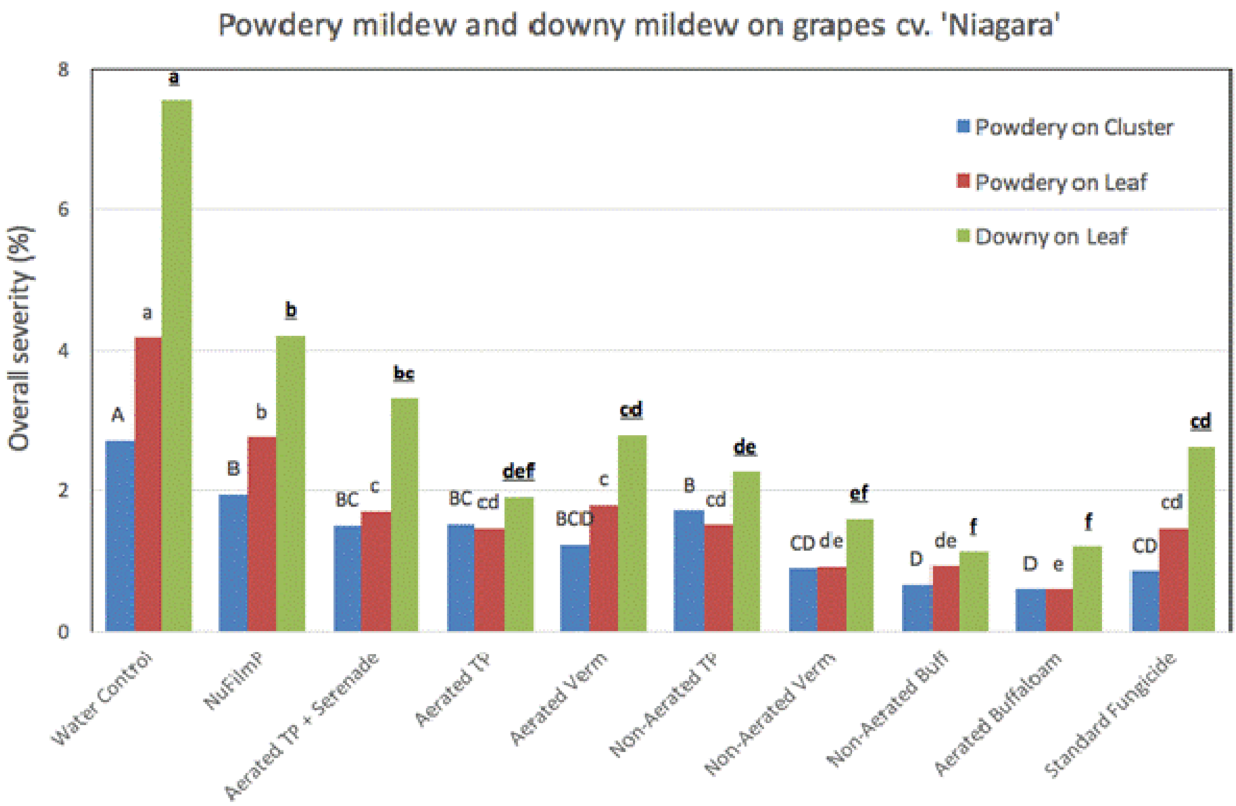


Figure 9. Comparison of aerated and non-aerated compost teas (CT), the spreader-sticker NuFilm P, a CT spiked with the biological control Serenade Max (*Bacillus subtilis*), and a standard fungicide (Manzate/Sovran/Orius/ Phostrol/Revus Top), for their ability to suppress powdery and downy mildew on grapevines. TP=transplant compost, Verm=vermicompost, Buff=Buffaloam compost. All the CTs used NuFilm P as an adjuvant. Bars of the same color sharing the same letter are not significantly different from each other at $P \leq 0.05$.

c) Grape trial in 2014 for black rot, powdery mildew, downy mildew, and Phomopsis control

The experiment was conducted in a mature vineyard at the Clarksville Research Center in Clarksville, MI on 'Niagara' grapes. Vines were spaced at 7 x 9 ft and were cordon trained on a 2-wire trellis and hand pruned. Treatments were applied to 4-vine plots and were replicated 4 times in a randomized complete block design. Compost tea was made with vermicompost from MSU prepared from pre-consumer food waste and leaves fully composted by *Eisenia foetida*. Brewing methods for compost tea were both aerated for 48 hours, and non-aerated for 14 days (two treatments). Compost tea was incorporated into a spray schedule with the fungicides lime sulfur and Cueva, as well as the same spray schedule of lime sulfur and Cueva with water sprays as a control treatment. The other positive and negative control treatments in the study were untreated and a conventional fungicide spray schedule of Manzate, Rally, Abound, and Ziram. Sprays were applied weekly and roughly coincided with phenological stages. There were 11 total spray dates, though some treatments did not receive all sprays (conventional fungicide sprays were on the 2nd, 3rd, 4th, 6th, and 8th spray dates only). Diseases were visually rated on 25 randomly selected leaves and clusters from the center vine in each plot. Black rot and powdery mildew were rated on both leaves and clusters, downy mildew on leaves only, and Phomopsis on the clusters (both rachis and fruit). Disease incidence was calculated as % leaves or clusters with disease, and severity was calculated as % area symptomatic on diseased plant parts only. Overall severity was calculated as (incidence x severity)/100. Disease pressure was very low in this plot; it is unclear how compost tea would have responded under a higher disease pressure situation. The aerated compost tea used in a spray schedule with the fungicides lime sulfur and Cueva controlled the disease particularly effectively for all of the diseases that were assessed, with no statistical difference between this spray regimen and the conventional fungicide spray program (Figures 10 A & B, additional data not shown for black rot and downy mildew).

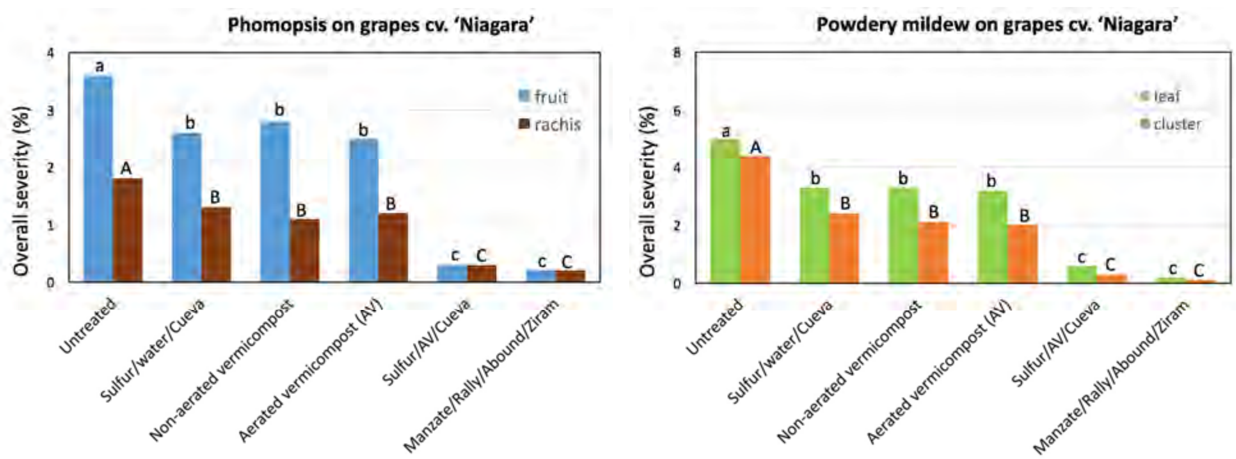


Figure 10: Effect of compost teas applied as a foliar spray on Phomopsis on both the rachis and the fruit (A) and powdery mildew on both the leaf and the cluster (B) after 12 applications. Bars of the same color sharing the same letter are not significantly different from each other at $P \leq 0.05$.

d) Grape trial in 2014 for powdery mildew control

The experiment was conducted in a mature experimental 'Riesling' vineyard in Traverse City, MI on 'Riesling' grapes. Treatments were applied to 3-vine plots and were replicated 4 times in a randomized complete block design. Three varieties of compost tea were used, all from the starting compost of Dairy Doo from Morgan's Composting, Inc. Dairy Doo only was used for aerated compost tea, brewed 48 hours without additives, and for non-aerated compost tea, fermented two weeks with occasional stirring. For each of these the ratio of compost to water was 1:5. A proprietary blend of Dairy Doo with additives including fish emulsion and kelp extract was also used (referred to as "Morgan's blend"), aerated in a 300 gallon brewer for 24 hours at an approximate ratio of 1:50. Compost teas were applied weekly, either as a foliar spray or as a root drench. A negative control of an untreated treatment was used, for a total of 7 treatments. Powdery mildew was visually rated on 25 randomly selected leaves and clusters from the center vine in each plot. Disease incidence was calculated as % leaves or clusters with disease, and severity was calculated as % area symptomatic on diseased plant parts only. Overall severity was calculated as (incidence x severity)/100. Soil samples from the top 6 inches were analyzed for activity of 7 soil enzymes involved in soil organic matter decomposition, indicating soil microbiological activity. For the leaves, the foliar sprays were more effective at disease suppression than the drenches (Figure 11), this was also generally true for disease on the fruit. There were differences between the various compost substrates as well, with the Dairy Doo being generally more effective than the Morgan's blend. This may be due in part to the greater compost to water ratio of the former relative to the latter. Whether a compost tea was aerated or non-aerated, however, did not have statistical significance when used as either a drench or a foliar spray. In general, compost teas suppressed microbial extracellular enzyme activity compared to the untreated control, which was rather unexpected and indicates the need for further research into the effects of compost teas on soil biology and organic matter.

