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Compost Tea and Milk to Suppress Powdery Mildew (Podosphaera xanthii) on Pumpkins and Evaluation of Horticultural Pots Made from Recyclable Fibers Under Field Conditions

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(*Podosphaera xanthii)* on Pumpkins

and

Evaluation of Horticultural Pots Made from Recyclable

Fibers under Field Conditions

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COMPOST TEA AND MILK TO SUPPRESS POWDERY MILDEW (PODOSPHAERA XANTHII) ON PUMPKINS AND EVALUATION OF HORTICULTURAL POTS MADE FROM RECYCLABLE FIBERS UNDER FIELD CONDITIONS

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Compost tea and milk to suppress powdery mildew (*Podosphaera xanthii)* on pumpkins

Abstract

Powdery mildew (caused by *Podosphaera xanthii)* a common problem for vegetable growers, and the cost of controlling the disease with fungicides to the growers and the environment is high. An alternative approach for control using methods approved for organic production are sprays based on teas made from compost, both actively aerated (ACT) and non-aerated (NCT) compost teas, and sprays made from diluted milk. We evaluated these sprays for control of powdery mildew on pumpkins in field trials in Connecticut in 2008 and 2009, and in greenhouse trials in 2009. We also evaluated the compost teas and milk in the greenhouse in 2009, as well as additives, like liquid seaweed and humic acid, used to enhance the effectiveness of compost teas. Applications were applied to the leaves before disease symptoms were noticed and visual assessments of the plants were made on a weekly basis. In 2008 both the ACT and NCT treatments applied in combination with a milk spray significantly reduced the incidence of powdery mildew compared with compost tea applied without the additional milk spray. In 2009 the treatments were changed to evaluate the effect of milk applied alone, and the compost teas were evaluated without the additional milk application. In both locations the compost teas provided no control of powdery mildew when compared to the untreated control plots. The milk treatment provided significantly less disease than the untreated control, and the chemical treatment had equal or significantly less disease than the milk. In greenhouse trials the milk treatment was as effective as the chemical control, and the enhancer products, liquid seaweed and humic acid, were as effective as the

compost teas at suppressing powdery mildew with all treatments reducing disease when compared with the untreated control. These results suggest that enhancers added to compost teas may provide as much control as the teas, and milk may be an effective control for powdery mildew on pumpkins. Both organic and conventional growers could benefit from using milk in place of the fungicides typically sprayed to control powdery mildew.

1. Introduction

Powdery mildew is a disease that can greatly reduce the yield of cucurbits. The main causal agent for the powdery mildew is (*Podosphaera xanthii*) (also known as *Sphaerotheca fusca* Fr.) (McGrath, 2001). There are many different fungicides available to control powdery mildew. However, their effectiveness is often greatly reduced due to the development of resistant strains of powdery mildew (McGrath, 2001). Resistance can develop rapidly when fungicides are used curatively, as some IPM programs recommend (McGrath, 2001). To minimize the problem of developing resistant strains of powdery mildew, other materials for controlling the fungus would allow for a reduction in pressure on the fungicides.

One natural material that has shown some capability for suppression of fungal diseases are various types of compost teas (Al-Dahmani, 2003, Scheuerell, 2006, Al-Mughrabi, 2006 Joshi, 2009, Pant, 2009, Kone, 2009). Compost tea is a liquid extract of compost made by steeping the compost in water for various time periods. The Romans and Egyptians used compost teas or materials similar in preparation from manures and composts as long as 4,000 years ago (Cato and Varro, 1934). Compost teas are thought to suppress disease by promoting the proliferation of beneficial microbes, which then act as a biological control over pathogens (Diánez, 2007).

There are two main types of compost teas: actively aerated compost tea (ACT) and non-aerated compost tea (NCT) (Litterick, 2004). Actively aerated compost tea is made by the constant induction of air into a water-compost mixture. Non-aerated compost tea is made by simply placing the compost into water and allowing it to steep for a predetermined length of time. The addition of air to the compost-water mixtures creates aerobic conditions for the microbial growth, while the stagnate NCT's provide conditions primarily for the growth of anaerobic microorganisms.

The mode of action for disease suppression by compost teas is not well understood (Scheuerell, 2002). One hypothesis is that the physical and chemical properties of the nutrients in compost teas, the humic components in the teas, or a combination of the nutrients and humic components may improve the nutritional status of plants, be directly toxic to the pathogen, and/or induce systemic resistance to the pathogen (Kone, 2009). Another hypothesis is that compost teas are thought to act as a bio-control of pathogens by favoring the growth of beneficial bacteria on the leaf surfaces (Diánez, 2007). The effect of an applied liquid like a compost tea on the bacterial and fungal communities living on the leaf surfaces is not well documented because there is little known about the relationship between fungi and bacterial communities on the leaf surfaces (Suda, 2009). It is known that bacteria and plants often interact physically by surface colonization, which results in the bacteria either externally or internally bound to plant tissues as individual colonies or in groups of colonies (Ramey, 2004).

There are a number of published reports showing empirical evidence of the effectiveness of compost teas for disease suppression. Foliar sprays of NCT against angular leaf spot (caused by *Phaeoisariopsis griseola* (Sacc.) Ferraris) reduced the disease on French bean, (*Phaseolus vulgaris* L.), but a chemical control offered the greatest level of control of the angular leaf spot (Joshi, 2009). In a study on tomatoes, (cultivar Bush Beefsteak) a significant decrease in gray mold (caused by *Botrytis cinera*) and powdery mildew (caused by *Oidium neolycopersici*) was measured on plants treated preventively with NCT compost teas (Kone, 2009). An ACT prepared using kelp, humic acids and rock dust showed significant control of damping-off (caused by *Pythium ultimum* in cucumber plants (*Cucumus sativus* cv. Marketmore 76) grown in container medium (Scheuerell, 2004).

There have been a few studies comparing ACT's with NCT's for disease suppression. A reduction in bacterial leaf spot (caused by *Xanthomonas vesicatoria*) in tomato seedlings (cv. Ohio 7814) treated with ACT and NCTs was measured compared with a water only control treatment. There was no difference in disease control between the two compost tea methods (Al-Dahmani, 2003). The plant growth of pak choi (*Brassica rapa* cv. Bonsai, Chinensis group) plants was the same for each compost tea and the microbial populations and activity of the two compost teas were not different between production method (Pant, 2009). An ACT and a NCT equally suppressed damping-off (caused by *Pythium ultimum*) in cucumbers (*Cucumus sativus* cv. Marketmore 76) when applied as a soil drench (Scheurell, 2004). In another study comparing the ability of ACT and NCT to suppress gray mold (caused by *Botrytis cinera*) on Geraniums ('Ringo Red 2000'), there was no significant difference between the two types of compost in disease ratings for 85% of the linear contrasts. However, the control of Botrytis by both types of the compost teas was minimal (Scheuerell, 2006).

The biological activity of microorganisms in compost teas is often enhanced by the addition of a food source for the microorganisms at the beginning of the brewing process (Pant, 2009; Scheuerell, 2006). The ingredients used as the food source vary but often include molasses, kelp, humic acid and proprietary food packets that contain mixtures of 80% organic and 20% natural minerals derived from sulfate of potash-magnesia, feather meal, soy meal, cottonseed meal, mycorrhizae, kelp and alfalfa meal.

The addition of food sources to compost tea is thought to enhance microbial activity of the finished compost tea, however, there has been little to no scientific studies on the effect of food sources on the tea or on the suppression of plant diseases (Pant, 2009). Only one study was found in the literature comparing compost tea made with and without the addition of a microbial food. The addition of microbial food to an ACT significantly increased the bacterial population numbers in the ACT compared with the same ACT without the addition of microbial food as measured by culturing the teas, but there was no difference in the reduction of gray mold (caused by *Botrytis cinerea*) on Geraniums between the two teas under experimental conditions (Scheurell, 2006).

There is a potential problem with the addition of food sources to compost teas during the brewing process. *Escherichia coli* and *Salmonella* bacteria are known to increase in compost teas when food sources are added during the brewing process (Ingram and Millner, 2007). The chance of human pathogens in a compost tea is also increased when partially stabilized compost is used as the material for brewing (Al-Dahmani, 2003). Molasses, in particular, can result in the proliferation of pathogenic bacteria, which means the addition of food sources should be avoided when compost teas are to be used on fresh produce meant for human consumption due to the potential public health risk (Duffy, 2004).

Tea enhancers are typically added to a compost tea after the brewing cycle is completed and immediately before the tea is applied. Kelp and humic acid are the more common enhancers with humic acid also being a recommended substrate for increasing microbial populations in ACT (Naidu, 2010). Foliar applications of enhancers as the sole ingredient in a spray have also been reported. Humic acid and seaweed extract applied to the foliage of creeping bentgrass improved the drought resistance of the grass (Zhang, 2004). This suggests that the enhancers themselves may have disease suppressive qualities.

The use of tea enhancers may improve the ability of the fungi and bacteria to colonize leaf surfaces by reducing shock of transition from the relatively microbe-friendly environment of the brewer to field conditions. The bio-control fungus *Microsphaeropis ochracea* was studied in vitro on apple leaves for control of apple scab, and the results showed that low concentrations of tea enhancers such as oils and surfactants could increase the effectiveness of the original bio-fungicide but further research is needed (Bailey, 2007).

Other natural products, such as milk and whey, can suppress powdery mildew (Bettiol, 1999; Ferrandino, 2006; Bettiol, 2008). Milk based sprays seem to be more effective during times of low inoculum pressure. Milk sprays were 50-70% effective in reducing foliar symptoms of powdery mildew on field pumpkins as compared with the chemical control when there was low disease pressure (Ferrandino, 2006). Whey has also shown a high level of disease suppression when sprayed twice a week in a greenhouse where the whey reduced the incidence of powdery mildew (caused by *Podosphaera xanthii*) by 71-94% in cucumbers (*Cucumis sativus,* cv Safira) and 81-90% in zucchini squash (*Cucurbita pepo* cv. Caserta) while the control plants had a disease rating of 40-50%. In this controlled environment, whey was able to achieve mildew control comparable with commonly used fungicides (Bettiol, 2008). These findings suggest that milk and whey may provide better suppression of powdery mildew than compost teas without the potential to contaminate the crop or the environment with pathogenic bacteria (Bettiol, 1999).