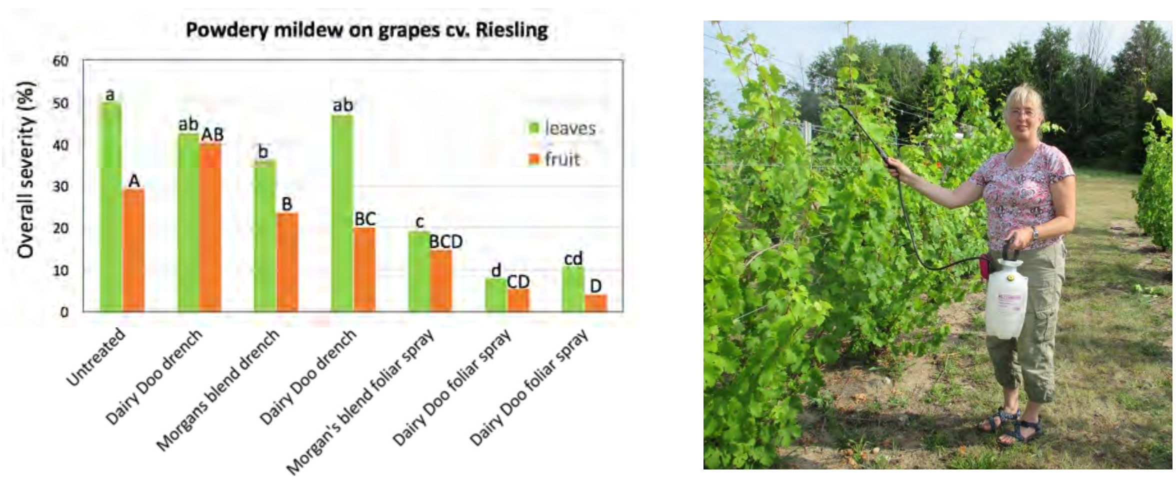


Figure 11: A) Effect of compost teas applied weekly as a spray or a soil drench on powdery mildew severity on cv. Riesling leaves and fruit in 2014. Bars of the same color sharing the same letter are not significantly different from each other at $P \leq 0.05$. B) Compost tea application to 'Riesling' grapevines in Traverse City, MI.

e) *Grape trial in 2015 for black rot, powdery mildew, downy mildew, and Phomopsis control*

The experiment was conducted in a mature vineyard at the Clarksville Research Center in Clarksville, MI. Vines were spaced at 7 x 9 ft and were cordon trained on a 2-wire trellis and hand pruned. Treatments were applied to 4-vine plots and were replicated 4 times in a randomized complete block design. Compost tea was made with Dairy Doo® compost from Morgan's Composting, Inc. Two gal of Dairy Doo compost was placed into a 1 gal mesh paint strainer bag and then immersed in 10 gal of on non-chlorinated well water and allowed to steep for 2 weeks with agitation for several minutes every two days. Compost dilutions were made with non-chlorinated well water. Treatments included the compost tea undiluted and diluted at 1:2, 1:5 and 1:10. Treatments were applied following approximate phenological stages, and were sprayed approximately weekly or biweekly, with application timing being a treatment factor. Undiluted compost tea was applied with and without the spreader-sticker NuFilm P, both weekly and biweekly, and in a spray schedule alternating with Cueva, a copper based organic fungicide. Positive and negative control treatments, untreated and Double Nickel respectively, were also used. Diseases were visually rated on 25 randomly selected leaves and clusters from the center vine in each plot. Black rot and powdery mildew were rated on both leaves and fruit clusters, downy mildew on leaves only, and Phomopsis on the clusters (both rachis and fruit).

Disease incidence was calculated as % leaves or clusters with disease, and severity was calculated as % area symptomatic on diseased plant parts only. Overall severity was calculated as (incidence x severity)/100. There were significant differences in the disease suppressive effects of the various treatments relative to the untreated control and one another.

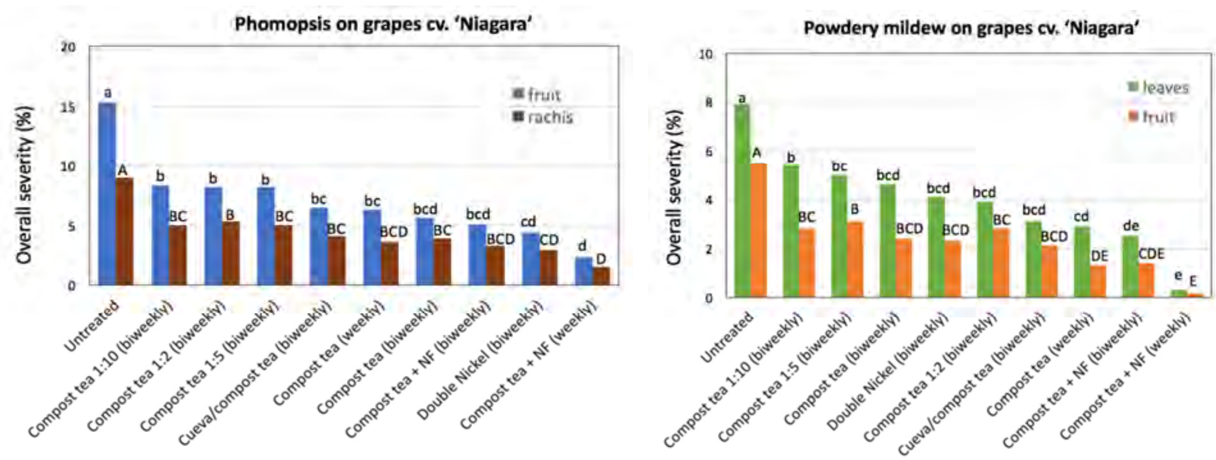


Figure 12: Effect of compost teas applied as a foliar spray on Phomopsis on both the rachis and the fruit (A) and powdery mildew on both the leaf and the cluster (B) after 6 or 12 biweekly or weekly applications, respectively. NF=NuFilm P. Numbers as part of treatment represent dilution rates of compost tea. Bars of the same color sharing the same letter are not significantly different from each other at $P \leq 0.05$.

f) Tomato trial in 2016 for tomato leaf mold, Fulvia fulva

The experiment was conducted in a passive solar greenhouse located at the Student Organic Farm of MSU in Holt, MI. The varieties 'Celebrity' and 'Big Beef' were used. Treatments were applied to 2-plant plots and were replicated 3 times in a randomized complete block design. Three composts were used to make compost teas. "LGC" compost tea was prepared from thermophilic compost made of dry leaves, fresh cut grass, and coffee grounds. Vermicompost tea was prepared from pre-consumer food waste and leaves fully composted by *Eisenia foetida*. Dairy Doo compost tea was made with Dairy Doo compost from Morgan's Composting, Inc. The vermicompost tea was also used in a treatment in which NuFilm P. Unsprayed plants were used as a negative control. All compost teas were made with aeration at a rate of 1 part compost to 5 parts water, being brewed for 48 hours. Treatments were applied weekly for 12 weeks. Diseases were visually rated on 30 leaves from 2 plants as disease incidence, severity and overall severity as described above. Harvest data were collected throughout the season for both number of tomatoes harvested and total weight of harvested tomatoes. For 'Celebrity' tomatoes the Dairy Doo compost tea and the vermicompost tea with NuFilm P decreased overall severity compared to the untreated control. For 'Big Beef' all treatments were statistically better than the untreated control. In 'Celebrity', vermicompost tea resulted in the highest yield for both number of tomatoes and total weight (data not shown). Differences observed between 'Celebrity' and 'Big Beef' tomatoes may be due in part to the dense and compact nature of the former providing more ideal conditions for proliferation of leaf mold and therefore having higher disease pressure.

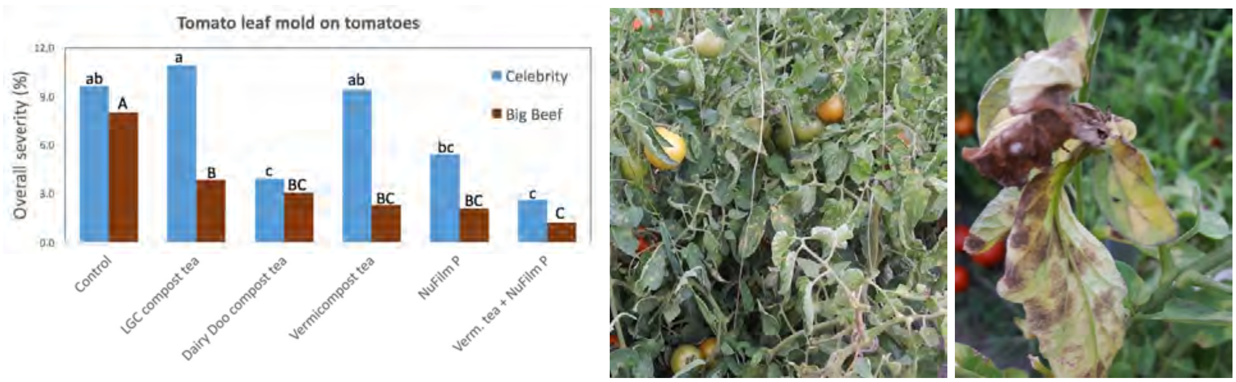


Figure 13: A) Effect of compost teas on tomato leaf mold on tomato varieties 'Celebrity' and 'Big Beef' after weekly applications. Different composts were used to make compost teas: leaf/grass/coffee (LGC) compost, Dairy Doo, and vermicompost. The adjuvant NuFilm P was a treatment on its own and with vermicompost tea. Bars of the same color sharing the same letter are not significantly different from each other at $P \leq 0.05$. B) Tomato plants infected with tomato leaf mold, C) Close-up of tomato leaf mold on underside of a tomato leaf.

g) Winter squash trial in 2016 for powdery mildew, Podosphaera xanthii

The experiment was conducted at the Student Organic Farm of MSU in Holt, MI. Three cultivars of winter squash were used: butternut ('Waltham'), delicata and hubbard ('Blue Ballet'). Treatments were applied to 2-plant plots and were replicated 3 times in a randomized complete block design. Three composts were used to make compost teas as described under the tomato experiment. Unsprayed plants were used as a negative control. Treatments were applied weekly, for a total duration of 12 weeks. Diseases were visually rated on 30 randomly selected leaves from the two plants in the experimental unit. The only variety for which there was a significant difference between treatments was the butternut squash (Figure 14). All treatments reduced the disease relative to the untreated control, however, the treatments did not differ significantly from one another.

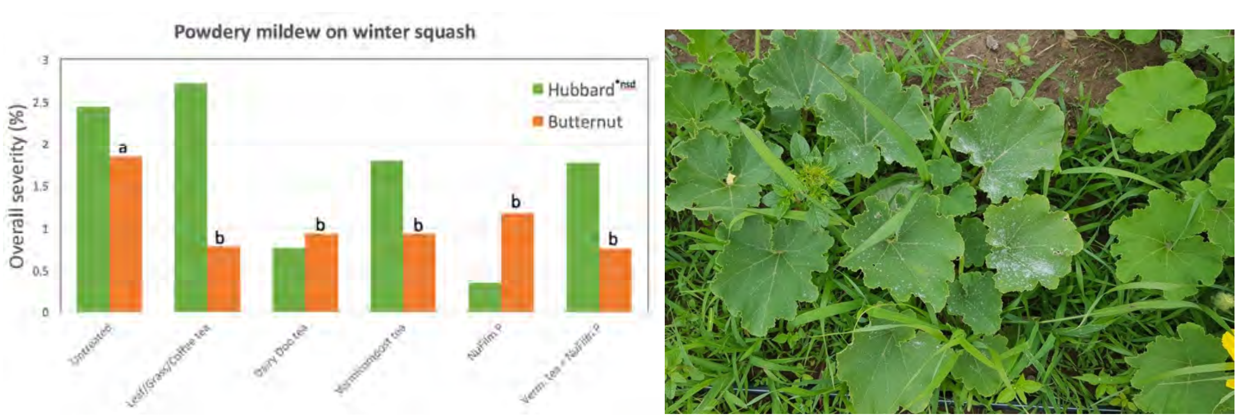


Figure 14: Effect of compost teas applied as a foliar spray on powdery mildew on winter squash varieties Hubbard and Butternut. Bars of the same color sharing the same letter are not significantly different from each other at $P \leq 0.05$. *no significant difference in disease for the hubbard squash.

Comments on the effect of substrate:
The 2013 grape field trial tested three different composts: Buffaloam (primary feedstock: hot-composted buffalo manure), vermicompost (primary feedstocks: vegetable kitchen waste and dry leaves composted by worms), and transplant compost (primary feedstocks: hot-composted straw, hay, wood shavings, and peat). From the 2013 grape field trial, there were significant differences between some of the compost teas based upon the starting compost, but not all and the differences were consistent across all three diseases/plant parts of downy mildew on the leaf, and powdery mildew both on the leaf and on the fruit. The composted buffalo manure overall was more effective for disease suppression for all diseases.

The 2014 'Riesling' grape trial used the same compost, but for one treatment there were modifications to the compost prior to brewing, referred to as Morgan's blend. From the 2014 'Riesling' trial there were statistical differences in effectiveness of the compost teas made from the two composts for disease suppressiveness. Powdery mildew on the leaves had less overall severity with the Dairy Doo compost tea as compared with the Morgan's blend compost tea.

The vegetable field trials of 2016 for both tomatoes and winter squash had substrate as a variable being tested, having used three different composts to make compost teas. There appeared to be differences in substrate effects on disease suppressive ability in the trial with tomatoes in 2016. Dairy Doo compost tea outperformed the compost tea made from the vermicompost and the leaf/grass/coffee for the 'Celebrity' tomatoes, however, there was no statistical significance in differences in the variety 'Big Beef' from one substrate to another. The trial with winter squash demonstrated no significant difference in ability of these particular compost teas to suppress disease based upon substrate.

In another experiment, composts were made with varying feedstocks with a primary aim of assessing the effects on the nutrients and biology of the resultant composts. These composts were used in compost tea trials wherein the nutrient content of compost teas was evaluated as well as the teas for disease suppressive abilities. In the development of bioassays in objective 1, many of the bioassays used these composts to assess differences between the substrates. These are referred to as "designer composts" in the results and discussion. Microbial counts of the compost teas made from these designer composts were plated onto potato dextrose agar (PDA) after dilution to a concentration of 10^4 and 10^5 colonies per mL for counting bacterial colonies. Direct counts of microbes by light microscopy were also carried out, counting bacteria, fungi and protozoa. For all of these teas, readings of electrical conductivity and dissolved oxygen were taken. The designer composts were used in two of the trial runs of compost tea effectiveness against Pythium on dry beans, and in two of the trial runs of compost tea effectiveness against powdery mildew on cucumbers. Additionally, these teas were used in the germination bioassay of *Botrytis cinerea* spores. For the designer composts, there were statistical differences between different compost substrates used to make the compost teas. Compost tea made from a designer compost of hot composted dry leaves, fresh grass, and pine wood shavings was consistently one of the better performers.

Substrate, or the compost from which the compost tea is made, has a distinct effect on the efficacy of a compost tea to control disease. There are many differences within composts, from the biology to the nutrients and other chemical factors such as pH and electrical conductivity. All of these may play a role in how effective a compost tea is at suppressing disease. In many of the trials, there were statistically significant differences based upon the compost, when brewed and applied in the exact same manner.

Comments on effect of brewing method
The primary brewing methods used were aerated or non-aerated. Initial trials indicated an ideal length of brewing of 14 days for non-aerated teas, and 24-48 hours for aerated teas. When feasible within the experimental design, these brew times were used. There were instances, however, when a shorter period was used, particularly in field trials for non-aerated teas with weekly sprays a 7-day brew time was used. With all of these, however, length of brewing time was not being assessed for these brew methods, but rather whether the tea was aerated or non-aerated.

Field trials conducted in 2013 and 2014 on 'Niagara' grapes in SW Michigan included treatments of compost teas that were brewed using both methods. In 2013 there were three different composts used that were brewed both with and without forced air: vermicompost (from worms processing food waste and leaves), hot composted buffalo manure, and hot composted vegetative material such as straw and hay. In the grape field trial of 2013, the only compost for which the brewing method appeared to have a difference was with the vermicompost teas. For both downy mildew and powdery mildew on the leaf, non-aerated vermicompost tea was significantly more effective at controlling the diseases than the aerated vermicompost tea, 79% versus 63% and 79% and 57% for downy and powdery mildew, respectively. For all others comparing the compost tea made with and without forced air there were no significant differences.

In 2014 only one compost was used, brewed using both aerated and non-aerated methods.
In the grape field trial of 2014 for three of the seven the diseases being rated on the various plant parts, non-aerated compost tea was numerically more effective than aerated, and for four of seven aerated was numerically more effective. None of these differences were significant, however. For all of the compost tea treatments, they were significantly different than the untreated control.

The 2014 'Riesling' grape trial treatments included teas that were aerated and non-aerated from the same compost substrate, thereby looking at differences in the effectiveness of the brewing method. Non-aerated teas were brewed for 7 days, and aerated teas actively aerated for 48 hours. The 2014 'Riesling' grape field trial showed no statistical difference between the aerated and non-aerated teas whether they were applied as a drench or as a foliar spray. As a drench the difference in the overall severity was numerically great but due to the high degree of variability within the treatment there was no statistical significance.

In conclusion, brewing method appears to have an effect under some circumstances, but the effect was not consistent across all of the diseases, as in 2014 'Niagara' grape trial in which aerated teas had greater efficacy for some diseases but decreased efficacy for others. In many trials there were not significant differences between compost teas that were aerated versus non-aerated. Considering the variability in whether aerated versus non-aerated teas were more effective, the general conclusion could be made that aeration is not necessary to obtain disease suppression. This may decrease the barrier to use of compost teas as specialized equipment would not be needed. Time for preparing teas may play a prominent role as well, however, considering the length of brewing time for aerated being much shorter than non-aerated.

Comments on addition of biocontrol agents:
Bacillus subtilis is a soil bacterium that has been shown to have antagonistic activity against a number of different plant pathogens. Common commercial formulations of this Biocontrol agent include Serenade which was tested in a number of different experiments. As can be seen under Objective 1, Serenade was used in a number of different bioassays.

In the grape trial of 2013, aerated vermicompost tea was sprayed with and without Serenade added. In the grape trial of 2013 for powdery mildew on both the leaf and fruit there was no significant difference between the compost tea with and without Serenade. For downy mildew on the leaf, there was a significant difference between them with the aerated tea performing better than the tea with Serenade, 75% control versus 56% control, respectively.

Compost teas spiked with Serenade from the various bioassays did not work better than the compost teas on their own and in some instances teas spiked with Serenade had decreased efficacy. Actinovate contains the active ingredient *Streptomyces lydicus* as a biocontrol agent. Actinovate was used in an experiment testing germination of *B. cinerea* spores.
Spore germination was significantly decreased, often 100%, by compost tea treatments, regardless of addition of Actinovate. While Actinovate did not have a negative effect on the efficacy of compost tea to suppress germination, its addition was not necessary for suppression.

Beauveria bassiana is a fungus that is capable of killing insects and is available in a commercially available form as the insecticide Mycotrol O. This was used in conjunction with compost tea and sprayed on barley plants infested with bird-cherry oat aphids. Effectiveness of the Mycotrol O was limited. There was no significant reduction in aphids by use of the biocontrol agent with compost tea, nor by compost tea on its own.

Many biocontrol agents have been developed as commercial formulation that may be purchased. Compost tea itself is a biocontrol agent, utilizing the microorganisms from the compost as a means of suppressing disease. Addition of specific biocontrol agents in the studies conducted was generally not effective at increasing efficacy of disease suppression, and at least in one field trial actually decreased efficacy of compost tea.

Comments on addition of adjuvants
Adjuvants that have been used in this compost tea research include Tween, and NuFilm P. In some of the bioassays developed under objective 1, adjuvants, or spreader-stickers, were used if the compost teas were used as a foliar spray, though not in all. For these experiments, however, there was not a control in which compost teas were used with and without adjuvants to test the efficacy of the adjuvant itself and how it interacts with the compost tea, but rather used with all compost tea sprays. This was true for some of the field trials as well, however for the grape field trial in 2015 and the vegetable trials in 2016 adjuvants were tested with and without compost teas.

In the field trial on 'Niagara' grapes assessing a number of different diseases of interest in 2015, compost tea was used with and without NuFilm P. Amongst other treatments discussed in other sections of this report, the treatments of interest as relate to adjuvants were undiluted compost tea at two different spray schedules- weekly or biweekly, and with and without NuFilm P added at 0.125%. NuFilm P being added prior to spraying teas increased efficacy in the trail with grapes (Figure 15). For all diseases in this trial, undiluted compost tea with NuFilm P at 0.125% sprayed at weekly intervals was the most effective in control of the disease when looking at overall severity. As a percentage of control relative to the untreated control, this treatment was between 83% (Phomopsis on the rachis) and 97% (Powdery mildew on the cluster) effective for control. However, it was only powdery mildew on the leaf and Phomopsis on the fruit in which there was a statistical difference between the compost tea with and without the addition of NuFilm P, for the spray schedule that was weekly. The lack of significance despite differences in means values for overall disease may be due to variability in effectiveness within a treatment. For this trial there were three replications of each treatment.

Treatment	Application timing	Control as % relative to untreated control treatment													
		Black Rot on cluster		Black Rot on leaf		Powdery mildew on cluster		Powdery mildew on leaf		Phomopsis on rachis		Phomopsis on fruit		Downy mildew on leaf	
Untreated		0	a	0	a	0	a	0	a	0	a	0	a	0	a
Compost tea undiluted	1, 3, 5, 7, 9, 11	68	b	39	bc	56	bcd	42	bcd	57	bc	63	bcd	59	bc
Compost tea undiluted + NuFilm P	1, 3, 5, 7, 9, 11	70	bc	58	cd	75	cde	68	de	63	bcd	67	bcd	78	cde
Compost tea undiluted	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	75	bc	52	cd	76	de	63	cd	60	bcd	59	bc	79	cde
Compost tea undiluted + NuFilm P	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	91	c	88	d	97	e	96	e	83	d	85	d	95	e

Figure 15: Effect of the use of adjuvants with compost tea for suppression of black rot, powdery mildew, Phomopsis, and downy mildew on 'Niagara' grapes in 2015. Treatments sharing the same letter within a column are not significantly different from each other at $P \leq 0.05$. Spray dates: 1 = 10 June (3-7 in. shoot), 2 = 17 June (6-10 in. shoot), 3 = 26 Jun (pea-sized fruit), 4 = 2 Jul, 5 = 9 Jul, 6 = 16 Jul (pre-bunch closure), 7 = 23 Jul, 8 = 30 Jul, 9 = 6 Aug, 10 = 13 Aug, 11 = 20 Aug, 12 = 27 Aug.

The vegetable field trials of 2016 for both tomatoes and winter squash had addition of adjuvants as a treatment factor. The adjuvant NuFilmP was a treatment on its own, used with a compost tea, and the compost tea used without the NuFilm P addition.

For all of the cucurbits, there was no significant difference between the compost tea on its own and addition of NuFilm P. For the tomato field trial there was a decrease in the overall disease severity for both varieties of tomato from compost tea on its own versus compost tea with NuFilm P. However, only in the 'Celebrity' tomatoes was overall disease severity significantly decreased with the addition of NuFilm P to the tea (Figure 16).

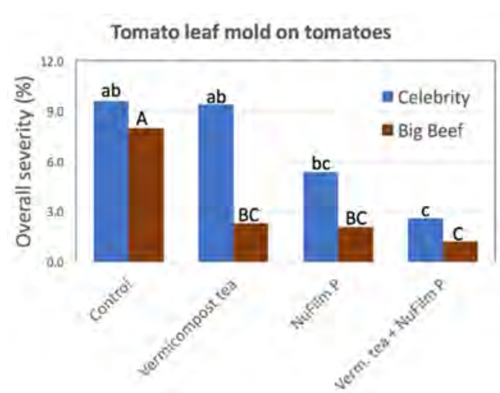


Figure 16: Effect of the use of adjuvants with compost tea for suppression of tomato leaf mold on tomatoes. Bars of the same color sharing the same letter are not significantly different from each other at $P \leq 0.05$.