<u>The objectives of this study were to:</u>

A.) Determine the effect of an ACT and a NCT to suppress powdery mildew on cucurbits grown in the field

B.) Evaluate the performance of compost tea when applied to acorn squash grown under greenhouse conditions

C.) Assess the influence of tea enhancers on powdery mildew on cucurbits in the greenhouse when sprayed alone

D.) Compare treatments of milk for suppression of powdery mildew to a standard chemical control method.

2. Materials and methods

2.1 Compost tea Preparation

Compost and other tea brewing supplies (humic acid, kelp, foods) required for the growing season were purchased in May of each year from Keep-It-Simple, Redmond WA. This minimized the storage time and allowed the compost to be from the same lot for the entire growing season. The water for the compost tea was from a municipal water supply that added chlorine to the water. The water was placed in the brewer where it was actively aerated for 20 minutes as directed by the manufacturer to allow the chlorine to outgas from the water to reduce the concentration of the chlorine. Both the ACT and NCT methods of producing the compost tea were set-up inside a storage shed that was located in a heavily shaded area, which reduced large temperature fluctuations. After making each compost tea batch, the entire brewing system was completely rinsed out with regular water giving the inside of the tank a quick scrub to maintain the white color of the tank and to prevent slime or biofilms forming on the tank, which could alter the composition of the teas as the season progressed.

Actively aerated compost tea treatments were produced in a Keep-It-Simple professional 105.8L brewer according to the manufacture's (Keep-It-Simple, Redmond, WA) specifications (Table 1). The tea was made by adding a 50/50 mixture of Keep It Simple professionally prepared fungal and Keep It Simple professionally prepared bacterial compost at a ratio of 1:28 (compost:water) to the suspended 400-micron mesh bag, which reduces the chance of clogging application equipment. Then, 710 cm^3 of the premade (proprietary) microbial food and 80 cm^3 of a water soluble humic acid product "LC-85" (Organic Approach, PA) were added to 105.8L of the degassed municipal water. After everything was added, the mixture was allowed to brew for the required 22-24 hours using the supplied brewing equipment. Upon the conclusion of the pre-determined brew time the liquid was passively transferred to holding units that were brought to the field for direct application.

The NCT was made using the same procedure as used for the ACT, except the ingredients were placed in a 600-micron mesh bag, which steeped in a plastic container of degassed water for 6-8days. At the conclusion of this time period this fermented brew was transported directly to the field for application.

All the compost tea brews had tea enhancers added just before application based on the manufacture's recommendations. The entire recipe for the compost teas is located in Table 1.

Table 1.
Ingredients used to make actively aerated compost (ACT) and non-aerated compost teas (NCT)

Material	Rate in 105.8L of water	Supplier
Fungal Compost	1900 cm^3	K-I-S (Keep-it-Simple, Inc.)
Bacterial Compost	1900 cm^3	K-I-S (Keep-it-Simple, Inc.)
Humic Acid	80 cm^3	K-I-S (Keep-it-Simple, Inc.)
Microbial Foods	710 cm^3	K-I-S (Keep-it-Simple, Inc.)
Enhancers		
Seaweed	4 mL per L	Organic Approach, LLC
Humic Acid (LC-10+7)	4 mL per L	Organic Approach, LLC
Humic Acid (LC-12)	4 mL per L	Organic Approach, LLC

2.2 Field Trials

Spray applications were made to three crops in 2008 and 2009. The crops were: pumpkins (*Cucurbita. pepo* cv. Spirit), and two winter squashes, acorn (*C. pepo* cv. Table Ace) and delicata (*C. pepo* cv. Delicata). Seeds from identical seed lots were used for both years. Only the results from the pumpkins are reported because the acorn and delicate squash had rapid and widespread powdery mildew infestations that overwhelmed all treatments including the chemical control.

Experiments were located in two locations in both 2008 and 2009. One location was the University of Connecticut's Storrs Research Farm. The soil was well-drained Paxton fine-sandy loam. The other location was at the Connecticut Agricultural Experiment Station in Windsor, CT, and the soil was an excessively drained Windsor loamy sand. No irrigation was used at either location.

Pumpkin seeds were directly sown in the field in black agricultural plastic. A Latin Square design was used with treatments organized in 5 rows and 5 columns with 5 replications. In 2008 the east side of the field had an additional row that was deemed a no spray row to act as a local inoculum source, and in 2009 this category was expanded to all perimeter plants. The plot size was 13.7 m wide and 13.7 m long with 2.4 m spacing in 2008, while in 2009 the width was changed to 31.7 m wide and the row length was increased to 37 m with 4.5 m spacing. There were four plants in each plot. Spacing between plants within each plot was ~15 cm in 2008 and ~30 cm in 2009. The space between the rows was cultivated to control weeds and Strategy® (Ethalfluralin: N-ethyl-(2-methyl-2-propenyl)-2,6-dinitro-4-(trifluoromethyl) benzenamine + Clomazone: 2-(2-Chlorophenyl)methyl-4,4-dimethyl-3-isoxazolidinone) was applied once in the inner row space only at the Windsor location during the 2009 growing season. All seeds were sown between June 16 and June 24 at both locations for both years. Harvest of the fields occurred shortly after the last spray between September 8 and 12. The harvest was completed by hand harvesting the fruits from the four pumpkin plants in each treatment for a total of 20 plants per location.

During the 2008 trial powdered milk was mixed at full strength then diluted to a ratio 40% milk and 60% water. Applications of the milk were made 3-4 days after the compost tea applications on a once a week frequency. The milk treatments in 2009 consisted of pasteurized whole milk (3.5% fat) purchased at a grocery store (various brands) and applied as a separate treatment without the application of compost tea, and the treatments were applied every 6-8 days. The mixtures were made immediately before application to the plants.

The chemical control at the Storrs location was chlorothalonil (2,4,5,6-tetrachloroisophthalonitrile, Group M5) applied every 6-8 days. At the Windsor location the sterol inhibitor myclobutanil (a-butyl-a-(4-chlorophenyl)-1H-1,2,4, triazole-1 – propanitrile, Group 3) was used in conjunction with chlorothalonil. The rate of application of the chlorothalonil was 1.68 kg a.i. per hectare and the myclobutanil was applied at the rate of 146.15 mL a.i. per hectare. Applications were made in 2008 by using a hand pump SP-Systems (model# SP-0) 4-gallon backpack sprayer with the included brass cone nozzle used for applications. Both the tops and undersides of the leaves were sprayed, but the most efficient coverage was on the upper leaf surface. In 2009 a gas powdered Stihl SR 420 backpack mist blower was used for the applications. In both years the total spray volume in the field increased proportionally with plant growth but the rate per leaf area remained consistent because sprays were applied until leaf run-off occurred. In 2008 at the Windsor location the chemical control sprays were stopped in mid-season due to concern about spray drift into the other treatments and was the reason for the chemical control not being included in the data analysis.

Treatments were only applied in the early morning or late evening (Al-Dahmani, 2003), which should be the standard practice when applying this type of product to ensure an easy transfer for the biological agents and to reduce the chance of plant stress. As with many contact spray products it can be difficult to maintain leaf coverage during periods of heavy rainfall as Ferrandino (2006) reported, and this was the reason for a spray frequency of 6-8 days instead of the more common 7-10 day interval.

Evaluations of the treatments in the field were made visually about once a week at each location and began when the plants covered about one square meter in leaf surface area. A visual estimate of the percent of powdery mildew coverage as part of the total area on the upper sides of the leaves was documented for the same plant area during the entire trial. Early in the disease progression the number of colonies were counted, and then as the disease continued to progress a shift was made to visually estimate the total percent of the leaves covered with powdery mildew. A conversion from number of colonies to percent coverage was completed by equating 30 colonies to 1% coverage, which enabled the entire season's disease progression to be in the same units.

For the field trials, the area under the disease progress curve (AUDPC) which is a measure of quantitative disease over repeated disease assessments was calculated for each replicate (Jeger, 2000) with $y(0) = y_0$ as the initial infection or the disease level at $t = 0$. $A(t_k)$, the AUDPC at $t = t_k$, is the total accumulated disease until $t = t_k$, given by

$$A_k = \sum_{i=1}^{N_i-1} \frac{(y_i + y_{i+1})}{2}(t_{i+1} - t_i)$$ (APSnet, 2011).

Comparisons were made using the Bonferroni condition (Bonferroni, 1936 and Quinn, 1989) procedure of SysStat version (11) at $P<0.05$.

2.3 Greenhouse Trials

The experiments in the greenhouse in 2009 were completed in the Floriculture Greenhouses at the University of Connecticut in Storrs, CT. The 'Table Ace' winter squash (*Cucurbita pepo*) variety was selected for the greenhouse experiments because it has a more compact growth habit. Two seeds were direct seeded into a 20.3 cm diameter plastic pot containing Fafard 3B potting mix. The 20.3-cm pot size accommodated the growth habit of the plants for the duration of the trial without resulting in the plants becoming root-bound. All the pots were thinned to allow only one plant per pot with a total of three replicate plants per treatment in each of the four trials. Pots were tagged at seeding and were arranged in a Completely Random Design (CRD). The experiment was repeated four times with a new set of test plants for each replication using plants of approximately the same age.

All treatments were identical to those used in the 2009 field trial study. In the case of the compost teas, a select sample was taken from the main holding tank; tea enhancers were added in the same proportions before being applied using a hand-held pump spray bottle (Dynalon Quick Mist). The proper dilution rate was calculated for both the chlorothalonil and milk treatments, which were applied following the same procedure as the compost tea treatments. Careful attention ensured both the tops and bottoms of the leaves had the treatments applied to them.

Applications occurred before 0500 hr. on the same day the identical treatments were sprayed in the 2009 Storrs, CT field experiment. All replicates of the same treatment were grouped together during the application process to minimize drift and interactions.

After the treatments dried on the leaves the plants were transferred from the clean germination and propagation greenhouse section to a section that had a high level of powdery mildew inoculum pressure where the plants were again randomized in a CRD design. A one week incubation period in the powdery mildew rich section elapsed before visual assessments were documented to offer consistency across all trials. The initial inoculum was obtained from the field by putting trap plants in the field to catch powdery mildew spores. These plants were brought into the greenhouse to allow for passive infection to occur on trial plants. Plants showing advanced to severe infestations of powdery mildew, typically a total of 6-12 plants, were placed on the perimeter of the bench with all the plants in the trial organized in a completely randomized design in the interior of the bench. This layout allowed for equal opportunity for inoculum to reach all plants.

Plants were evaluated for powdery mildew about 1-week after being transferred to the inoculum rich section. Visible powdery mildew colony counts were made, which did not include the cotyledons or the first true leaf due to increased incidence of damage during initial transport or hand watering events. Three plants per treatment were evaluated for total number of visible powdery mildew colonies present on the upper leaf surface. The data from the greenhouse experiments were counts of the visible colonies of powdery mildew per plant. The data were analyzed in PROC MIXED (SAS, 9.2) as a randomized complete block design with each of the four trials completed over 5 weeks used as replications. Mean comparisons were performed using a LSD test $P<0.05$. The results are expressed as the means of the colony counts.

2.4 Tea Enhancers

Testing of the effectiveness of the materials used as enhancers to the compost teas was completed in the greenhouse in 2009. The enhancers were evaluated when sprayed alone with no other material. The same methods were used in these trials as was used in the greenhouse trial of the field treatments in 2009. Sufficient plants were started to allow for a total of three plants per treatment. This trial followed the same procedure as the previous greenhouse trial with the only alterations being that applications occurred at low light and the experiment was repeated five times with plants of approximately the same four-week age.

Treatments consisted of only those enhancers that were mixed with the compost tea immediately before application. This included the liquid seaweed at a rate of 4 mL per L and both humic acids (LC-12 and LC-10+7) each at a rate of 4 mL per L in combination. The seaweed and humic acid additives were applied in combination at the rates stated above to evaluate the effectiveness when sprayed together. A whole milk trial of 40% dilution and a chlorothalonil treatment were applied to serve as consistent comparisons across all trials.

There were three plants per treatment per trial with five trials completed in succession about 1 week apart. Each trial was considered a replication that was separated by time. Visible colonies of powdery mildew per plant were counted. The data were analyzed in PROC MIXED (SAS, 9.2) as a randomized complete block design. Mean comparisons were performed using a LSD test $P<0.05$. The results are expressed as the means of the colony counts.

Results and Discussions:

3.1 Weather

Rainfall in July and August when the plants were in the field in 2009 was much greater than the long-term average at both locations (Table 2). In 2008 rainfall was below normal at Storrs and above normal at Windsor. Rainfall in both years was more than adequate for the development of powdery mildew spores, but the frequency of rainfall and the large amount in 2009 provided favorable conditions for the development of the powdery mildew than in 2008.

Table 2
Seasonal Rainfall Amounts

Location, Year	July	diff	August	diff	Totals	diff
Storrs, 2008	115	+11	82	-25	**197**	-14
Windsor 2008	200	+107	171	+68	**371**	+175
Storrs 2009	195	+91	101	-6	**296**	+85
Windsor 2009	284	+191	72	-29	**356**	+162

-Amount in mm

-Diff compared to 102 year average for Storrs and 30 year average for Windsor

3.2 Field trials in 2008

At both locations the ACT and NCT did not significantly differ ($P<0.05$) in their ability to reduce disease levels (Figs. 1, 3, 4). This finding suggests that the method of production may not have a great influence on the efficacy of the teas. Even though the materials used to make the teas were the same, the duration and method of brewing were different, which should select for two different types of microbes. The overall aroma produced was noticeably different and suggests that the teas contained different types and amounts of microbes. The ACT produced what is typically referred to as an earthy aroma and the NCT with its long production time and stagnant water, had a much stronger and fouler odor. This pungent odor is thought to potentially detract from the applicator willingness to adopt the NCT production method (Scheuerell, 2004). But due to the difficulty of standardizing production methods and the unknown composition of compost teas it is difficult to compare the results from different production methods.

At both locations there were two treatments that consisted of milk sprayed 3-5 days after the ACT and NCT sprays were applied. The milk treatments showed significant reductions in disease compared with the plants that had only compost tea applied (Figs. 1, 2), and the milk treatments provided similar reductions in powdery mildew whether applied with the ACT or NCT. The additive effect of the milk treatment on disease control could be due to more than one mode of action (Bettiol, 1999). This author speculated that a milk spray partially controlled powdery mildew in zucchini squash in greenhouse conditions by either of two pathways: inherent germicidal properties or by inducing systemic resistance.

A chemical control was included at the Storrs location in 2008 and 2009 and at the Windsor location in 2009. This treatment was significantly more effective for disease control than all the other treatments at Storrs, CT in 2008 (Fig. 1) and Windsor in 2009 (Fig. 4). Unfortunately, the yields for all the plots in all years were not significantly different from one another (data not shown). The lack of a response in yield to the suppression of powdery mildew was probably due to the small sample size, 20 plants harvested per plot, and not due to non-effective control of the powdery mildew.

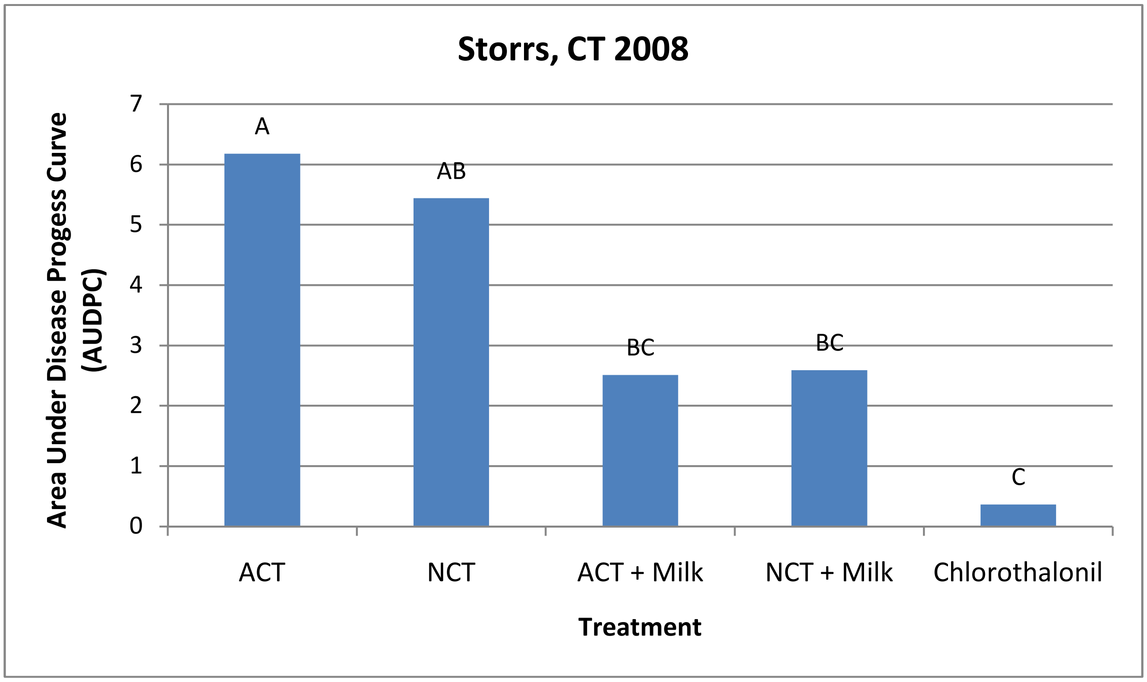

Fig. 1. Powdery Mildew levels expressed as the Area Under Disease Progress Curve (AUDPC) on field pumpkins (*Cucurbita pepo*) grown at Storrs, CT in 2008 and treated with biological controls: Actively Aerated Compost Tea (ACT) and Non-aerated Compost Tea (NCT). Milk (40% in 60% water) was applied 2-3 days after the compost tea treatments. The Chemical treatment followed a common cucurbit spray schedule. Bars with the same letter are not significantly different based on the Bonferroni condition ($P<0.05$). Values are means of 5 replications.

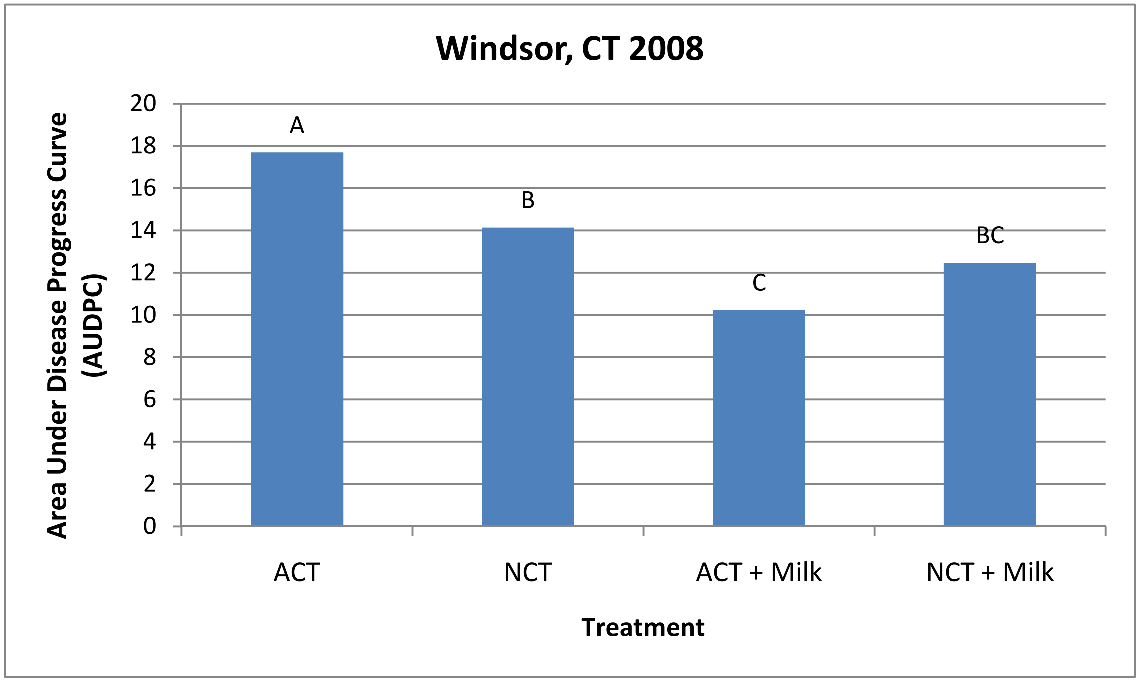

Fig. 2. Powdery Mildew levels expressed as the Area Under Disease Progress Curve (AUDPC) on field pumpkins (*Cucurbita pepo*) grown at Windsor, CT in 2008 and treated with biological controls: Actively Aerated Compost Tea (ACT) and Non-aerated Compost Tea (NCT). Milk (40% in 60% water) was applied 2-3 days after the compost tea treatments. Bars with the same letter are not significantly different based on the Bonferroni condition ($P<0.05$). Values are means of 5 replications.