Use of adjuvants increased disease suppression efficacy of compost teas, as well as having an effect when sprayed on their own.

Objective 4) Examine the mechanism(s) of disease and insect suppression.

Identification of bacteria in compost teas

Due to the minimal effects of compost teas on insects, we decided to focus most of our efforts on diseases. This experiment was designed to identify the key bacteria responsible for the disease-suppressive activity of compost tea. Twenty composts were selected and aerated compost tea with 1:5 compost to water ratio was brewed for 48 hours. The compost teas were serially diluted to 10^{-6} and plated onto nutrient agar (NA). Morphologically unique colonies were identified and streaked on NA to obtain single colonies: 75 colonies were selected for screening against *Botrytis cinerea* to identify bacteria which were antagonistic to fungal pathogens. An agar plug with *Botrytis cinerea* with actively growing mycelia was placed on a plate and a ring of bacteria was plated equidistant from the plug (Fig. 18). A mycelial plug on a plate without bacteria served as control. The percent inhibition was calculated by measuring the diameter of mycelial growth around the plug and comparing it with the control. Based on colony morphology and percent inhibition, 48 bacterial isolates were chosen for further analysis. Genomic DNA was extracted and 16s rDNA was amplified using PCR and sequenced. The sequences were assembled and compared to published GenBank sequences using NCBI-BLAST. Most of the bacteria identified were *Bacillus spp.* which are known to produce antibiotics and are used in commercially available biocontrol agents (Fig. 18).

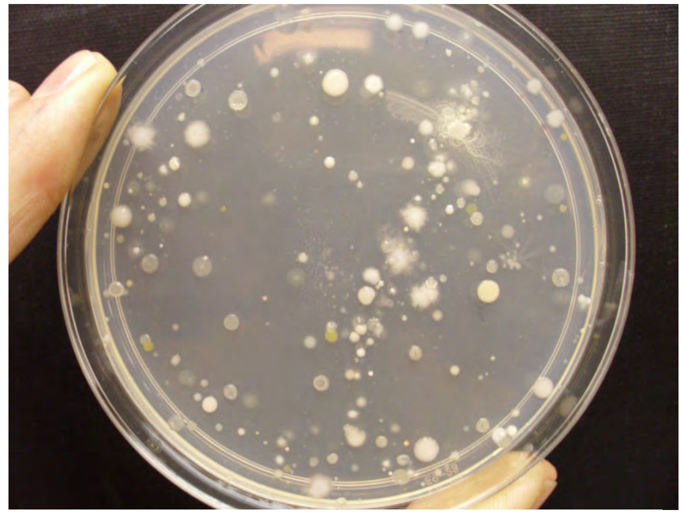
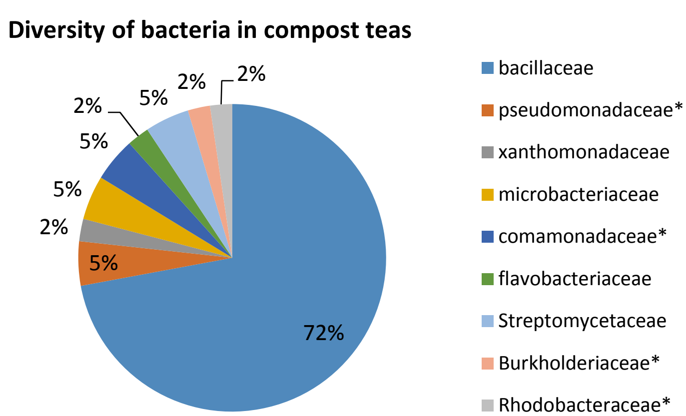


Figure 17. A variety of bacterial colonies growing from compost tea applied to the surface of a nutrient agar plate.



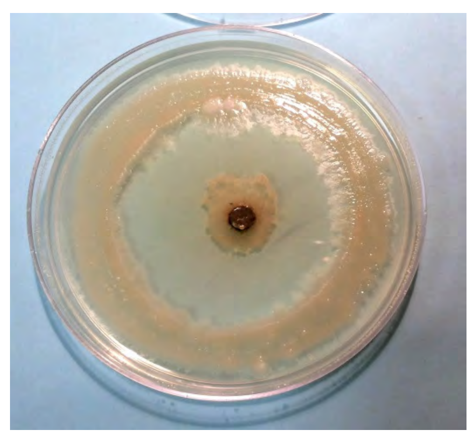


Figure18. The pie chart is a visual representation of the bacterial diversity of antagonistic bacteria found in various compost teas. The image on the right is a plate of nutrient agar with a plug of the plant-pathogenic fungus *Botrytis cinerea* in the center and a bacterial ring surrounding it. The growth of the fungus is restricted due to one or more antifungal substances produced by the bacteria, showing antagonistic activity against the fungus.

Effect of compost teas on microbial populations on grape leaf surfaces

Compost tea is known for its rich microbial diversity and is often credited with increasing the counts of beneficial bacteria which suppress fungal pathogens using multiple mechanisms. The primary use of compost tea is as a foliar spray for the control of foliar fungal pathogens. In 2015 and 2016, we quantified the number of bacteria, fungi, and yeasts present on grape leaves after foliar application of compost tea over time to determine the potential mechanism of action and longevity of the response. In 2016, aerated Dairy Doo (manure-based) and Transplant (plant-

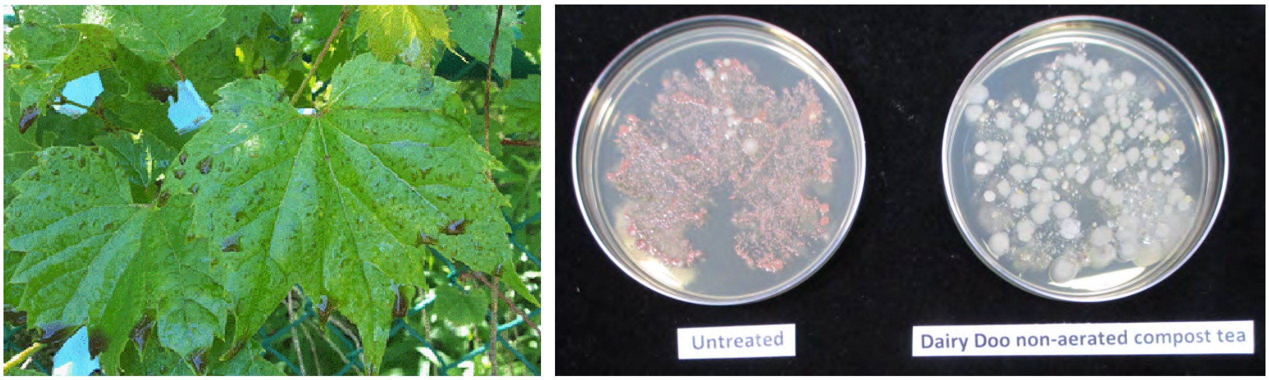


Figure 19. A) Compost tea residue visible after application to grape leaves. B) Impression left by grape leaves pressed on agar media, showing mostly yeast colonies (pink) from untreated leaves and predominance of *Bacillus* (creamy white) and other bacteria from leaf treated with Diary doo (manure-based) compost tea.

based) compost teas were applied to fully expanded leaves of ‘Niagara’ grapevines at Michigan State University in East Lansing. The average temperature during the week of this experiment in August was 74˚C with a couple of cloudy days and no rainfall. Unsprayed leaves served as a control. Leaves were sampled before application, after 6-8 hours and then every day for the next 7 days. The leaves were collected into sterile bags and brought back to the lab and shaken in PBS buffer for 3 minutes to dislodge the microbes from the leaf surface. 100 µl of this suspension was then plated onto acidified potato dextrose agar and nutrient agar and allowed to incubate for 3-5 days before counting colonies. The results show that bacterial populations increased after application of compost teas for up to about 7 days, more so in the Dairy Doo than Transplant compost tea treatment. Fungal populations dropped compared to the unsprayed control but rebounded at the end. These fungi were mostly saprophytic and part of the natural flora on grape leaves.

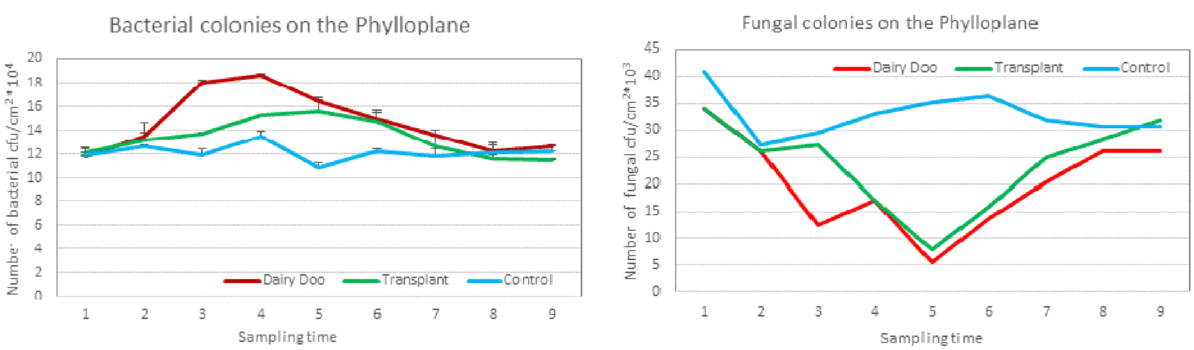


Figure 20. Microbial populations on grape leave surfaces in response to compost tea applications of Dairy doo (manure-based) and Transplant (plant-based) compost teas as measured for 8 days after application.

Assessment of drenches versus foliar sprays for disease control in grapes
In the 2014 trial conducted on 'Riesling' grapes in Traverse City (see objective 3 above), we specifically compared drenches of various compost teas with foliar sprays of the same compost teas for control of powdery mildew on leaves and fruit. The results clearly showed that foliar sprays were more effective than soil drenches and indicate that contact activity of the compost

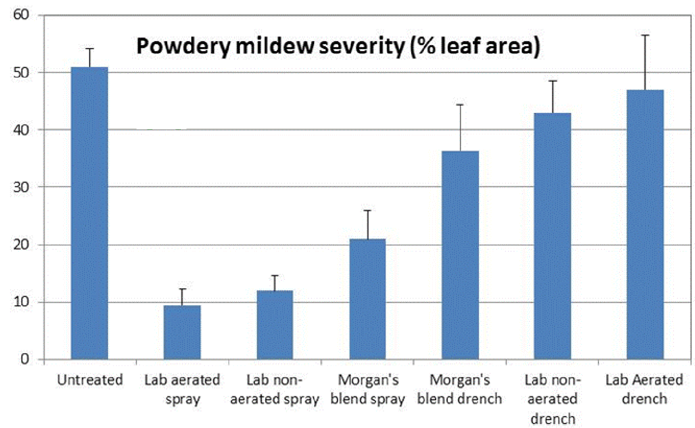


Figure 21. A) Application of compost tea soil drenches to grapevines, B) Powdery severity on grape leaves in response to foliar sprays and soil drenches of the same compost teas, showing superiority of foliar sprays.

tea against the powdery mildew fungus is important. However, the foliar disease reduction by Morgan's blend drench may indicate that induced resistance could play a role and needs to be further investigated.