3.3 Field trials in 2009

In 2009 a no treatment control was included at both locations and was not significantly different from the compost tea treatments (Fig. 3, 4). The similar performance of the aerated and non-aerated compost teas in both growing seasons is consistent with the findings of Scheuerell (2006), who stated there was no consistent benefit to aeration of compost teas for disease suppression. The inability of the compost teas to provide disease suppression different from a no-spray control indicates that the compost teas had no suppressive capability for powdery mildew on pumpkins in this field experiment.

The milk treatment provided a significant level of reduction in powdery mildew that was significantly better ($P<0.05$) when compared to the no-spray control and to the compost tea applications at both locations (Fig. 3, 4). The Storrs field showed milk was as effective as the chemical control, which suggest an effective organic option for powdery mildew control. At the Windsor location, however, the milk treatment was not as effective as the chemical control. The milk treatment probably was less effective at Windsor because there was more disease pressure as shown by the higher AUDPC values for Windsor compared with Storrs. At Storrs there were no plants nearby that could supply inoculum, but at Windsor there were several trials being conducted with plant species susceptible to powdery mildew and the disease was not aggressively controlled in the plots, which increased the amount of inoculum pressure.

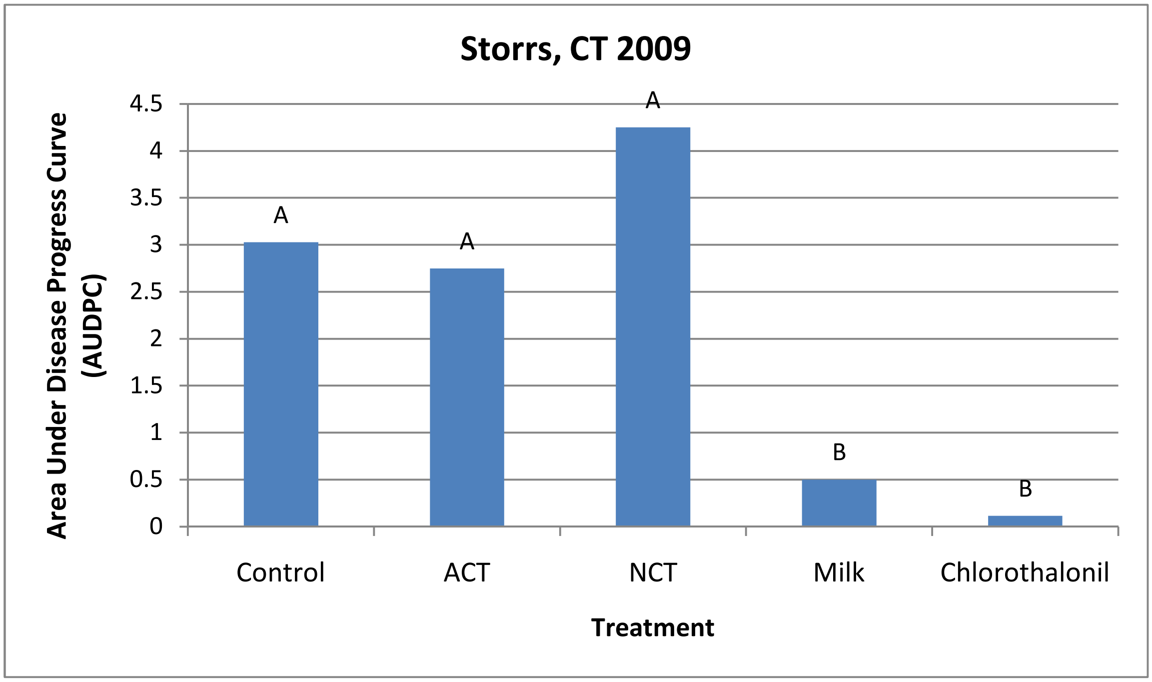

Fig. 3. Levels of Powdery Mildew expressed as the Area Under Disease Progress Curve (AUDPC) for field pumpkins (*Cucurbita pepo*) grown at Windsor, CT in 2009. All treatments Actively Aerated Compost Tea (ACT), Non-aerated Compost Tea (NCT), Milk (40% milk, 60% water) and the Chemical (typical cucurbit program) were applied alone and on a 6-8 day schedule. The Control treatment was a no treatment control. Initial applications started preventively 30 days post field seeding and continuing until harvest. Bars with the same letter are not significantly different based on the Bonferroni condition ($P<0.05$). Values are means of 5 replications.

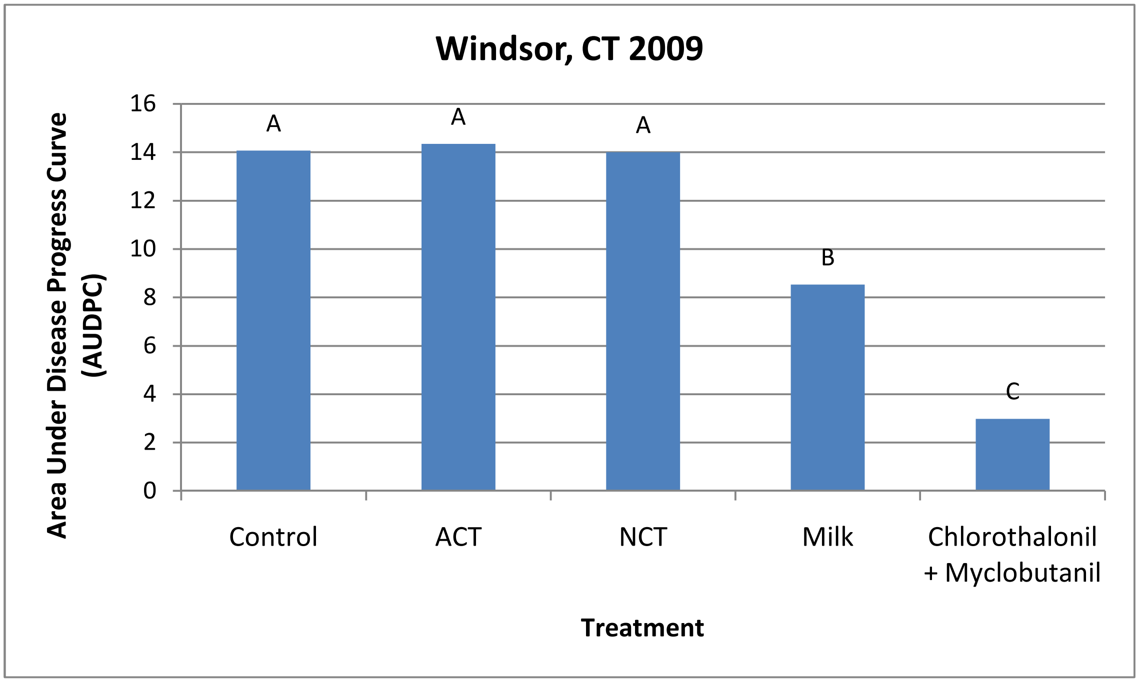

Fig. 4. Levels of Powdery Mildew expressed as the Area Under Disease Progress Curve (AUDPC) for field pumpkins (*Cucurbita pepo*) grown at Windsor, CT in 2009. All treatments Actively Aerated Compost Tea (ACT), Non-aerated Compost Tea (NCT), Milk (40% milk, 60% water) and the Chemical (typical cucurbit program) were applied alone and on a 6-8 day schedule. The Control treatment was a no treatment control. Initial applications started preventively 30 days post field seeding and continuing until harvest. Bars with the same letter are not significantly different based on the Bonferroni condition ($P<0.05$). Values are means of 5 replications.

The Storrs location represents more closely the disease situation growers would experience. Growers typically will be aggressively controlling diseases, and there would not be any plants allowed to develop large amounts of inoculum as was done with the no-spray treatment Other studies have shown significant control of powdery mildew with milk (Ferranndio, 2006), and with whey (Bettiol, 2008). The use of milk and whey should be attractive to growers because both products are environmentally friendly and are less expensive than fungicides (Bettiol, 2008). Milk has several properties that might favor powdery mildew suppression. A simple physical barrier may be created reducing the attachment efficiency of the fungus to the leaf surface. The pH of milk, which is slightly basic, could be altering the pH of the leaf surface and slowing the development of this surface living fungus. Milk also contains lactoferrin, which is a natural antimicrobial agent (Brown, 2008). Studying powdery mildew (caused by *Erysiphe (Uncinula) necator*) on grapevines Crisp, (2006) suggested a mode of action of milk based on the components producing oxygen radicals in natural sunlight. They also found supporting evidence that lactoferrin ruptured conidia and damaged the hyphe 48 hours after initial treatment (Crisp, 2006). All of these findings suggest multiple modes of action, and any of the modes of action or combinations of the modes could be responsible for the efficacy of milk.

3.4 Treatments applied under greenhouse conditions

The no treatment control had the greatest number of colonies of powdery mildew (Fig. 5). In contrast to the field experiments, both the compost tea treatments had a significantly greater level of control than the no-spray control treatment, even though the teas were identical in the field and the greenhouse. This suggests that the greenhouse environment does not always predict the control observed in the field. This is probably due to the vastly different conditions in the greenhouse compared with the field, especially rainfall events in the field that wash the treatments from the leaf surface.

The two contrasting methods of tea production achieved levels of control that were not significantly different (Fig. 5). This finding is consistent with previous studies (Scheurell, 2006, Scheurell, 2004, Al-Dahmani, 2003) and, suggests that the ingredient producing the knock-down effect of powdery mildew is common to both teas.

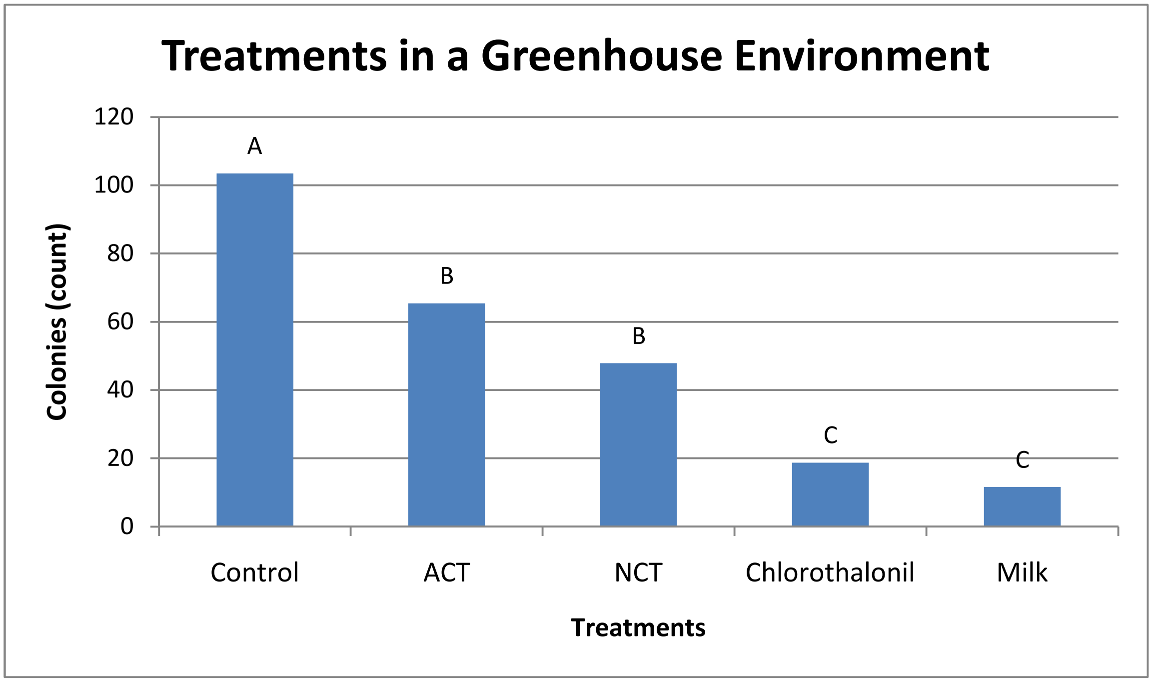

Fig. 5. Effect of biological treatments: Actively Aerated Compost Tea (ACT), Non-aerated Compost Tea (NCT) and Milk (40% milk, 60% water) preventively applied to Acorn squash (*Cucurbita pepo*) plants grown under greenhouse conditions on powdery mildew colony formation. The Control treatment was a no treatment control and the Chemical treatment was an application of a chlorothalonil. Each replication was a new set of test plants that were passively inoculated from trap plants showing high levels of disease. Bars with the same letter are not significantly different at ($P<0.05$) according to LSD test. Values are means of 4 replications separated by time.

The most significant level of disease control was obtained with the milk and the chlorothalonil treatments, but each treatment did not differ from each other (Fig. 5). These findings concur with Bettiol (1999) who reported the same ability of milk to control powdery mildew as a chemical control when the milk was sprayed at 20-50%

concentration. For this trial, a 40% concentration of milk was selected because that concentration resulted in minimal milk residue on the leaves. Milk has other advantages besides low cost, especially in a closed environment like a greenhouse, the use of a product with no time required for re-entry would be particularly appealing.

3.5 Tea enhancers applied under greenhouse conditions

For these greenhouse trials, the same initial dilution rate of 1:250 (additive : water) or 0.4% was used to ensure consistency to the previous trials. The no-spray control had the highest level of infection and this shows there was sufficient inoculum present for robust infection (Fig. 6). The humic acid treatment did not differ significantly from the no-spray control, which suggests that humic acid is not providing any direct control when added to the teas. The humic acid and seaweed combination treatment was statistically similar to the humic acid, seaweed and milk treatments. Since the combination treatment did not offer any greater degree of control then the individual components of which it was composed, there are no interactive effects between the humic acid and kelp treatments when used together.

The seaweed treatment provided significantly greater control of powdery mildew compared with the no treatment control (Fig. 6). This evidence suggests that the seaweed could have been the active ingredient in the compost teas and not the components of the teas by themselves that provided the disease control. The addition of the seaweed immediately before spraying to both the teas could be responsible for the reduction in powdery mildew for both types of teas, and for the similarity of disease control seen in both compost tea production methods.

These data for the seaweed used as an enhancer are similar to results reported by Scheuerell (2004) who showed that control of damping-off (caused by *Pythium ultimum*) in cucumbers (*Cucumus sativus* cv. Marketmore 76) was affected more by the type of enhancer added than the by the ACT sprayed. The enhancers are usually a material that can be more easily replicated than a compost tea (Scheuerell, 2004), and this makes it more likely to apply only an enhancer to obtain the same reduction in disease as by applying a compost tea.

In this trial as in the previous greenhouse trial both the milk and chemical treatments were the most effective and did not differ from one another ($P<0.05$) in their effectiveness.

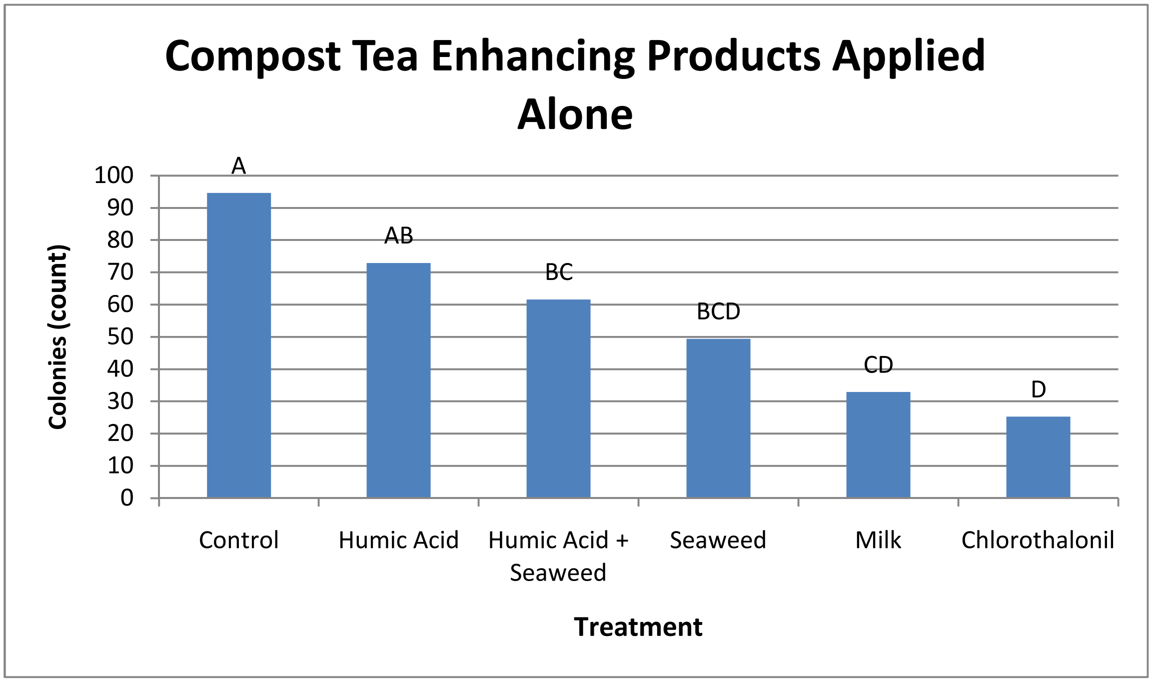

Fig. 6. Tea enhancing products applied alone without being added to the compost tea to determine the innate ability to suppress Powdery Mildew colony formation on Acorn Squash (*Cucurbita pepo*) in a greenhouse environment. All were applied at the same dilution rate as previous trials. Bars with the same letter are not significantly different at ($P<0.05$) according to LSD test. Values are means of 5 replications separated by time.

4. Conclusions

These field data suggest that compost teas are not an effective treatment for control of powdery mildew, and that both methods of tea production are equally non-effective. The results from the greenhouse suggest that the enhancers typically added to compost teas may provide some control of powdery mildew, but these materials need to be tested in the field to verify the results from the greenhouse. Both greenhouse and field results indicate that milk provides control of powdery mildew similar to the control provided by a fungicide. Organic and conventional growers could benefit from using milk in place of the fungicides typically sprayed to control powdery mildew.

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Evaluation of Horticultural Pots Made from Recyclable Fibers under Field Conditions

Abstract

The horticultural industry is seeking alternatives to plastic pots to increase overall sustainability and reduce waste. Pots made from various recyclable fibers have become increasingly available, but there is little information available about the growth of plants in fiber pots and the degradation of the pots under field conditions. This study evaluated the growth of garden mums in replicated field trials in pots made from peat fiber (Jiffy pots), coir fiber, and dairy manure fiber (Cowpots) in 2008. Each type of fiber pot produced significantly different shoot fresh weights, with the Cowpots producing the greatest fresh weight. In 2009 the types of fiber pots were expanded to include pots made from wood fibers that were certified organic (DOT pots), pots made from straw fibers (Straw pots), and plastic pots. The growth and yield of garden mums and tomatoes were evaluated in replicated field trials, and the degradation of the pots was estimated. During the 2009 growing season the garden mums yielded similar fresh weights in all the fiber pots, except the straw pots yielded significantly less biomass than the peat pots. The field grown tomatoes also produced similar yields across all fiber pots. The tomatoes initially grown in plastic pots that had the plastic pots removed before transplanting into the field, however, produced significantly greater tomato yield than all the fiber pots except the DOT pots. The pots degraded at significantly different rates during the growing season.

The Cowpots and the DOT pots had the greatest amount of degradation, and the straw and coir pots had the least amount of degradation. There was no significant correlation between the yield of the mums or the tomatoes and the amount of pot degradation. These results suggest that the type of fiber used to make a horticultural pot does not have a major effect on plant growth when the pots with plants are transplanted into the field, but the pots degrade at significantly different rates, which could result in the pots with slow rates of degradation accumulating in the field.

Introduction

In agriculture and particularly in the production of horticultural products there has been shift away from petroleum based products and products that create waste that is not recyclable (Blake, 1997). Horticultural pots made from plastic are the most common type of pot used in the horticultural industry. Of the estimated 542 million pounds of plastic used in agriculture annually, 320 million pounds (59%) is attributed to plant containers (Garthe and Kowal, 1993). In 2004 the results of a survey completed by Penn State University's College of Agricultural Sciences estimated that of the 320 million pounds of plastic used for nursery pots, bedding plant trays and cell packs each year only about 100,000 pounds was recycled (Garthe, date unknown). The unrecycled plastic, especially the pots, can create a disposal problem (Sharanya, 2007). One possible solution to this problem is to grow plants in pots made from a recyclable material or a natural material that provides nutrients to the plant when the pot degrades in the soil. Pots made from degradable materials would also enable the pots to be planted directly into the soil without removing the plant, which increases efficiency (Horinouchi, 2008).