Evaluation of compost tea as a nutrient source for cucumber plants
This experiment was designed to evaluate the effect of compost tea on improvement of overall plant health, which may have an impact on disease control. Cucumber seeds were planted in 3-inch pots in the greenhouse in standard greenhouse potting mix. The experiment was set up in a randomized complete block design with three replicates of 10 plants per treatment. Aerated Dairy Doo compost was applied as a foliar spray and a root drench every week for 8 weeks. Greenhouse fertilizer (Peters professional fertilizer 20-20-20) was applied at recommended rates as a positive control and water served as a negative control. The plants were watered as needed and staked after 3 weeks. Shoot and root length and plant dry weight was measured to evaluate growth of the plants. While regular fertilizer increased plant growth the most, compost tea applied as a drench appeared to be benefit the plant more than foliar sprays probably due to the easier uptake of nutrients from soil. However, differences between the treatments were not statistically significant. Further studies are needed to show if improved plant nutrition contributes to disease resistance or promotes disease development.

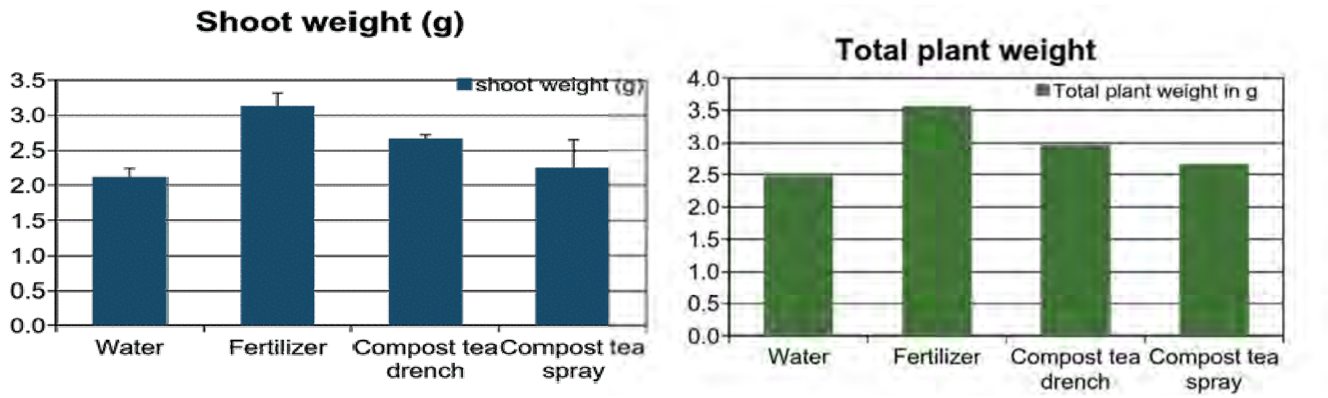


Figure 22. Shoot dry weight (A) and total dry weight (B) of potted cucumber plants after application of Dairy Doo compost tea by foliar or drench applications.

Presentations:

1. MOSES Organic Farming Conference, oral presentation titled “Unraveling the mysteries of compost teas”, Lacrosse, WI, February 2013.

2. Organic Farmer Reporting Session, poster presentation “Unraveling the mysteries of compost teas”, East Lansing, MI, March 2013.

3. Plant Science Graduate Student Research Symposium, poster presentation “Unraveling the mysteries of compost teas”, East Lansing, MI, March 2013.

4. MOSES Organic Farming Conference, poster presentation titled "Unraveling the mysteries of compost teas for insect and disease suppression", Lacrosse, WI, February 2014.

5. MSU CANR Luncheon, poster presentation "Compost tea effectiveness against plant diseases", East Lansing, MI, March 2014.

6. Greater Lansing Housing Coalition- Workshop on composting and compost tea, Lansing, MI, May, 2014

7. NW Orchard and Vineyard Show: What are compost teas? January 2014, Traverse City, MI.

8. Great Lakes Fruit and Vegetable EXPO, poster presentation titled "Can compost teas provide disease suppression and nutritional value to fruit crops?", Grand Rapids, MI, December 2014.
9.
10. Michigan Organic Farm and Food Alliance (MOFFA) Organic Intensives- oral presentation on "Reading the compost tea leaves", East Lansing, MI, March, 2015.

11. Great Lakes Fruit and Vegetable EXPO, oral presentation "Biological components of composts and compost teas", Grand Rapids, MI, December 2015.

12. NW Orchard and Vineyard Show: Utility of compost teas for grape disease control. January 2015, Traverse City, MI.

13. Schilder, A. C., Comer, D., Tiemann, L., Biernbaum, J., Comer, B., Pochubay, E., and Powers, K. 2015. Effects of compost teas on powdery mildew severity and soil biology in wine grapes. International Workshop on Fungal Grapevine Diseases, 29 Apr-2 May 2015, Eger, Hungary (poster).

14. Great Lakes Fruit and Vegetable EXPO, poster presentation titled "Effect of compost tea dilution and timing on control of grape diseases", Grand Rapids, MI, December 2015.

15. Great Lakes Fruit and Vegetable EXPO, poster presentation titled "What happens on leaves and in soil after application of compost tea? Grand Rapids, MI, December 2014.

16. Southwest Horticulture Days, oral presentation: “Is it teatime yet?” Benton Harbor, Feb. 2016.

17. Viticulture Day, oral presentation: “Evaluation of compost teas for disease control in grape”, July 2016, Benton Harbor, MI.

18. Morgan’s Composting Field Day, “Compost teas and their uses”, August 2016, Sears, MI.

19. Parallel 45 meeting,” Demonstration of compost teas in vineyard”, Sept 2016, Shady Lane Cellars, Suttons Bay.

20. Great Lakes Fruit and Vegetable EXPO, poster presentation titled "Evaluation of compost teas for disease suppression", Grand Rapids, MI, December 2016.

21. Southwest Horticulture Days, oral presentation: “Is it teatime yet – part 2?” Benton Harbor, Feb. 2017.

22. Kotamraju, G., Sysak, R., Gillett, J. and Schilder, A. 2016. Utility of compost tea for disease management in grapes. American Phytopathological Society Meeting, 30 Jul-3 Aug, 2016, Tampa, FL.

23. Schilder, A. 2016. Empowering farmers: dormant sprays and compost teas. Invited seminar, Dept. Plant Pathology, Sher-e-Kashmir University of Agricultural Sciences and Technology, Srinagar, Kashmir, March 4, 2016

We are currently working on four refereed publications for submission to scientific journals in 2016. We have also produced a fact sheet draft (see attached) to be printed in 2016 and have attached a selection of three posters that have been presented at various meetings.

Compost Tea Production and Use

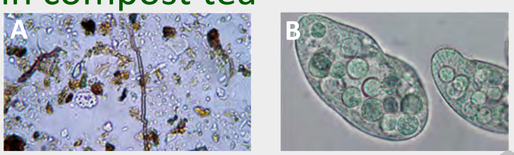
Brooke Comer[1] and Annemiek Schilder[2]. [1]Department of Horticulture, [2]Department of Plant, Soil and Microbial Sciences, Michigan State University, East Lansing, MI 48824.

What is compost tea?

Compost tea is a watery fermented extract of compost. It is aimed at obtaining the soluble nutrients and multiplying beneficial microbes from the compost in an aqueous solution that can be applied to plants or soil. Compost tea also contains organic matter, plant and microbial metabolites and growth-promoting substances. Additives may change the composition. Liquid that comes out of a compost pile is leachate and is not compost tea and, if coming from an active compost pile, may contain harmful pathogens that have not been eliminated by the composting process.

Organisms in compost tea

Bacteria
Fungi
Protozoa
Nematodes

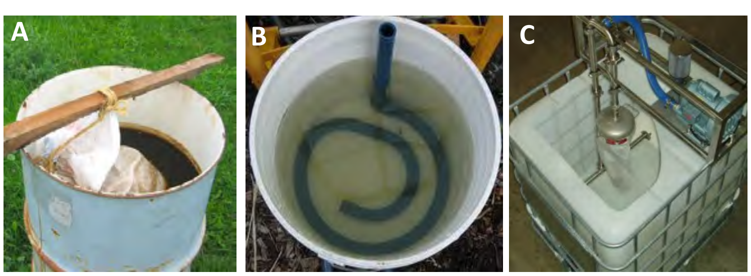


A) Bacteria, fungal hyphae, and organic particles in compost tea, and B) ciliated protozoans.

Benefits of compost tea

Compost tea is easy to prepare and affordable. It provides many of the benefits of compost but is easier to apply, especially after planting or for perennial crops. A good and reliable compost source is important. Compost tea will only be as good as the compost it is made from. Growers can make their own compost or purchase compost that is commercially available. The primary benefits of compost tea:

- *Disease suppression*
- *Acts as dilute fertilizer for plant nutrition*
- *Increase in seed germination and seedling growth*
- *Improved soil properties*



Examples of compost tea brewers: A) non-aerated, B) and C) aerated. *(ask permission and give credit or change photographs)*

How to make compost tea?

There are multiple ways to make compost tea. Factors that could influence the effectiveness of compost teas include the quality of the compost, concentration, water source, use of additives, fermentation time and temperature, and application rate and timing. Compost teas can be aerated or non-aerated. Aeration is not needed for disease suppression, but speeds up the brewing process. Factors in deciding on a method and brewer include spray volume needed, cost, and ease of cleaning. Use potable water (~pH 7). If water contains chlorine, let sit for 24 hours before using. Place compost in a mesh bag such as a paint strainer.

The higher the compost to water ratio, the greater the benefits, particularly with regard to soluble nutrients and beneficial microbes. A recommended rate for brewing compost tea is between 1:5 and 1:10 (v/v) compost to water. Keep brewer out of direct sunlight if possible and maintain temperature around 68-75°F.

Aerated compost teas:
Aerated for 12-48 hours (longer brewing time is recommended for disease suppression).
Many brewer designs and sizes, all use forced aeration via a pump for air circulation or re-circulation of the water; must maintain 6 ppm dissolved oxygen.

Non-aerated compost teas:
Let compost steep in water for 7 to 14 days (longer brewing time recommended for disease suppression)
Manual agitation of compost tea is recommended at the start and at least once a week.

Additives (see rules/regulations):
Additives are sometimes used to increase numbers and/or diversity of microbes. However, additives are not needed to achieve disease suppression. Additives may decrease dissolved oxygen, especially in non-aerated systems due to increases in microbial activity.

- Simple sugars such as molasses (not recommended)
- Humic acid, kelp extract
- Fish emulsion/hydrolysate
- Minerals, rock dust
- Biocontrol organisms
- Commercially available “compost tea activators”

Applying Compost Tea

Compost tea application may be to leaves (foliar), to roots or both. For control of foliar pathogens, compost tea has to be applied foliarly. The best type of sprayer for your operation will depend on the size of the area you are spraying and equipment available. If applying to roots, compost tea may be added into a fertigation system or otherwise watered into the soil around the plants. For foliar application, thorough coverage is important since compost tea acts as a biological contact fungicide. A sticker-extender such as NuFilm-P (OMRI listed) aids coverage and retention and has been shown to increase disease control efficacy (Schilder, unpublished data). Application in the late afternoon or early evening may slow desiccation and UV-inactivation of microbes and their metabolites.