Horticultural pots made from manure fibers would provide an additional benefit of exporting phosphorus from livestock farms. Phosphorus accumulation on agricultural fields is an increasing common problem in areas where livestock are concentrated for efficient production (Whalen, 2001). Fiber pots called CowPots were developed to create a usable product that could be used to export manure and the phosphorus contained in the manure from the farm to non-farmland. Export of phosphorus is needed because phosphorus accumulates in fields nearby livestock barns when grain is imported to feed the livestock and about 70% of the phosphorus in the grain is excreted in the manure, which is applied to fields nearby the livestock barns (Sharpley et al., 2003). Repeated applications of the manure to meet the nitrogen needs of crops cause accumulation of phosphorus in the soil because the ratio of nitrogen to phosphorus in manures does not match the ratio of nitrogen and phosphorus taken up by plants. Export of the phosphorus in horticultural pots made from manure fibers could substantially reduce the accumulation of phosphorus in fields nearby livestock barns, and provide income from the sale of the manure used to create the pots.

Natural and recyclable materials besides manure fibers are used to make horticultural pots. The types of non-manure materials used for pots include: coir, which is a fiber from the husks of coconuts primarily from India and Sri Lanka; straw, from the straw of small grains; wood, which is from spruce trees and are sold under the trade name DOT and are the only certified organic pots available in the market; and peat, which is primarily fibers from peat bogs in Canada and are sold under the trade name of Jiffy pots. The Jiffy pots are the industry standard because the pots have been sold since 1954 and were the first fiber horticultural pot sold in the market (Anonymous, 1954).

Only a few studies in the literature were found comparing growth of seedlings or plants in plastic pots with the growth in fiber pots. The porous nature of fiber pots has been shown to cause a more rapid drying of the post during plant production (Chapman, 2006), and the increased tendency to dry rapidly required more frequent watering compared with pots made from plastic. Biodegradable pots with a corn base have improved growth of tomato plants when the irrigation frequency was increased, but overall the plant performance did not match that of the plastic control pots suggesting multiple factors affecting seedling growth (Sakurai, 2005b). The fact that fiber pots need more frequent irrigation compared with plastic pots is easy to understand because the fiber pots have greater porosity and result in greater surface area for evaporation.

Studies about the growth of plants in fiber pots with different origins of the fibers are few. One study showed that geraniums ('Pink Elite') grown in substrates made from peat or coir did not significantly differ in days to flower, height, shoot fresh weight, number of axillary branches, or number of flowers (Evans, 1996).

<u>The objectives of this study were to:</u>

1.) Compare the growth of field-grown fall garden mums and the yield of field-grown tomatoes in pots made from various fibers and in pots made from plastic.

2.) Estimate the percentage degradation of fiber pots after garden mums and tomatoes were grown in the pots for a growing season

We selected garden mums and tomatoes as test crops to evaluate the pots over a full growing season, and the tomatoes had the added benefit of a high nutrient demand.

2. Materials and methods

2.1 Field Grown Garden Mums

Rooted cuttings of four varieties (Alberta, Gentle Alberta, Glenda, and Golden Cheryl) of garden mums (*Chrysanthemum morifolium*) were obtained from Yoder Bros (Barberton, OH). During the third week of June, eight cuttings of each variety were potted up in three types of fiber pots; CowPots CowPots, (324 Norfolk Rd, East Canaan, CT 06024, 4.5 inch), coir pots (EcoDepot, LLC 1405 Benson Ct, Suit D Arbuts, MD, 21227, 4.25 inch), and peat pots (Jiffy, 3.25 inch).

The size of each pot was similar with the CowPots measuring 11.4 cm (4.5 inch), the coir pots 108.0 cm (4.25 inch) and the Jiffy pots 82.6 cm (3.25 inch). The pots were filled with Fafard 3B potting mix that had been amended with Osmocote 14-14-14 at 3 g/L and placed in cavity trays. Cuttings were watered in by hand with a 15-4-15 fertilizer solution at 150 mg N/L and this same process was repeated for each irrigation.

Two weeks after planting the cuttings into the pots roots emerged from the bottom of all three of the types of pots. The pots were then planted in a raised bed containing a sandy loam soil and mulched with shredded cedar bark about 4-cm deep. Irrigation was provided as needed by an overhead sprinkler.

Thirteen and fourteen weeks after planting into the raised bed, in late September, when the plants were in full flower, the entire above-ground portion of the plants was harvested and weighed immediately. Root balls were inspected by digging from the ground and shaking vigorously to remove soil attached to the fiber pots to expose the outer surface. The same procedures were followed for the 2009 trial except there were two additional fiber pot treatments. A DOT (Bethel Organics, Inc. 8780 NW Bethel Farms Rd., Arcadia, FL 34266) pot made from 80% wood fiber and 20% peat moss and certified as organic by the US National Organic Program, and a pot made from straw (Ivy Acres, Inc. 1375 Edwards Ave., Baiting Hallow, NY 11933) by compressing the straw grass fibers together and adding a proprietary binder.

Shoot fresh weight data was measured on four plants per block with a total of 16 plants per pot type, and the data were analyzed using analysis of variance with the means separated by using a LSD test at an alpha value of 0.1. The SAS program PROC MIXED (SAS 9.2) was used for the analysis.

The nonparametic statistical Kolmogorov-Smirnov test was used due to the small sample size to determine goodness of fit. An alpha level of 0.1 was chosen for determining the Kolmogorov's statistic *D*.

2.2 Field Grown Tomatoes 2009

Better Bush (semi-determinate) tomato seeds were sown in Redi-Earth plug mix in 392 cell plug trays. The tomato seedlings were transplanted into fiber pots or plastic pots containing Metro-mix 360 potting mix. The five types of fiber pots were: CowPots (4.5 inch), coir pots (EcoDepot, 4.25 inch), peat pots (Jiffy, 3.25 inch), straw pots, (Ivy Acres, 3 inch), and DOT pots (Bethel Organics, 2.5 inch). A standard plastic pot was used as a control (Landmark Plastic, 3.5 inch). Plants were grown to transplant size, about 20 cm tall, in the UConn Floriculture greenhouse. Irrigation was provided by a flood and drain system with liquid fertilizer applied at each irrigation event using a 15-4-15 formulation at about 150 mg/liter nitrogen.

The field used for the experiment was located at the University of Connecticut Storrs Research Farm. The soil in the field was analyzed for the nutrient content by using the modified-Morgan test, and recommended amounts of lime and fertilizer were applied for the tomato plants. A sheet of 6-mil black agricultural grade plastic (manufactured by Filmguard) was laid over the entire experimental area to suppress weeds. The fiber pots were planted as whole pots into the soil by hand, and the plants in the plastic pots were planted into the soil as root balls after removal of the plants from the plastic pots. All the pots and plants were planted on June 10, and the entire pot was covered with soil. The experimental design was a randomized complete block (RCBD) with six replicate plants per fiber pot treatment in each row. Each plot had 43 plants in the row that were spaced 30-cm apart within the row and each row was spaced 1.52 meters apart. Approximately 15-cm squares were cut in the plastic to allow the planting of the pots. There were a total of six rows per plot and the inner four rows were used for yield determination with 36 plants harvested from each row across all treatments.

After the tomato plants were tall enough to require support, wooden stakes 1.52 meters long were added between every other plant to support Jude twine used as part of a basket weaving support system that was implemented for each row. As the season progressed, two tiers of twine were needed to keep the fully grown plants upright and off of the ground.

All plants were treated with an aggressive weekly fungicide program consisting of spraying Alliette, Tanos, Bravo, Prisidio, Manzate in a rotation in accordance with local laws and requirements. No fungal diseases were observed for the duration of the trial.

When the tomatoes were close to maturity the first truss on all test plants was tagged and monitored for maturity. USDA standard grading guidelines were used to estimate the stage of ripeness. When one of the tomatoes on the truss reached at least the ‘Pink’ stage of ripeness the entire truss was harvested and weighed in the field.

Truss weight data was generated from six plants per block with a total of 24 plants per pot type and was analyzed using analysis of variance and means were separated by a LSD test at an alpha value of 0.1. The SAS program PROC MIXED (SAS 9.2) was used for the analysis.

2.3 Decomposition Evaluation

In the 2008 field experiments with garden mums the degradation of the pots was visually inspected, but no formal rating scale was used to rate the amount of degradation.

In 2009 a rating system was developed to rate the amount of degradation of the pots. The pots in the mum and tomato experiments were evaluated for the amount of degradation that occurred over the growing season. At harvest the plants were cut at ground level for measurement of fresh weight, but the stem and a tag remained to mark the center of the plant. The root balls were removed by careful extrication of the pot and roots from the soil. An estimated percentage of the amount of the pot that remained based on visual observation was documented with two people present to evaluate and agree on the degree of degradation. The following predetermined ranking scale was used.

1 = 0-5%

2 = 5-20%

3 = 20-50%

4 = 50-80%

5 = 80-95%

6 = 95-100%

Pots that were ranked 'six' could be considered reusable and had only slight decomposition. A ranking of 'one' meant the materials of the pot were well broken down to the point that only minimal material could be found.

The nonparametic statistical Kolmogorov-Smirnov test was used due to the small sample size to determine goodness of fit. An alpha level of 0.1 was chosen for determining the Kolmogorov's statistic *D*. Cumulative frequencies were calculated by dividing frequencies in the previous rating by the current rating across all rating levels.

3. Results and discussion

3.1 Garden mum field trials

Rainfall and temperature during the growing season were near normal in 2008, but rainfall and temperature in 2009 was much greater than normal (Tables 1 and 2). The mean shoot yields of the mums in the three types of pots planted in both 2008 and 2009 were considerably lower in 2009, with a mean shoot yield of 547 g compared with a mean of 700 g in 2008 (Figs. 1, 2). The wetter and cooler conditions in 2009 were probably responsible for the overall lower yields.

Table 1

Growing Degree Days (GDD)

	2008	**2009**	**AVG**
June	498	382	446
July	682	549	615
August	536	638	561
September	403	346	338
Sum	2118	1915	1959

Growing degree days for the 2008 and 2009 growing seasons with the 102 year (1888-1990) average shown for comparison based on the GDD (86,50) system.

There were significant differences in growth of garden mums when transplanted in various horticultural pots in both 2008 and 2009 (Figs. 1, 2). In 2008 there were three different types of pots and three significantly different shoot weights. The CowPots yielded substantially more than the Jiffy or Coir pots, and the Jiffy pots yielded more than the coir pots. One possible reason for the differences in growth among the three pots could be the different rate of breakdown of the pots in the soil. Only a crude assessment of the degradation of the pots was made, but the Cowpots were almost completely degraded, while the Jiffy pots were partially degraded and the coir pots had little noticeable degradation (data not shown). More rapid access by the roots to the field soil may have contributed to the increased growth by the CowPots.

In 2009 there were five different types of pots evaluated. The straw pots produced the smallest amount of shoot growth (Fig. 2), and the Jiffy pots produced the greatest amount of shoot growth. The DOT wood fiber pots, the CowPots and the coir pots produced similar amounts of shoot growth, and the amounts were not statistically different from each other. These results are different from 2008 when the CowPots produced the most shoot growth (Fig 1).

Table 2

Seasonal Rainfall Amounts

Location, Year	**June**	diff	**July**	diff	**August**	diff	**September**	diff	**Growing Season Totals**	diff
Storrs, 2008	108	+22	115	+11	82	-25	233	+136	**538**	+144
Storrs 2009	145	+59	195	+91	101	-6	42	-55	**483**	+89
Amounts in mm										
Diff compared to 102 year average										

The results from 2009 suggest that except for the straw pots there is little difference in growth of mums when planted in pots made from different fibers. The variance in plant growth in 2009 was much greater than in 2008 with a coefficient of variance of 24.5 in 2009 and 15.7 in 2008. The variance could be due to the unusually high rainfall in 2009 (Table 2). High rainfall could cause more variability in yield due to differential absorption of water by the pots made from fibers with different abilities to absorb water. CowPots are known to retain more water than Jiffy pots and to produce lower biomass yields when irrigated with the same amount of water as Jiffy pots in the greenhouse (Freund, 2007) .

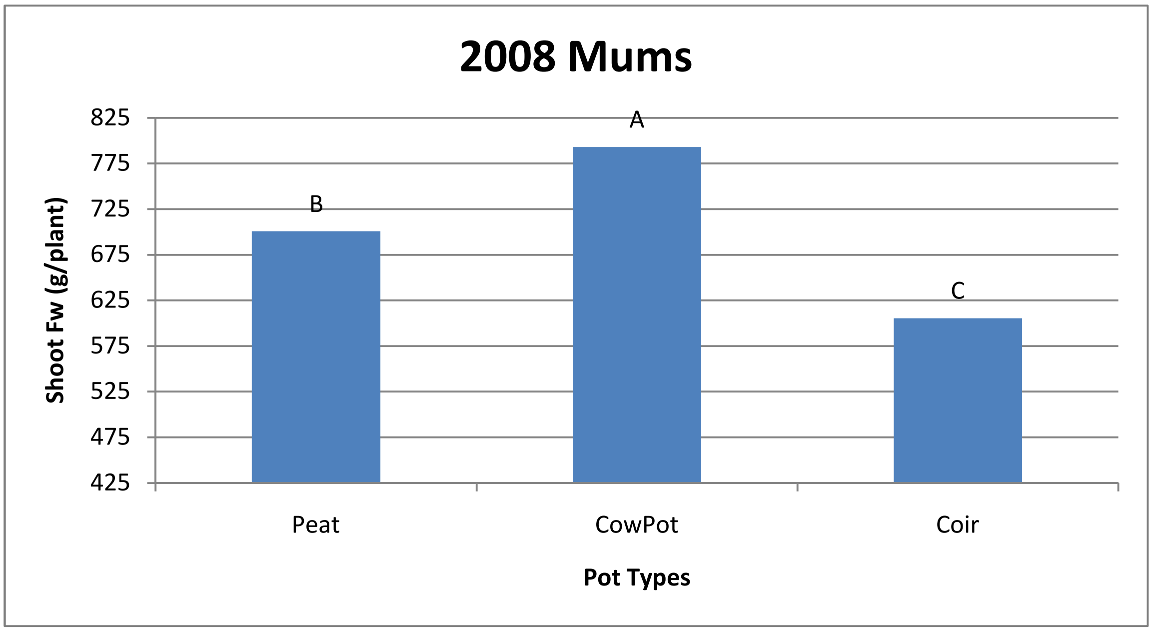

Fig.1. Mean shoot fresh weight of garden mums grown under field conditions in horticultural pots made from peat, manure fibers (CowPot), and coconut fibers (Coir). Bars with different letters denote significant differences ($P < 0.1$) based on a LSD means separation. Values are means of 4 replications.

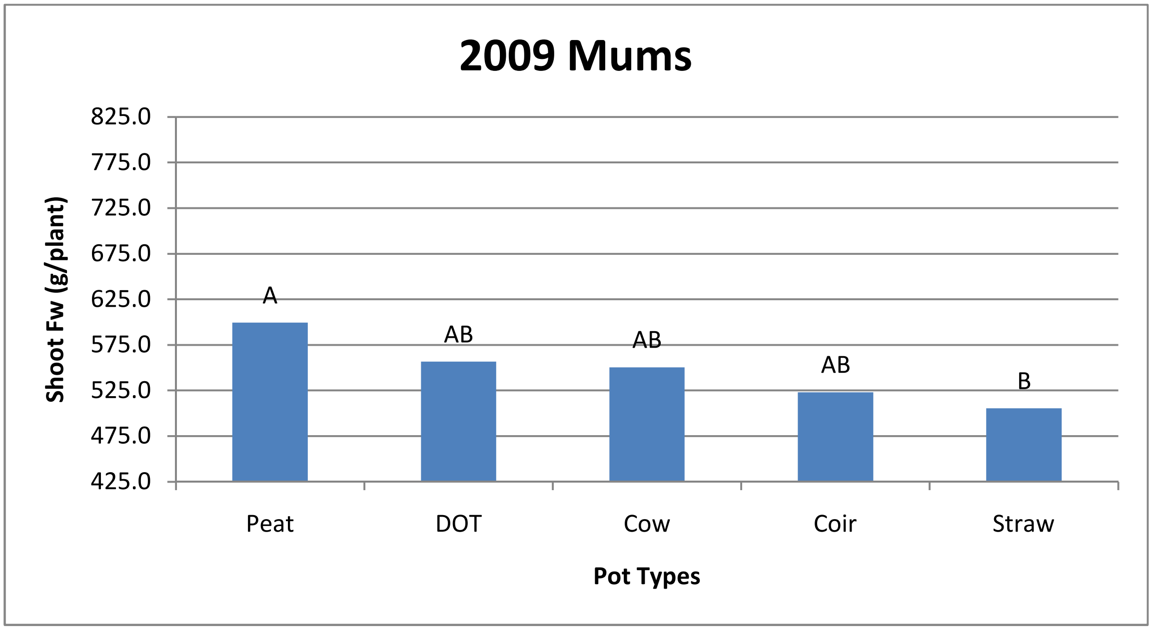

Fig. 2. Effect of pot type on shoot fresh weight of garden mums grown during the 2009 season. Only the peat fibers (Jiffy) and Straw pots differed significantly (P<0.1) LSD test. Conditions were cool and wet all season which influenced overall plant growth. Values are means of 4 replications.

3.2 Tomato trust harvest 2009

Tomato plants grown in the plastic pots and transplanted as root balls after removal from the pots produced the greatest yield of tomatoes from the first truss (Fig. 3), which was significantly different from tomato yield from plants grown in the Straw, Coir, Peat and CowPot pots. The greater yield from the plants grown in the plastic pots could have been due to restriction of root growth caused by the pots. When the roots of the plants grown in the plastic pots were examined at the end of the season, the roots radiated out evenly from the center of the plant, which allowed the roots to maximize contact with the soil. The roots of the plants grown in all the fiber pots showed restricted growth at the end of the season compared with the plants growth in the plastic pots. In the only experiment we could find in the literature comparing the growth of plants initially grown in plastic pots or a peat pots and then transplanted into simulated field conditions showed no significant difference in growth caused by the pots (Evans and Hensley, 2004). The simulated field conditions used in the experiment, however, were more similar to greenhouse conditions than field conditions because the plants were transplanted into 4-L round plastic containers containing a soilless mix and the plants were subsequently grown for 12 weeks in a greenhouse.

The yield of tomatoes grown in fiber pots was not significantly different across all the pots (Fig. 3). The variance was high in the experiment with a CV of 26.8%. This is similar to the CV of 24.5% in the 2009 experiment with mums where pots had little effect on the shoot weight of the mums. The unusually high rainfall in 2009 may have caused the high variability because fiber pots are known to differentially repel and absorb water (Evans and Karcher, 2004), which could have created large differences in the moisture conditions in the root zone.

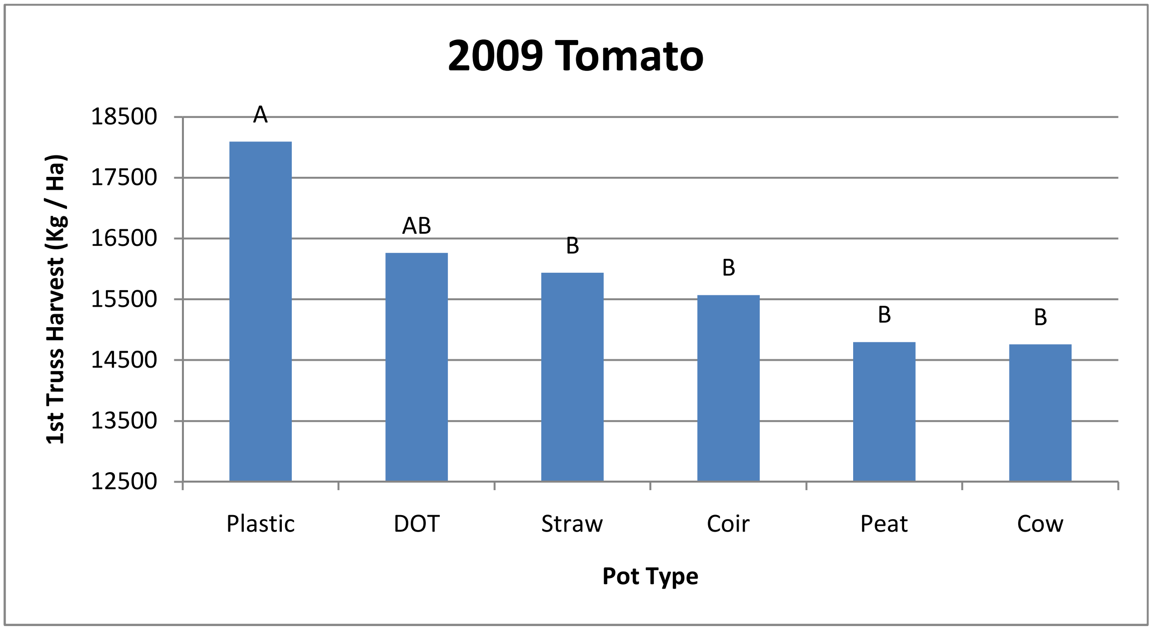

Fig. 3. Yield of tomatoes from the first truss when transplanted into a field soil in horticultural pots made from wood fibers (DOT), straw, coconut fibers (Coir), manure fibers (CowPot), peat fibers (Jiffy) or transplanted as a root ball after growing to transplant size in plastic pots. Bars with different letters denote significant differences ($P < 0.1$) LSD test. Values are means based on 4 replications.