Rules and Regulations

Use of compost tea has been reviewed by the National Organics Standards Board and rules set by the National Organic Program (NOP):

- Use potable water
- Sanitize all equipment before use
- Make with compliant compost/vermicompost (https://www.ams.usda.gov/sites/default/files/media/5021.pdf)
- If made without any additives, compost tea may be applied without restriction
- If made with additives, may be applied without restriction **if** the production system (same compost, additives and equipment) are pre-tested and meet recreational water quality guidelines of the EPA
- If compost tea is made with additives but is not pre-tested, it must be applied no less than 90/120 days prior to harvest (above ground/below ground portion harvested)
- Never use for edible sprouts

If crops are certified organic, you should check with your certifier before applying compost tea to plants grown for human consumption. Certifiers may differ in their interpretation of the rules and what they allow in an organic systems plan.

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Disease Suppression

Studies have shown variability in disease suppressive ability of compost teas, depending on the disease, the host plant and the compost tea itself. Some studies have been contradictory with respect to efficacy against specific diseases, most likely due to variability between compost teas and method of application.

Compost teas contain millions of microorganisms that have the ability to suppress diseases when applied to plant surfaces or soil. Most of the efficacy appears to be due to bacteria, such as *Bacillus, Pseudomonas* and Actinomycete species which are known to produce antimicrobial compounds and may also compete with plant pathogens for space and nutrients. Specific strains of these bacteria are used in commercial biocontrol products for this reason. However, microbes or compounds in compost teas may also induce natural plant defenses and improve overall plant health by supplying needed nutrients or stimulating soil biological activity.

In field trials conducted at Michigan State University, the spray regimen with the highest degree of efficacy has been weekly sprays of undiluted compost tea made with 1:5 (v/v) compost: water with addition of a spreader-sticker such as NuFilm-P. However, compost tea may not hold up under high disease pressure. It should therefore not be used as a stand-alone disease control method and be complemented with (organic) fungicides. Examples of diseases where compost teas have been shown to be suppressive (Scheuerell, 2002; Edwards & Arancon, 2004; Schilder, unpublished data):

- Early blight, leaf mold of tomato
- Late blight of potato
- Apple scab and cedar-apple rust
- Powdery mildew of grape and cucurbits
- Downy mildew of grape
- Black rot and Phomopsis of grape
- Pythium root rot
- Gray mold

Food safety concerns

Escherichia coli, Salmonella and coliform bacteria are of particular concern due to foodborne illnesses. Although proper composting effectively reduces human pathogens to non-detectable levels (Lung, 2001), there is fear that if present at all in compost these bacteria may proliferate during the compost tea-making process when additives such as molasses are used (Brinton, et al., 2004; Duffy, et al., 2004). Use of plant-based composts may circumvent this issue. If manure-based, make sure the compost is compliant and, if possible, tested for human pathogens.

EFFECTS OF COMPOST TEAS ON POWDERY MILDEW SEVERITY AND SOIL BIOLOGY IN WINE GRAPES

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Introduction

Compost 'teas' are watery extracts of compost, aimed at obtaining soluble nutrients and beneficial microbes from the compost in an aqueous solution that can be applied to plants, either as a foliar spray or soil drench. There are two basic types of compost tea: non-aerated compost tea, which is made by steeping compost in water in an open container for a certain amount of time; and aerated compost tea, which is prepared by forcing air through water mixed with compost and optional additives (Ingham, 2003). Various studies have shown suppression of a range of fungal and bacterial plant pathogens (Scheuerell & Mahaffee, 2002; 2006). Composts contain millions of microorganisms that have the ability to suppress plant diseases when applied to plant surfaces or soil by competition for nutrients, secreting antibiotics or activating natural plant defense responses (Agrios, 2005). Compost teas are notoriously variable due to differences in the compost and brewing conditions and research-based information on efficacy is limited. The goal of this project is to determine whether compost teas provide disease suppression and nutritional benefits, using grapes as a test crop.

Figure 1. A) Barrels used to make Lab aerated and non-aerated compost teas, with 1100-liter brewer used to make Morgan's Blend tea in the background. B) Compost teas used in the trials, C) Paint strainer bag filled with compost, D) Drench application, E) Spray application.

Materials and Methods

We evaluated compost teas under field conditions in an MSU vineyard (NW Research Center cv. Riesling) and three commercial vineyards in NW Michigan (Mawby's, Shady Lane, and Brengman Brothers). The compost teas tested were Dairy Doo compost + water, aerated for 48 hours (=Lab aerated); Dairy Doo compost + water, steeped with occasional stirring for 2 weeks (=Lab non-aerated); and a proprietary blend of Dairy doo compost with kelp extract and fish emulsion, aerated in a 1100-Liter FlowerField brewer for 24 hours (= Morgan's blend). Compost teas were manually applied to grapevines on a weekly basis from July 12 until September 30 as a drench (3.8 L per vine) or foliar spray with a backpack sprayer (~470-700 L/ha equivalent). At the station, the plots consisted of 3 vines, replicated 4 times. The untreated control only received water (3.8 L per vine) during a dry period. No fungicides were applied. On the commercial farms, only the Morgan's blend was applied as a drench and spray in 3-vine plots replicated 3 times. For effects on plant nutrition, petiole samples were taken at the end of the season and sent to A&L Labs in Indiana for nutrient analysis. Soil samples from the top 6 inches were analyzed for activity of 7 soil enzymes involved in soil organic matter decomposition, indicating soil microbiological activity.

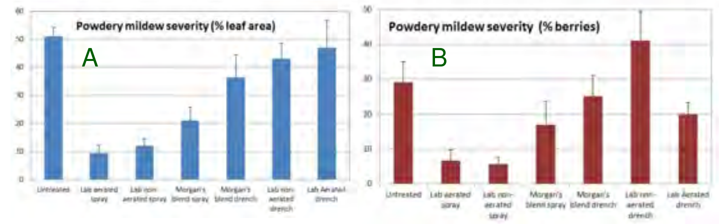

Figure 2. Effect of compost teas applied weekly as a spray or a soil drench on powdery mildew severity on cv. Riesling leaves (A) and fruit (B) in September after 12 applications.

Results

Compost teas applied as foliar sprays significantly reduced powdery mildew severity on the leaves and fruit at the end of the season, particularly in the case of the Lab aerated and Lab non-aerated teas. The sprayed vines also were greener at the end of the season than the untreated control, which was attributed to lower disease levels rather than a nutritional effect. The Lab compost teas were generally more effective than the Morgan's Blend, which may be due to the higher compost to water ratio in the Lab teas (1:5 v/v) compared to the Morgan's Blend tea (1:50 v/v), but possibly also to different microbes as evidenced by isolations. Some nutrients increased (Mg, C, Na, Mn) and some decreased (N, S, P, K, Ca, Zn, Fe, Cu, Al) in leaf petioles but this varied with compost tea and site. Powdery mildew could have also affected leaf nutrient status, emphasizing the need to investigate the nutritional effects in the absence of disease. In general, compost teas suppressed microbial extracellular enzyme activity compared to the untreated control, which was rather unexpected and indicates the need for further research into the effects of compost teas on soil biology and organic matter.

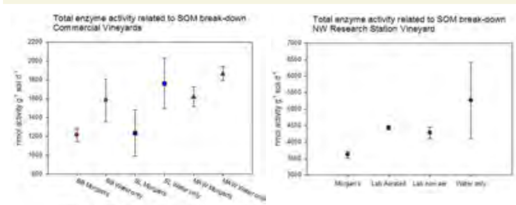

Figure 3. Effect of compost teas applied as soil drenches on soil enzyme activity related to soil organic matter (SOM) breakdown in commercial and research vineyards.

Conclusions

Compost teas reduced powdery mildew when applied as a foliar spray. Aeration was not necessary to obtain disease suppression, so specialized equipment is not needed. The main 'active ingredient' appears to be bacteria and their antibiotics although induced resistance may also play a role. Compost teas can be made relatively inexpensively and can be used as a supportive treatment, either in combination or alternation with fungicide sprays. Use of plant-based composts or well-composted manure-based composts should not pose issues with respect to *E. coli* and other human pathogens. However, National Organic Program (NOP) regulations with regards to compost teas should be followed. Further research is needed on the use and effects of compost teas.

Acknowledgements

We thank the Michigan State Horticultural Society and the Ceres Trust for funding this project. We also thank Brad Morgan from Morgan's Composting in Sears, MI for providing compost and his sage advice , and Dane Terrell of Flowerfield Enterprises, Kalamazoo for lending us a large compost tea brewer and sharing his wealth of compost tea knowledge. In addition, we thank Andy Fles of Shady Lane Winery for help in preparing the compost teas and allowing us to conduct a field trial at Shady Lane; Robert Brengman of Brengman Brothers Vineyard of Traverse City and Larry Mawby of L. Mawby Vineyards in Suttons Bay, MI, for allowing us to conduct trials in their vineyards. We also thank Esther Dzikushie and NWHRC staff for help in applying compost teas and for general support.

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MICHIGAN STATE UNIVERSITY AgBioResearch

What happens on leaves and in soil after application of compost tea?

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Introduction

The general definition of compost tea is a watery fermented extract of compost aimed at obtaining soluble nutrients and beneficial microbes from the compost in an aqueous solution that can be applied to plants or soil. Compost teas have been reported to suppress soil-borne and foliar plant diseases. There is also a general notion that compost teas improve “soil health”. In a previous experiment, however, compost teas appeared to suppress soil enzymatic activity, a measure of soil microbial activity. Therefore we decided to investigate how compost teas affect soil biology and nutrient content, as well as microbial populations on plant foliage. We were also interested in the consistency among batches of compost tea and whether compost teas can be tank-mixed with fungicides.

Consistency of compost tea among batches

One of the issues with compost tea is possible variability due to differences in brewing conditions. The goal of this experiment was to study the differences among batches of compost tea. We used Morgan’s Dairy Doo compost (manure-based) and transplant compost (plant-based) from the Student Organic Farm for the study. Compost teas were brewed in a 1:5 (v/v) ratio of compost to water in inverted, covered 2-L soda bottles at 22-23° C, either with a constant air supply from an aquarium pump for 48 hours (aerated tea) or occasional stirring (non-aerated) for 14 days. Compost teas were brewed at four different times, with three replicate samples each. Temperature, electrical conductivity (EC), and oxygen level were measured and the number of colonies per mL were calculated using dilution plating on nutrient agar. Oxygen level and temperature were quite consistent and not statistically different (data not shown). As expected, the oxygen content was higher in the aerated teas than in the non-aerated teas. The EC was highest in aerated Dairy Doo compost tea and number of bacterial colonies per ml was lowest in aerated transplant compost tea, but the batches were fairly consistent overall.

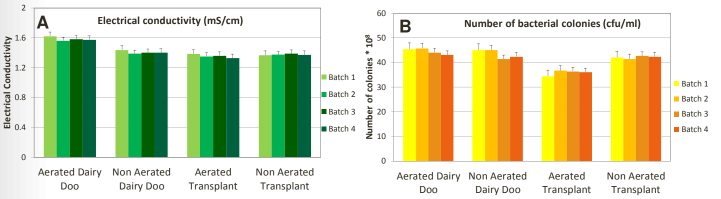

Fig 1. The graphs above represent the variation in electrical conductivity (A) and bacterial populations (B) among four different batches of compost tea made from Dairy Doo compost and Transplant Compost.

Effect of compost tea drenches on soil nutrient content

The impact of regular compost tea applications on nutrient content and soil biology of the soil was investigated on two soil types (loam and sandy loam) on the Plant Pathology farm at Michigan State University in East Lansing, MI. One gallon of aerated dairy doo compost tea was applied within the cut rim of a 5-gallon bucket pressed into the ground. Tap water served as a control. There were six replicates per treatment. Undiluted compost tea was applied weekly for 12 weeks during the summer. Soil samples were collected with a ½-inch soil corer every month and sent for analysis to the MSU Soil and Plant Nutrient testing Lab. In Table 1, you can see that at the end of the season, the soil content of phosphorus (P), and potassium (K) were increased by addition of compost tea and Calcium (Ca) and Magnesium (Mg) decreased. The pH increased slightly. In addition, the infiltration rate of water was reduced by compost tea, indicating better soil structure. Analysis of soil aggregate stability and soil enzyme activity is in progress. Large increases in potassium with frequent application of undiluted manure-based compost tea may be of concern as an ion imbalance may develop. Effects of other types of compost tea should be studied also.

Table 1. Soil nutrient content and other soil characteristics after 12 weekly applications of Dairy Doo compost tea.

	pH	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Organic Matter (%)	Nitrate-N (ppm)	Ammonium-N (ppm)	Soluble salts (mmhos)	Total N (%)	Water infiltration rate (min.)
Water control (loam)	7.0	23.7	79.7	1803.0	308.3	3.4	0.6	1.1	0.1	0.2	29.9
Compost tea (loam)	7.1	48.0	274.0	1718.7	291.0	3.7	0.6	1.0	0.1	0.2	20.9
Water control (sandy loam)	6.0	17.3	73.0	732.0	139.0	3.1	0.9	1.0	0.1	0.1	6.0
Compost tea (sandy loam)	6.2	37.0	266.7	688.7	126.7	3.1	0.9	0.8	0.1	0.1	3.5

Effect of compost tea on microbial populations on leaves

Aerated Dairy Doo compost tea was applied to fully expanded leaves of a ‘Niagara’ grapevine at Michigan State University in East Lansing. Unsprayed leaves served as a control. Leaves were sampled at 6-8 hours after application and then every day for the next 7 days. The leaves were brought back to the lab and 2-cm discs were cut out and shaken in 20 ml of PBS solution for 60-90 sec to dislodge the microbes from the leaf surface. 10 µl of this suspension was then plated onto potato dextrose agar and nutrient agar and allowed to incubate for 3-5 days before counting colonies. Bacterial populations were higher on leaves sprayed with compost tea but declined to almost background levels after a week. Both yeasts and fungi were reduced immediately after the application, but later increased over the control, probably due to added nutrients from the tea.

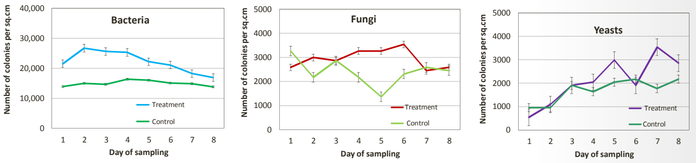

Fig 2. Changes in populations of bacteria, fungi, and yeasts on grape leaves over time after application of compost tea spray treatments compared to an untreated control. The values are number of colonies per sq. cm of leaf surface and represent the average of three replicates per sample.

Identification of antagonistic bacteria in compost tea

The fungicidal affect of compost tea is attributed to its bacterial population. Bacteria can cause disease suppression by producing toxins (antibiotics) or by competitive exclusion. Twenty different compost teas were brewed with aeration for 48 hours. 10 µl of a 10^{-6} dilution was plated onto nutrient agar and allowed to incubate for 3 days. Bacterial colonies with distinct morphology were isolated to obtain pure cultures. These cultures were plated surrounding a fresh plug of *Botrytis cinerea* and incubated for 5 days. The mycelial growth of the fungus was measured; 45 of these bacteria were selected based on their morphology and inhibition of mycelial growth and identified by molecular methods. From a preliminary analysis, bacteria previously shown to to be biocontrol agents were discovered in the teas. The bacteria isolated included *Bacillus cereus*, *Bacillus subtilis*, *Pseudomonas fluorescens*, *Burkholderia cepacia*, and *Leuconostoc* spp. Some of these are similar to bacteria used in commercial biocontrol products.

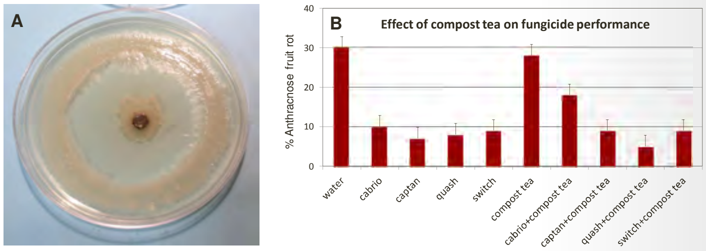

Fig 3. A) Inhibition of *Botrytis cinerea* in dual plate with bacteria from compost tea. B) Effect of mixing fungicides with compost tea on control of anthracnose fruit rot of blueberries. Values are the average of 3 replicates.

Are compost tea and fungicides compatible when mixed?

This experiment was designed to determine if compost teas and conventional fungicides are compatible when tank-mixed i.e., if either of them deactivates the other component. The effect of four different fungicides mixed with water or with undiluted Dairy Doo aerated compost tea was studied efficacy against anthracnose fruit rot in blueberries. Blueberries were dipped in conventional fungicides and in fungicide-compost tea mixtures and then inoculated with sprayed with a conidial suspension of *Colletotrichum acutatum*. A paired t-test revealed no statistical effect of the mixing. However, it was noted that Captan killed some types of bacteria in the compost tea.

Acknowledgements

We thank the Michigan State Horticultural Society for funding the project and Morgan’s Composting and John Biernbaum and Brooke Comer for providing compost. We thank Donny Comer, Brooke Comer, Kevin Fitzgerald, Elaina Goch, Roger Sysak and Jerri Gillett for their assistance and support. We are grateful for the assistance of the CANR statistical consulting center and MSU Soil and Plant Nutrient testing Lab.

MICHIGAN STATE UNIVERSITY AgBioResearch

Evaluation of Compost Teas for Disease Suppression

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Introduction

The general definition of compost tea is a watery fermented extract of compost, aimed at obtaining soluble nutrients and multiplying beneficial microbes from the compost in an aqueous solution that can be applied to plants or soil. Various studies have shown suppression of a range of fungal and bacterial plant diseases in different agricultural systems, although with inconsistent efficacy (Scheuerell and Mahaffee, 2006). Composts contain millions of microorganisms that have the ability to suppress diseases when applied to plant surfaces or soil by competition for nutrients, secreting compounds that are toxic to pathogens, parasitizing pathogens or activating plant defense responses. Factors that could influence the effectiveness of compost teas include the quality of the compost, water source, additives, fermentation time, temperature, application equipment, application timing, adjuvants, and application rates. Recent field trials in 2014 and 2015 showed good control of powdery mildew and other diseases in grapes. Based on these results, undiluted aerated compost tea sprayed at weekly intervals was selected to be evaluated for efficacy against powdery mildew (*Podosphaera xanthii*) on winter squash and tomato leaf mold (*Passalora fulva*) on tomatoes.

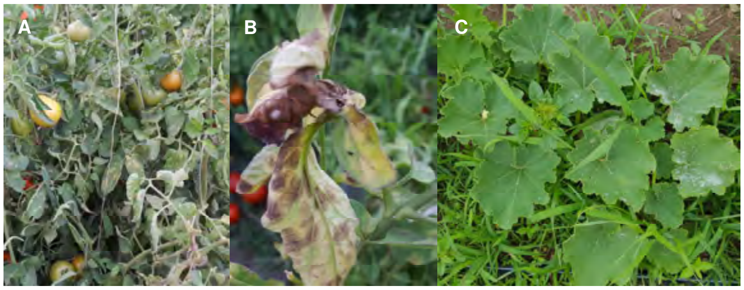

Figure 1. A) Tomato leaf mold on 'Celebrity' tomatoes. B) Close up of infected tomato leaf showing grayish sporulation on lower leaf surface. C) Powdery mildew symptoms on 'Blue Ballet' hubbard squash.

Materials and Methods

The experiments were conducted at MSU's Student Organic Farm at the Horticulture Teaching and Research Center (HTRC) in Holt, MI, with compost tea sprays being applied to tomatoes and winter squash. Six treatments were applied to experimental units and were replicated three times in a randomized complete block design for all of the cultivars sprayed. Treatments were applied to hoophouse tomatoes cv. Celebrity and Big Beef with each plot being comprised of two plants and a buffer plant between plots. Winter squash varieties in the field were butternut cv. Waltham, delicata (4 plants per plot), and hubbard cv. Blue Ballet (3 plants per plot) squash were also treated with compost tea. Compost teas were brewed for 48 hours in aerated bucket brewers at ratio of 1 part compost to 5 parts deionized water. Three composts were used: Dairy Doo® compost from Morgan's Composting, Inc. (Sears, MI) which is manure based, leaf/grass/coffee ground compost made at the HRTC in 2015, and vermicompost made from dry leaves and pre-consumer food waste from the HTRC. A sticker extender (NuFilm P) was tested on its own and in concert with the compost tea made from the vermicompost. Compost teas were applied weekly for a total duration of 13 weeks from June to September using a Chapin backpack sprayer until all leaf surfaces were covered to the point of runoff. Tomatoes were visually rated for tomato leaf mold incidence and severity and yield data were gathered(number of fruit and fruit total weight) throughout the harvest season. Winter squash varieties were visually rated for powdery mildew. Disease incidence was defined as % leaves with disease, and severity as % area symptomatic on diseased plant parts only. Overall severity was calculated as (incidence x severity)/100. Data were subjected to analysis of variance, mean separation, and regression in the StatGraphics statistical program.

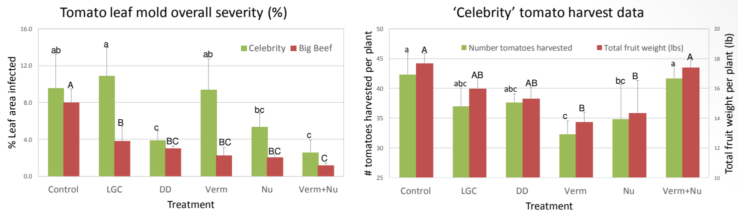

Figure 2. Effect of compost tea on A) tomato leaf mold overall severity of 'Celebrity' and 'Big Beef' tomatoes and B) yield components of 'Celebrity' tomatoes. Columns labeled with the same letter are not significantly different from each other ($P \leq 0.05$). LGC=plant-based hot compost made from leaves, grass and coffee grounds; DD=Dairy Doo manure-based hot compost; Verm=plant-based vermicompost; Nu=NuFilm P adjuvant.