All the fiber pots had some of the pot still visible at harvest and many of the fiber pots had substantial amounts of the pot walls and bottoms still intact. This suggests that some of the pots made from material that is slow to degrade, such as the Coir pots that contain phenolic compounds, may remain sufficiently intact in the soil, especially in arid or semi-arid climates, to require removal before planting another crop.

3.3 Decomposition evaluation

The amount of degradation of the fiber pots was documented in 2009. Visual, but unsystematic observations of the pots in the 2008 studies suggested there were large differences in the amount of degradation of the pots. In 2009 we used a systematic visual process to estimate the degradation of the pots after harvest of the plants. The results of the ratings of the amount of degradation are shown in Figures 4 and 5.

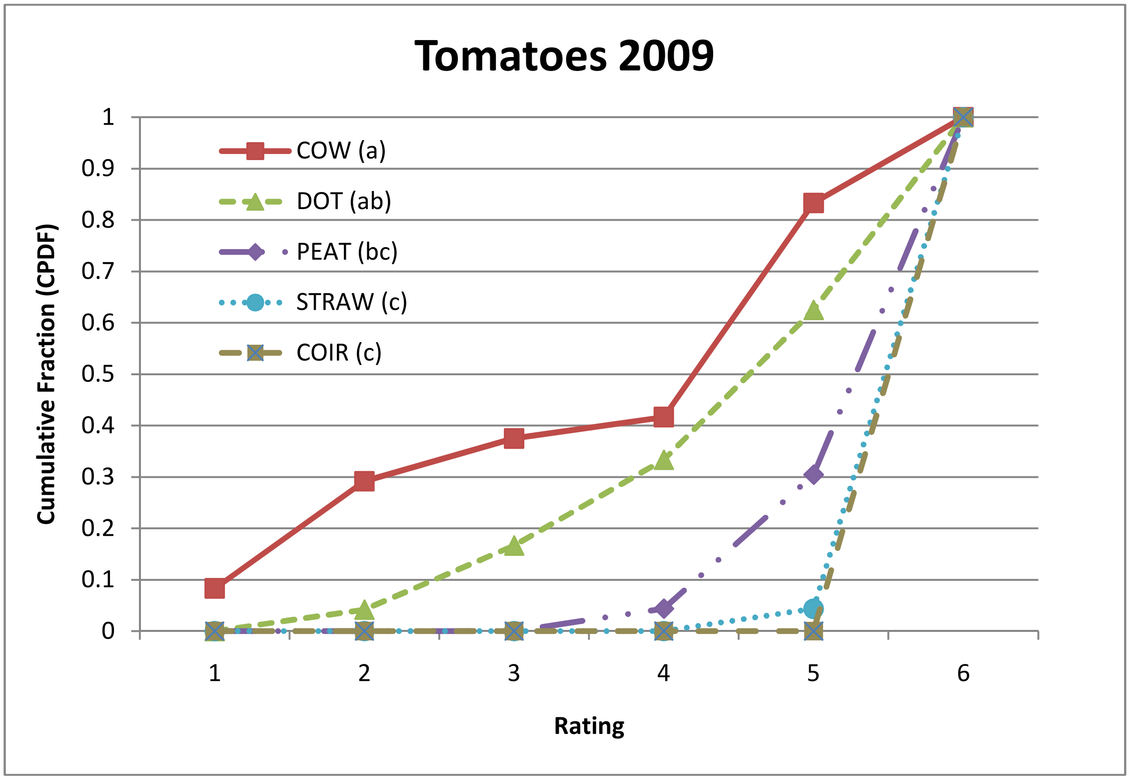

Fig. 4. Comparative breakdown of Tomato plants grown in different horticultural pots made from wood fibers (DOT), straw, coconut fibers (Coir), manure fibers (CowPot), peat fibers (Jiffy) after a growing season. Cumulative Fraction (CPDF) compared to the rating which represents the fraction of the pots in each treatment that have an equal or less than rating. Each rating number has a range where 1= 0 to 5% of pot visible; 2= 5 to 20%; 3= 20 to 50%; 4= 50 to 80%; 5= 80 to 95%; and 6= 95 to 100% of pot visible. Values based on 4 replications. (P>0.1)

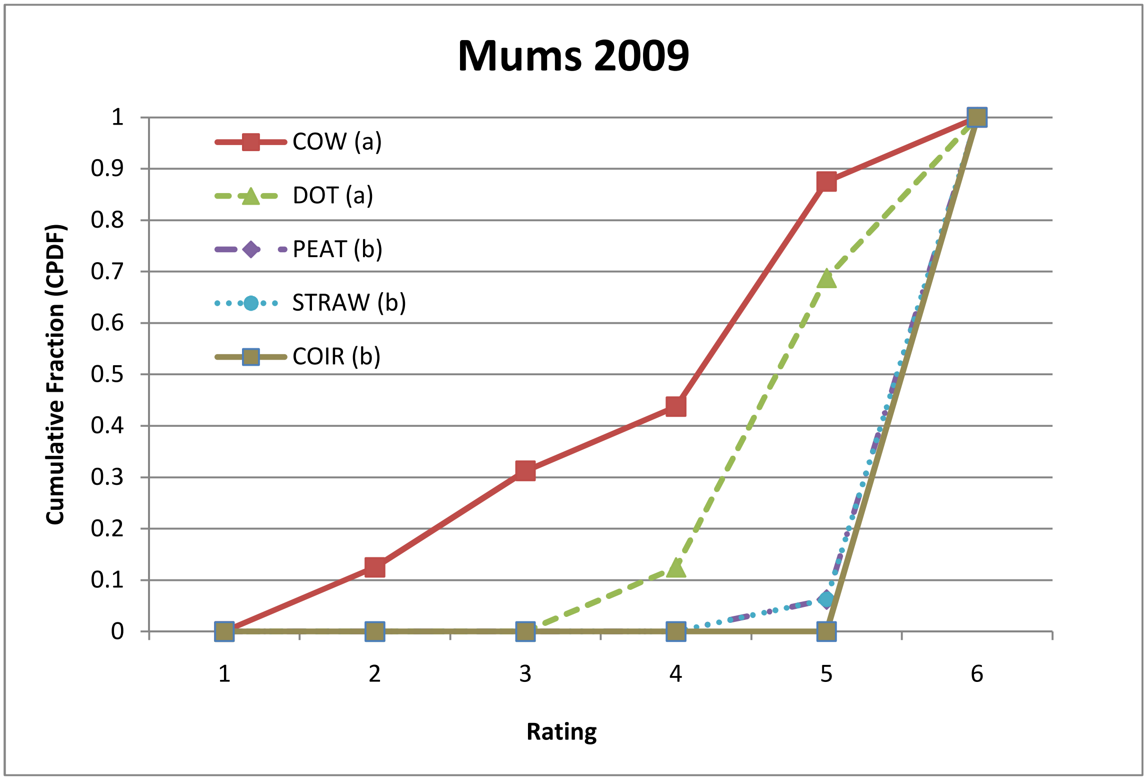

Fig. 5. Comparative breakdown of garden Mums grown in different horticultural pots made from wood fibers (DOT), straw, coconut fibers (Coir), manure fibers (CowPot), peat fibers (Jiffy) after a growing season. Cumulative Fraction (CPDF) compared to the rating which represents the fraction of the pots in each treatment that have an equal or less than rating. Each rating number has a range of pot material visually remaining following this scale, 1= 0-5%, 2= 5-20%, 3= 20-50%, 4= 50-80%, 5= 80-95%, 6=95-100%. Values based on 4 replications. (P>0.1)

The amount of degradation in the peat, straw and coir pots was not significantly different (Fig. 5) when mums were grown in the pots. All three of these pots had a cumulative probability of 50% of the pots rating about 5.4 at the end of the season, which means that 50% of the pots will have only about 10% of the pot degraded at the end of the season. In comparison the CowPots and DOT pots, which were significantly more degraded than the other three types of pots, and not significantly different from each other, had a cumulative probability of 50% of the pots rating about 4.7 or 70% degraded for the DOT pots, and 4.1 or 50% degraded for the CowPots. The pots with tomatoes grown in them showed a similar trend in degradation (Fig. 4) with the CowPots and DOT pots degrading the most and the peat, straw and coir pots degrading the least. These results are different from results reported by Evans and Karcher (2004) who showed an interaction between plant species and type of fiber pot with pot degradation during the growing season. The authors attributed the interaction to a larger and more vigorous root system in the tomatoes that physically broke apart the pots more than vinca and marigold plants. Mums have a similar root system as vinca and marigolds, but we did not observe differences in the physical breakage of the pots between the mums and the tomatoes.

There was no significant correlation of the degradation of the pots with the yield of the tomatoes or mums (data not shown). One of our hypotheses was that the quicker and more complete the breakdown of the pots the quicker the roots would access the field soil and the greater the yield. Other factors like the density of the fibers and the binders used to hold the pots together, which we did not measure, probably had an effect on root growth that masked the effect of the type of fiber.

4. Conclusions

The fiber pots affected the growth and yield of garden mums and tomatoes in different ways across the two years. Sometimes one type of pot provided better growth and yield and sometimes another type of pot provided better growth and yield. In general, the fiber pots provided similar growth yield. The pots degraded at significantly different rates during the growing season. The Cowpots and the DOT pots had the greatest amount of degradation, and the straw and coir pots had the least amount of degradation. One of our hypotheses was that the pots that degraded more quickly in the field would grow faster and yield greater, but these results do not support that hypothesis because there was no significant correlation between the yield of the mums or the tomatoes and the amount of pot degradation in the field. Overall these results suggest that the type of fiber used to make a horticultural pot does not have a major effect on plant growth when transplanted in the pots into the field, but the pots degrade at significantly different rates, which could result in the pots with slow rates of degradation accumulating in the field.

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