Results and Discussion

The effectiveness of compost teas varied between crops and varieties. Most compost teas provided fair to moderate control of tomato leaf mold on tomatoes. There were significant differences in disease severity between the tomato varieties, with 'Celebrity' experiencing higher disease pressure than 'Big Beef' (Figure 2A). This may be due in part to the dense and compact nature of 'Celebrity', providing more humidity for proliferation of leaf mold and more difficulty in obtaining good spray coverage. However, 'Celebrity' did show significant differences in yield as a result of the compost tea sprays, in terms of the number and total weight of tomatoes harvested (Fig. 2B). There did not appear to be a correlation between disease severity and yield data. Powdery mildew on the field-grown winter squash was more prevalent and appeared earliest in the hubbard squash. There were significant differences in powdery mildew ratings among treatments for butternut squash (Fig. 3). In the hubbard and delicata squash, the use of compost tea as a foliar spray did not significantly reduce disease over the untreated control. Excessively weedy conditions complicated the experiment; the use of weed mat will be critical in future. A cucurbit trial had also been planned but the transplants died from heat stress.

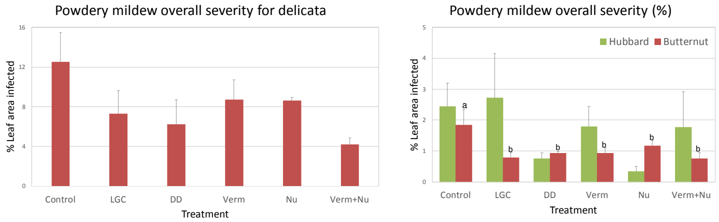

Figure 3. Effect of compost teas on powdery mildew overall severity in winter squash, A) delicata B) hubbard 'Blue Ballet' and Butternut 'Waltham'. Columns labeled with the same letter are not significantly different from each other ($P \leq 0.05$). LGC=plant-based hot compost made from leaves, grass and coffee grounds; DD=Dairy Doo manure-based hot compost; Verm=plant-based vermicompost; Nu=NuFilm P adjuvant.

Conclusions

This study shows that compost tea can provide significant disease control in hoophouse tomatoes and field-grown winter squash. Some compost teas were more disease suppressive than others. In general, compost tea made from Dairy Doo compost and vermicompost tea with NuFilm P adjuvant tended to be more effective than the other treatments. Nufilm P is known to have disease control properties of its own and improved efficacy. Later in the season differences in treatment efficacy were less apparent under higher disease pressure. Additional trials over multiple years are needed to confirm the results under different conditions.

Acknowledgements and References

We thank the Michigan State Horticultural Society for funding for compost tea research, the staff at the Student Organic Farm for their assistance and Morgan's Composting for the Dairy Doo compost used in this study.

Scheuerell, S., and Mahaffee, W. 2006. Variability associated with suppression of gray mold (*Botrytis cinerea*) on geranium by foliar applications of nonaerated and aerated compost Teas. Plant Disease 90:1201-1208.

MICHIGAN STATE UNIVERSITY AgBioResearch

Effect of compost tea dilution and timing on control of grape diseases

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Introduction

The general definition of compost tea is a watery fermented extract of compost, aimed at obtaining soluble nutrients and multiply beneficial microbes from the compost in an aqueous solution that can be applied to plants or soil. There are two basic types of "brewing methods": non-aerated and aerated, referring to "still" extraction or pumping air through the mixture. Various studies have shown suppression of a range of fungal and bacterial plant pathogens (Scheuerell and Mahaffee, 2002). Composts contain millions of microorganisms that have the ability to suppress diseases when applied to plant surfaces or soil by competition for nutrients, secreting compounds that are toxic to pathogens, parasitizing pathogens, or activating plant defense responses. Factors that could influence the effectiveness of compost teas include the quality of the compost, water source, added nutrients, fermentation time, temperature, application equipment, application timing, adjuvants, and application rates. A recent field trial in 2014 showed good control of powdery mildew in grapes with different manure-based composts. This experiment was conducted to determine the effects of application timing, dilution, and addition of an adjuvant on disease control efficacy in grapes.

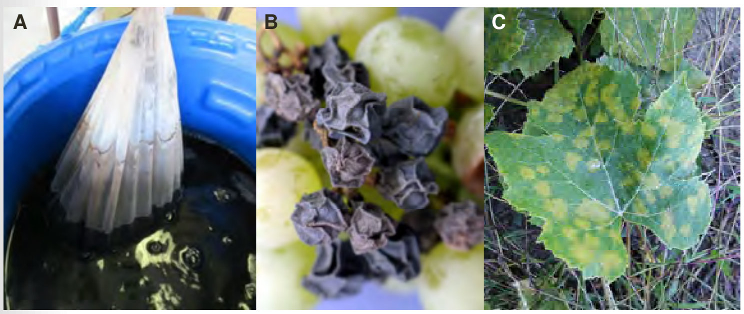

Figure 1. A) Compost in pain-strainer bag used in making compost tea. B) Black rot symptoms on 'Niagara' grapes, C) downy mildew lesions on 'Niagara' grape leaf.

Materials and Methods

The experiment was conducted in a mature vineyard at the Clarksville Research Center in Clarksville, MI. Vines were spaced at 7 x 9 ft and were cordon trained on a 2-wire trellis and hand pruned. Treatments were applied to 4-vine plots and were replicated 4 times in a randomized complete block design. Sprays were applied with a handheld Smith Contractor Sprayer equipped with a CFValve™ to maintain 29 psi at all times. Compost tea was made with Dairy Doo® compost from Morgan's Composting, Inc. (Sears, MI). Compost (1 gal) was placed into a 1-gal mesh paint strainer bag which was immersed in 5 gal of non-chlorinated well water in a 5-gal plastic bucket. The compost was allowed to steep for 2 weeks with agitation for several minutes every two days. Compost tea dilutions were made with non-chlorinated well water. Spray volume was 75 gpa. Spray dates and approximate phenological stages were as follows: 10 June (3-7 in. shoot), 17 June (6-10 in. shoot), 26 Jun (pea-sized fruit), 2 Jul, 9 Jul, 16 Jul (pre-bunch closure), 23 and 30 Jul (bunch closure), and 6, 13, 20, and 27 Aug (veraison). Rainfall between spray dates was 2.31, 0.51, 0.26, 0.29, 1.33, 0.17, 0.0, 0.86, 0.41, 1.01, and 0.57 in., respectively. Black rot was visually rated on 25 randomly selected leaves and clusters from each plot on 10 Aug. Similarly, powdery mildew was rated on leaves and clusters on 3 Sep, downy mildew was rated on leaves on 4 Sep, and Phomopsis was rated on clusters (rachis and fruit) on 16 Sep. Disease incidence was calculated as % leaves or clusters with disease, and severity was calculated as % area symptomatic on diseased plant parts only. Overall severity was calculated as (incidence x severity)/100. In October, all clusters were harvested from the untreated control and the best two treatments and weighed.

Acknowledgements and References

We thank the Michigan State Horticultural Society for funding this project. We thank Roger Sysak for applying the treatments , Jerri Gillett for data analysis, and Jerry Skeltis for assistance with plot maintenance. We thank Morgan's Composting for the compost used in this study.

Scheuerell, S., and Mahaffee, W. 2006. Variability associated with suppression of gray mold (*Botrytis cinerea*) on geranium by foliar applications of nonaerated and aerated compost Teas. Plant Disease 90:1201-1208.

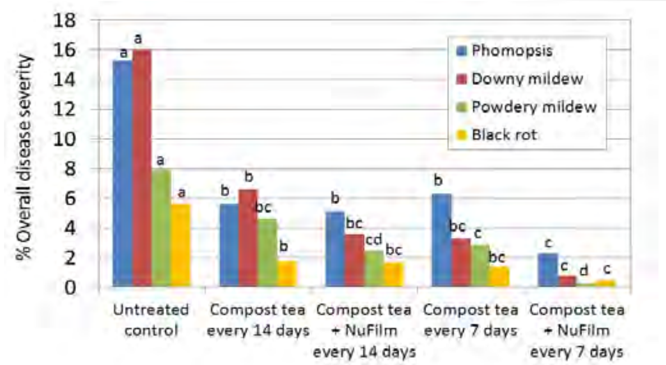

Figure 4. Effect of compost tea timing and addition of NuFilm P on control of Phomopsis fruit infection, downy mildew and powdery mildew leaf infection, and black rot on fruit in Niagara grapes in Clarksville, MI.

Results and Discussion

While disease incidence was high, disease severity and overall severity were low for black rot and powdery mildew, and moderate for downy mildew and Phomopsis. Most compost tea treatments provided fair to moderate control of black rot on the leaf and moderate to good control of black rot on the cluster. In both cases, undiluted compost tea with NuFilm-P sticker-extender applied every 7 days was the best and statistically better than the same compost tea applied without NuFilm-P, at least in terms of disease incidence. This treatment was as good as or better than a commercial bacterial biocontrol product Double Nickel 55 (*Bacillus amylolique-faciens*). Similar results were obtained for control of powdery mildew, downy mildew, and Phomopsis on the rachis and fruit. In general, diluting the compost tea and applying it every 2 weeks instead of every week resulted in lower efficacy, although disease control was evident even at the 1:10 dilution and dilution did not have as strong of an effect as expected. At the end of the season, when fruit rot had progressed and the vines started defoliating from downy mildew, differences between the treatments were still clearly visible. Fruit yield loss was primarily due to fruit shriveling from fruit rot. Yields were: 21.6 lb/vine in the 7-day undiluted compost tea + NuFilm P, 13.9 lb/vine in the 7-day undiluted compost tea, and 4.9 lb/vine in the untreated control.

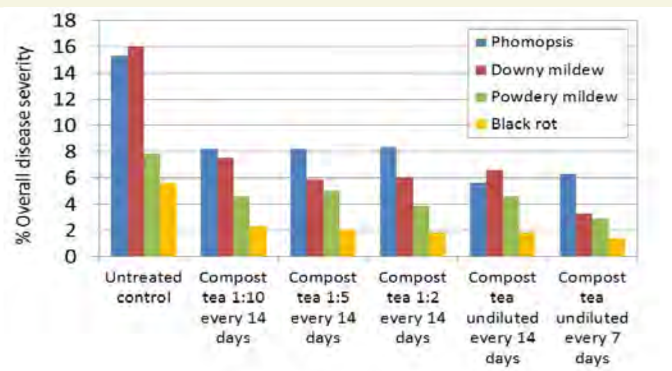

Figure 4. Effect of compost tea dilution and timing on Phomopsis fruit infection, downy mildew and powdery mildew leaf infection, and black rot on fruit in Niagara grapes .

Conclusions

This study shows that compost tea can have provide significant disease control in grapes, although variability in composts and the compost tea-making process may affect efficacy. The best disease control efficacy in this trial was obtained with undiluted tea applied on a weekly basis with NuFilm-P added. This sticker-extender is known to have disease control properties of its own. More work needs to be done to evaluate different kinds of compost teas in field-trials, especially those made from plant-based composts, due to the concern about human pathogens such as *E. coli* in manure, although proper heating during the composting process should kill these.

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